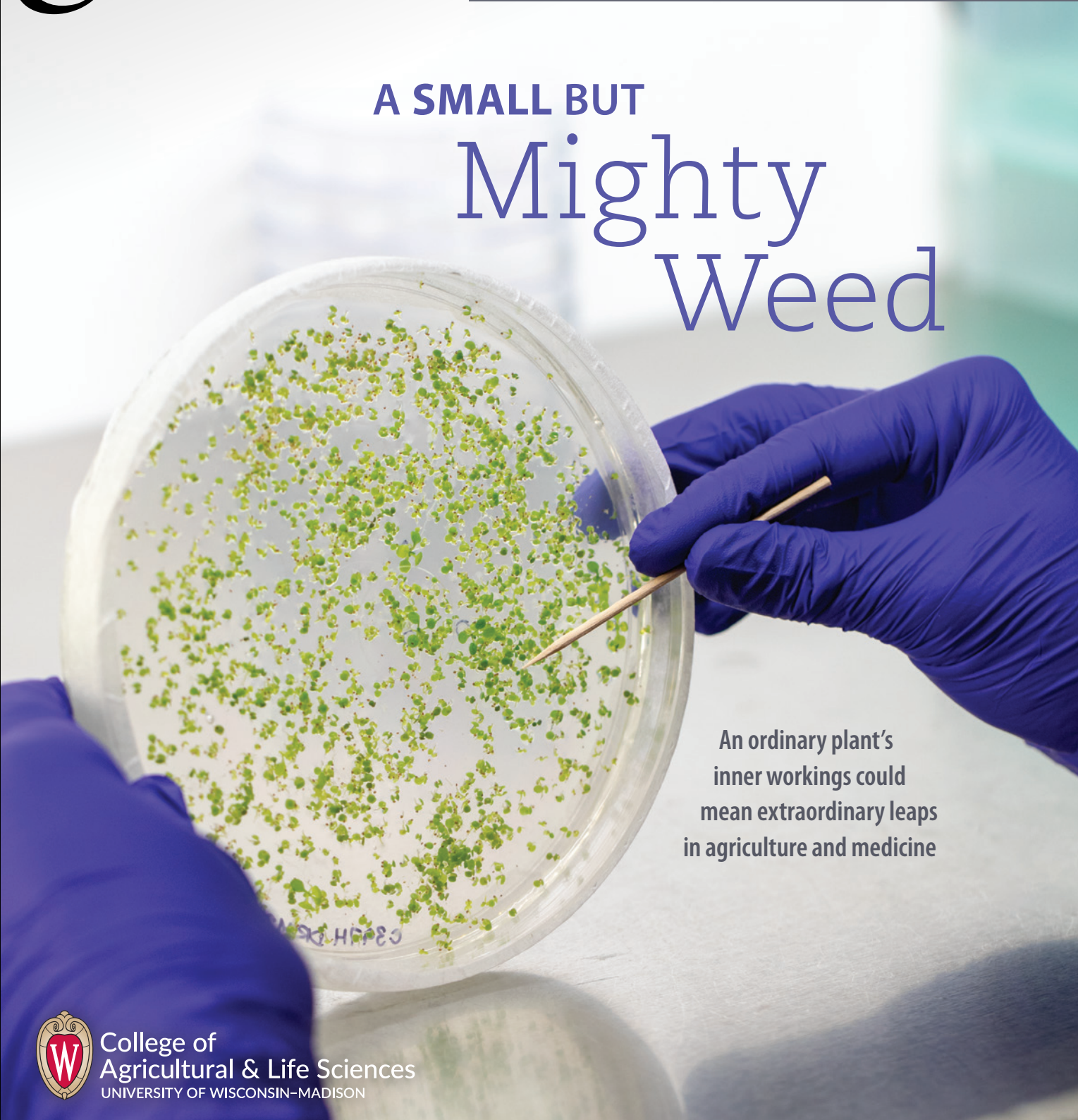


# grow

Wisconsin's Magazine for the Life Sciences • FALL 2019

food systems • health • bioenergy • environment • climate • communities

## A SMALL BUT Mighty Weed



An ordinary plant's  
inner workings could  
mean extraordinary leaps  
in agriculture and medicine



College of  
Agricultural & Life Sciences  
UNIVERSITY OF WISCONSIN-MADISON







# grow

Wisconsin's Magazine for the Life Sciences

## FEATURES

### 16 Deep in the Weeds

Close study of an ordinary plant's cellular mechanisms could lead to big advances in agriculture and medicine.

BY NOLAN LENDVED

### 22 A Model Solution

Researchers expand a powerful computer simulation tool to study and address nitrate contamination in Wisconsin's groundwater.

BY NICOLE MILLER MS'06

### 28 Big Data Wranglers

From computer vision to cloud computing, CALS scientists are finding ways to gather and analyze massive amounts of information for better farm management.

BY BOB MITCHELL BS'76

## DEPARTMENTS

### 4 In Vivo

BY DEAN KATE VANDENBOSCH

### 5 Front List

Five things everyone should know about *A Sand County Almanac*

### 6 On Henry Mall

Student team's innovative dessert earns silver in national contest

Sustainable dairy project finds ways to lower emissions while increasing profits

Class Act: Childhood experiences and fate lead returning adult student to genetics

A new, renewable way to make acetaminophen also improves the bottom line for biorefining

### 12 Field Notes

Borneo and Papua New Guinea: Soundscape ecology improves understanding of biodiversity in tropical forests

### 14 Living Science

Amanda Gevens helps potato and other vegetable growers defend their crops against disease

### 34 Working Life

In the Field: Alumni make their mark in environmental sciences

Catch up with Kristin Kohlmann BS'13

Give: The CALS Agricultural Experience immerses Chicago and Milwaukee-area high school students in the college and UW campus

### 39 Final Exam

ON THE COVER: *Arabidopsis thaliana* (thale cress) seeds sprout in a Petri dish in the lab of genetics professor Xuehua Zhong in the Discovery Building on the UW-Madison campus.

PHOTO BY MICHAEL P. KING

From left, conservation biology and physics major Grant Witynski and wildlife ecology majors Mace Drumright BSx'22 and Abby Haydin BSx'22 conduct a bird playback survey on a small lake at Kemp Natural Resources Station near Minocqua, Wis., as part of a wildlife ecology summer field practicum. Read more at [grow.cals.wisc.edu](http://grow.cals.wisc.edu).

PHOTO BY MICHAEL P. KING

Dean Kate VandenBosch

## The Future of Dairy Relies on Research



**Y**ears of low milk prices, rising costs, and trade policy turmoil have taken their toll on our state's dairy farmers and the dairy industry as a whole. Wisconsin lost 691 dairy farms in 2018, and it leads neighboring states in farm bankruptcies. These are trends we desperately want to reverse because when our \$45.6 billion dairy industry thrives, so does our state and its citizens.

Historically, Wisconsin farmers relied on agricultural research from UW–Madison and other UW System institutions to help build America's Dairyland. We're still here for them today. We're still focusing on core areas of nutrition, production efficiency, animal welfare, and disease prevention in dairy cows. And our researchers have branched into new territories as they develop stress-reduction programs for farmers, formulate novel dairy-based food products, and establish more sustainable farming practices. Just as in the past, the dairy industry will rely on this research to move into the future.

Recognizing this, the Department of Agriculture, Trade and Consumer Protection's Wisconsin Dairy Task Force 2.0 endorsed a plan to increase funding for dairy research at our UW agricultural schools. The task force stipulated that the research should focus on four key areas vital to the future of dairy farming in Wisconsin: stewarding land and water resources; enriching human health and nutrition; ensuring animal health and welfare; and growing farm businesses and communities. In June, the Wisconsin State Legislature and Gov. Tony Evers endorsed

this plan with a state budget that includes \$8.8 million for a "UW Dairy Innovation Hub" at UW–Madison, UW–Platteville, and UW–River Falls.

This reinvestment will generate vital new discoveries by providing improved research farms, labs, and equipment as well as new personnel. Specifically, in CALS, the proposal calls for 14–16 new faculty members, additional staff for operating enhanced facilities, and dozens of new graduate student research trainees and postdoctoral research fellows in the coming years. With the help of these added resources, we will train current and future industry leaders

who will help transfer the new knowledge we generate to farms, processing plants, watersheds, and beyond.

The Legislature's Joint Finance Committee voted to formally release the funds for this initiative in early October. Now it's time to get to work. Through the UW Dairy Innovation Hub's research, and through its partnerships with dairy farmers and the dairy industry, we will position Wisconsin as a global leader in food production and innovation for decades to come.

**"Historically, Wisconsin farmers relied on agricultural research from UW–Madison and other UW System institutions to help build America's Dairyland. We're still here for them today."**

grow

Volume 13, Issue 1 • FALL 2019

**Editor**

Nik Hawkins

**Writers**Michael P. King, Nicole Miller MS'06,  
Caroline Schneider MS'11**Designer**

Danielle Lamberson Philipp

**Photographer**

Michael P. King

**Editorial Assistants**Stephanie Hoff BSx'19,  
Andrew Pearce

Additional content contributed by University Communications and various freelancers.

**Contact Grow**

Grow Editor, 136 Agricultural Hall,  
1450 Linden Drive, Madison, WI 53706  
grow@cals.wisc.edu  
grow.cals.wisc.edu

**CALS ADMINISTRATION****Dean and Director**

Kate VandenBosch

**Senior Associate Dean**

Mark Rickenbach

**Associate Dean for Research**

Bill Barker

**Associate Dean for Extension and Outreach**

Doug Reinemann BS'80, MS'83

**Associate Dean for Academic Affairs**

Karen Wasserman

**Associate Dean for External Relations and Advancement**

Heidi Zoerb

**CONNECT WITH CALS****For Alumni****Office of External Relations**

608-890-2999

alumni@cals.wisc.edu

cals.wisc.edu/alumni/

**For Prospective Students****Office of Academic Affairs**

608-262-3003

undergrads@cals.wisc.edu

cals.wisc.edu/students/

**For Business and Industry****Office of Business Engagement**

1-877-627-9472

obe.wisc.edu

**To Make a Gift****UW Foundation**

608-263-4545

uwf@supportuw.org

supportuw.org/cals



College of  
Agricultural & Life Sciences  
UNIVERSITY OF WISCONSIN-MADISON



UWMadisonCALS



FPO  
FPO  
FPO FPO



## Five things everyone should know about . . .

### *A Sand County Almanac*

By Curt Meine MS'83 PhD'88 and Stanley Temple

- 1 **Aldo Leopold's book *A Sand County Almanac* was published 70 years ago.** But its message about our relationship with nature is more important now than ever. Written from 1933 to 1948, when Leopold was a professor of wildlife management in the University of Wisconsin College of Agriculture (now CALS), his collection of essays introduced a "land ethic" as a moral compass for how humans should live on the Earth. For Leopold, "land" encompassed "soil, water, plants, animals, and people," and he advocated for an ethical relationship with each and all, collectively.
- 2 **The original manuscript for *A Sand County Almanac* was rejected by several publishers.** They thought that such a book would have limited readership, in part because it introduced ideas that were ahead of their time. Publishers generally liked the engaging essays in the first half of the book, which describe seasonal events at Leopold's "shack" — his weekend getaway on a worn-out farm in Sauk County, Wisconsin. But they balked at the more thought-provoking essays on ecology and ethics in the book's second half.
- 3 **Leopold wouldn't live to see *A Sand County Almanac* in print.** On April 14, 1948, Oxford University Press informed Leopold that it wished to publish his manuscript. One week later, Leopold suffered a fatal heart attack while fighting a grass fire that had escaped from a neighbor's farm near the shack. In the months that followed, Leopold's son, Luna, took the lead in getting the manuscript, which was then called "Great Possessions," into print. Luna and Oxford eventually changed the name of the book to *A Sand County Almanac*.
- 4 ***A Sand County Almanac* became a classic with the emergence of the modern environmental movement.** Oxford published the book in the fall of 1949. It was widely and positively reviewed and well received by a core readership of conservationists. Sales remained modest, however, until 1968, when the first paperback edition appeared and helped inspire the rising environmental movement. Leopold's book has been translated into 14 languages and has sold more than two million copies. It continues to be widely read as an essential contribution to conservation thought.
- 5 **Leopold's transformative ideas are both timely and timeless.** His call for an ethic that recognizes our responsibilities to the land and to future generations provided a new philosophical foundation for conservation. Leopold could not fully anticipate the challenges now presented by climate change, biodiversity loss, and other pressing global issues. However, he held that an ethic to guide our relations with the natural world must continually evolve "in the minds of a thinking community." As he wrote in the foreword to the *Almanac*: "When we see land as a community to which we belong, we may begin to use it with love and respect."

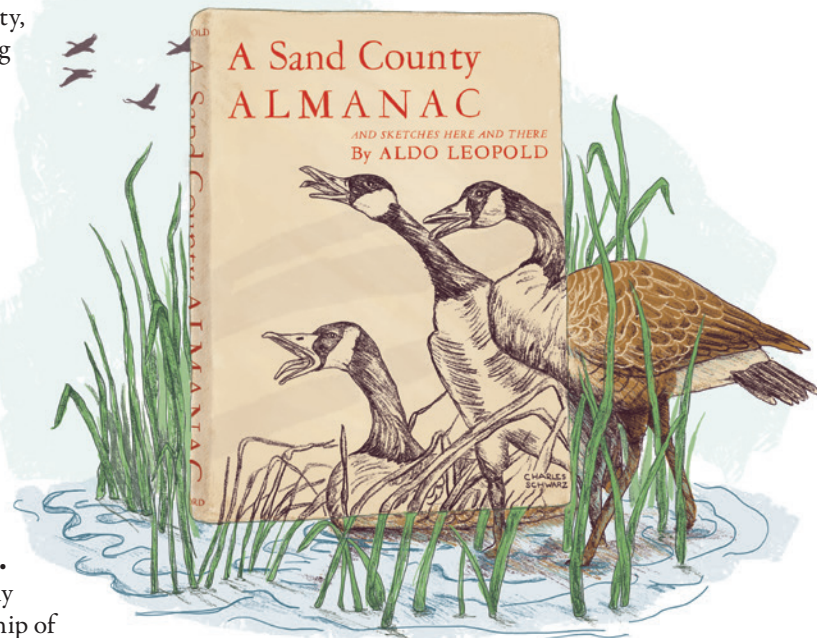


ILLUSTRATION BY DANIELLE LAMBERSON PHILIPP

Curt Meine is a senior fellow with the Aldo Leopold Foundation, adjunct assistant professor of forest and wildlife ecology, and author of *Aldo Leopold: His Life and Work*. Stanley Temple is professor emeritus of forest and wildlife ecology and environmental studies and senior fellow at the Aldo Leopold Foundation.



## Cookies à la Chickpea

Students' innovative dessert earns silver in national food development contest

A meringue cookie called Trinipea, which a team of food science students developed using aquafaba, the leftover liquid from the chickpea cooking process, earned second place at the International Food Technology Student Association & MARS Product Development Competition in May 2019.



PHOTO COURTESY OF THE TRINIEPA TEAM

**D**elicious desserts may not be the first thing that comes to mind when you think of chickpeas, but a team of food science students have whipped up a recipe to change that.

Last May, recent graduate **Emon Ali Khadem** BS'19 led a team of fellow students to compete with a product called Trinipea at the International Food Technology Student Association (IFTSA) & MARS Product Development Competition. Trinipea is a shelf-stable vegan meringue cookie that the students developed in vanilla, dark chocolate, and cacao nib flavors.

Whereas traditional meringue cookies rely on whipped egg whites to achieve their light, delicate texture, for Trinipea, the students turned to aqua-

faba, the leftover liquid from the chickpea cooking process. Aquafaba has a high protein and carbohydrate content, allowing it to be whipped into a foam just like egg whites.

It took more than 56 trials and recipe adjustments to arrive at the finished product formulation. Early versions were too fragile to ship. With each iteration, the team worked to increase hardness, density, foam stability, and crunch.

"The Trinipea meringue is dry but quite aerated, so it melts in your mouth," Khadem says. "Think Halo Top, but instead of ice cream, a dried sweet treat."

The meringue was tasty and creative enough to earn second place at the competition. More than 25 university teams submitted proposals to be a part of



the event, and the Trinipea team was one of just six selected to compete in the finals.

The innovative dessert idea grew from a desire to solve a problem.

“Each day, Americans eat two and a half times the daily recommended value of sugar, 40% of the world’s harvested food is wasted, and dessert options don’t necessarily account for dietary restrictions,” explains Khadem, who has just begun a career at PepsiCo in research and development. “We wanted to make something allergen free, low in sugar, and sustainable.”

The meringues are sweetened with a specialized Stevia variant that lends a more typical sugar taste with fewer off-flavors and less bitterness. A serving of 12 meringues contains only 70 calories.

The idea to use aquafaba to make Trinipea was inspired during one of four field trips integrated into the food science department’s food manufacturing class. During a tour of a facility that treats dairy waste streams in Richland Center, Wisconsin, the chemical engineers stressed the important role of food science innovation in solving food waste issues.

“It made us determined to reduce waste by upcycling ingredients from other processes,” says Khadem.

In creating Trinipea, the team applied a lot of what they learned about product development as members of the UW Food Science Club. The team also got help from Discovery to Product, a campus program that connects aspiring entrepreneurs with experienced commercialization and innovation specialists who are veteran business developers, entrepreneurs, product managers, and start-up executives.

While the Trinipea team is not planning to introduce the product to the marketplace, members are optimistic that something like it will appear on shelves within the next couple of years. It’s not uncommon for food companies to turn some of the student-developed concepts presented during the IFTSA & MARS Product Development Competition into new commercial products.

—JEN KOBYLECKY

Other Trinipea team members include recent graduates Emily Bruhn BS’19, Christie Cheng BS’19, Rachel Fehring BS’19, Dana McMorrow BS’19, and Elisabeth Weir BS’19, and current food science students Will Northway, Liana Rodier, and Yesha Shah.

## Awards and Honors

### GRAND CHALLENGER

**Ophelia Venturelli**, assistant professor of biochemistry, along with UW engineering professor **Brian Pfleger**, has received a Grand Challenges Explorations grant from the Bill & Melinda Gates Foundation to advance research on how to use human-associated intestinal microbes to combat malnutrition in developing countries. Venturelli also was named to a list of 34 young researchers featured in a special issue of *Biochemistry* called “Future of Biochemistry: The International Issue.”

### FANTASTIC WORK WITH FRUIT

**Amaya Atucha**, assistant professor and fruit crop extension specialist in the Department of Horticulture, made the Fruit + Vegetable 40 Under 40 Class of 2019, a group of exemplary agriculture professionals nominated by their peers for the impressive accomplishments of their early careers. The list is compiled each year by the trade magazines *Fruit Growers News* and *Vegetable Growers News*.

### TOP OF THE DAIRY WORLD

Dairy science professor emeritus **Randy Shaver** PhD’86 was selected as the 2019 Dairy Industry Person of the Year by the World Dairy Expo for excellence in the field and contributions to his community.

## Number Crunching

WISCONSIN’S FARMS AND  
AGRICULTURAL BUSINESSES GENERATED

# \$104.8 billion

in economic activity in 2017, up from \$88.3 billion in 2012, according to a study conducted by agricultural and applied economics professor **Steven Deller**. Most of the growth over those five years came in the food processing sector. Learn more at [go.wisc.edu/wis-ag-economy](http://go.wisc.edu/wis-ag-economy).

PHOTO BY SEVIE KENTON





# More Green, Less Greenhouse Gas

Sustainable dairy project finds ways to lower emissions while increasing profits

In 2013, the \$10 million Dairy Coordinated Agricultural Project, or Dairy CAP, set out to assess the greenhouse gas contributions of the dairy industry and help farmers meet the industry's goal to cut greenhouse gas emissions by 25% by 2020 while maintaining or boosting profitability. Six years later, the project has wrapped up with a set of promising solutions.

The Dairy CAP's recommendations center on efficiency. Researchers found that a combination of improved animal husbandry, different feeding strategies, and better manure management could allow dairies to cut emissions by a third to almost half while producing more milk with less feed to ensure economic feasibility.

CALS professors **Matt Ruark** and **Molly Jahn** led the Dairy CAP in collaboration with seven other universities, the U.S. Department of Agriculture (which funded the project), and the Innovation Center for U.S. Dairy, an industry-supported research group. The team issued its final report earlier this year.

"I think there are three big takeaways," says Ruark, a professor of soil science. "One, efficiency in milk production leads to reduction in greenhouse gas emissions. Two, reductions in greenhouse gases can be achieved along with reductions in nutrient loss and increases in economic returns. And three, dairy-based cropping systems can be adaptive to climate change."

Milk production emits greenhouse gases from three primary sources: methane produced in the rumen; emissions during manure storage and spreading; and the emissions associated with growing crops for feed. Methane — an inevitable byproduct of ruminant digestion — is 25 times more effective than carbon dioxide at trapping heat in the atmosphere. Nitrous oxide, derived from manure and fertilizer applications, is 10 times more potent than methane.

The Dairy CAP team tracked emissions at each of these stages. Experimental modifications were followed throughout their entire life cycle to identify how, for example, feed changes affected not just

the production of milk and methane but manure emissions and the growth of crops fertilized with that manure.

Experiments were conducted at the UW–Madison Dairy Cattle Center, the UW Arlington Agricultural Research Station, the USDA Dairy Forage Research Center in Prairie du Sac, Wisconsin, and at partner institutions. The experiments helped refine feed-to-manure computer models of emissions and economic returns for both 150- and 1,500-cow dairies.

The benefits from using the best cow genetics, feed practices, manure handling, and cropping systems added up quickly.

"If we implement these best management practices, we're going to reduce greenhouse gas emissions by 36% [for a 1,500-cow dairy]," says Ruark. "At the same time, we're going to reduce nitrogen losses to groundwater by 41%. We're going to reduce phosphorus losses to surface water by 52%. And we're going to increase net return 20%."

Similar practices could drop greenhouse gas emissions by 46% for 150-cow dairies, the researchers found.

One of the most effective ways to cut emissions is to use an anaerobic digester to convert the methane from stored manure into carbon dioxide. While this is an expensive solution, the costs could be partly offset by generating

and selling electricity from burning the methane or converting it into compressed natural gas to fuel cars and trucks.

Yet changing practices to cut emissions could be a tough sell as dairies continue to struggle through a years-long slump in milk prices, says agricultural and applied economics professor **Mark Stephenson**. An expert in dairy economics, Stephenson helped create a tool to evaluate alternative manure management practices for the Dairy CAP. Low milk prices are a major reason why 800 Wisconsin dairy farms have closed since August 2018.

"One of the legs of sustainability is economic," says Stephenson. "Just because you want to reduce





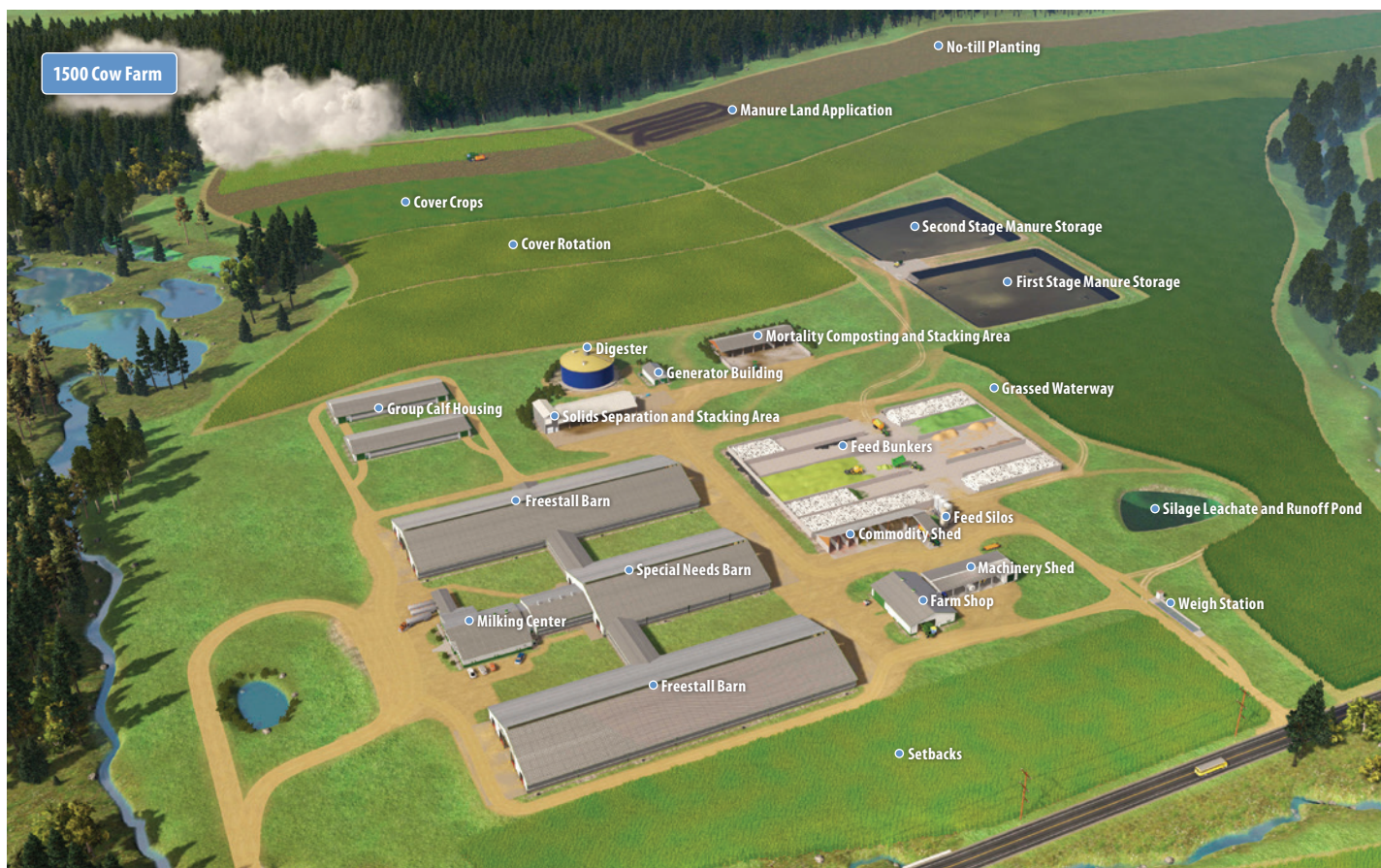


IMAGE COURTESY OF DAIRY CAP

greenhouse gases doesn't mean that you can afford to employ the best practices. The efficiency gains are key to the adoption."

That efficiency stems from improving the conversion of feed into milk through feeding practices and dairy cow genetics. These best practices can reduce costs for farmers and emissions from milk production. Researchers also assembled recommendations to help farmers adapt to a warming climate, such as ways to predict the ventilation needed in a barn to keep cows cool.

The project's findings have been distributed through fact sheets published by the Division of Extension and on the Virtual Farm website ([virtualfarm.psu.edu](http://virtualfarm.psu.edu)) hosted by The Pennsylvania State University. The site demonstrates the typical operations of both large and small dairy farms and ways that dairies can reduce their impact on the environment.

The Dairy CAP also looked toward the next generation. Project leaders partnered with Milwaukee's Vincent High School to help revive its original design as an agricultural school. The grant paid for agriculture outreach specialist **Gail Kraus** to join the school's staff and help design a new agricultural curriculum with six specialties.

"I had come to understand that to really enrich our campus environment we had to be active at the secondary and elementary level to open pipelines of students for college," says Jahn, who initiated a relationship with the school eight years ago.

The agricultural revival grew from teachers interested in teaching aquaculture and developed to include courses in the animal and plant sciences. Students were aided by an existing greenhouse and the addition of a menagerie of chickens, ducks, cows, and goats. They went on to show lambs at the 2018 and 2019 Wisconsin State Fairs. The grant also provided funds for students to attend pre-college programs at the University of Illinois at Urbana-Champaign.

"The Dairy CAP was a really exciting opportunity to work cooperatively with about 100 scientists all over the country," says **Carolyn Betz**, the project manager and author of the final report.

She recognizes that the challenges facing dairy farmers today may make it hard to quickly adopt new management practices. But Betz sees opportunity as dairies inevitably update their operations over time.

"When farmers are making changes anyway, we hope they'll incorporate these solutions," she says.

—ERIC HAMILTON

**One way the Dairy Coordinated Agricultural Project, or Dairy CAP, has distributed its findings is through the Virtual Farm website, which is hosted by project partner The Pennsylvania State University. The site demonstrates the typical operations of both large and small dairy farms and ways that dairies can reduce their impact on the environment.**





Carmen Nightfall

## Upbringing, Fate Lead Nontraditional Student to Genetics



PHOTO BY MICHAEL P. KING

**Carmen Nightfall, a genetics and genomics major, walks Chase in the Emerson East neighborhood of Madison, Wis. She works as a home animal care provider, among other jobs, while earning her degree.**

**H**ad it not been for her father's truck accident, **Carmen Nightfall** BS'x22 might never have attended college. But the unfortunate incident sparked a positive change for both of them. Today, she's well on her way to a bachelor's degree from CALS.

Nightfall's childhood did not give her a positive outlook on advanced education. While in high school in Arizona, she was overlooked for career counseling and didn't consider going to college. But when her dad's accident forced him into early retirement, they both began to look at things differently.

"My dad got curious about the surgeries they were doing on him, and he started taking classes," Nightfall explains. "He got a degree and then wanted to do his master's at UW. He went and actually

ended up getting an MD, and that got me thinking that it's never too late."

Now, at age 40, Nightfall is a genetics and genomics major and considering a switch to biology. As a returning adult student, she brings a bit more wisdom to campus than a typical undergraduate, including different perspectives on many aspects of life and worldly insight into several cultures. All of this stems from her unusual upbringing.

"My great-grandmother was a *curandera*, a Pascua Yaqui medicine woman," Nightfall says. "So I'm part Pascua Yaqui and part Irish, but I spent most of my time with Navajo and Hopi. I have kind of a mixed culture. Plus, my grandmother spoke Spanish, so our heritage is a mixture of Yaqui and Mexican traditions."

It was her grandmother, and her early experiences, that ignited Nightfall's interest in genetics and the body. During her childhood, she was often malnourished. As she got older and started receiving food more regularly, she became interested in how food affects health and the possible genetic components of health. Her grandmother would tell her stories of cures and treatments using herbs and foods.

Nightfall's fascination with food and health took a poignant twist in December 2017, when she found a lump on her throat and was diagnosed with cancer. She was able to complete the spring semester, but between her health, classes, and jobs, which include running her own dog-walking business, it was an overwhelming and stressful few months. Then, in October 2018, she had surgery to remove the lump. In May 2019, she underwent radiation therapy.

Just weeks after her radiation treatment, while still reeling from physical, emotional, and mental exhaustion, Nightfall was looking forward to another semester of school. While she doesn't run into too many students her age, she enjoys her classes and the opportunities to interact with people from differing backgrounds. And she is excited to see where her degree might take her next.

"I love hydrology and nature, but I also have an interest in genetics," Nightfall says. "I'd like to find a way to mesh hydrology, microbiology, and biology. And as cliché as it sounds, I want to figure out a way to serve people and animals and make the world a better place."

—CAROLINE SCHNEIDER MS'11



# From Poplar to Painkiller

A new, renewable way to make acetaminophen also improves the bottom line for biorefining

With a new method to synthesize a popular painkiller from plants rather than fossil fuels, a team of researchers led by biochemistry professor **John Ralph** PhD'82 has found a way to relieve two headaches with one process.

The group has been awarded a patent for a method to synthesize acetaminophen — the active ingredient in Tylenol — from a natural compound derived from plant material. The approach offers a renewable alternative to the current manufacturing process, which uses chemicals derived from coal tar. It also creates a useful product from an abundant but difficult-to-manage component of plant cell walls called lignin.

“Lignin is an extremely complex, messy polymer. No two molecules in a plant are exactly the same,” says Ralph, who is also affiliated with the Great Lakes Bioenergy Research Center (GLBRC), where the research team is based. “It’s very effective for providing structure and defense for the plant, but it’s challenging for us to break down into useable materials.”

The lignin in bioenergy crops, such as poplar, can create a headache for bioenergy researchers due to its recalcitrant tendencies, Ralph says. Once plant sugars are used to produce biofuels, the lignin that remains is typically burned for energy.

The patent application, filed by the Wisconsin Alumni Research Foundation, describes a way to convert a molecule found on lignin into acetaminophen. It was awarded in May 2019 to Ralph, GLBRC scientist **Steven Karlen**, and **Justin Mobley**, a former GLBRC postdoctoral fellow who is now at the University of Kentucky.

Structurally, acetaminophen is a relatively simple compound: a six-carbon benzene ring with two small chemical groups attached. Poplar trees naturally make a very similar structure, called p-hydroxybenzoate, attached to lignin.

“Although lignin itself is a challenge to break down, the p-hydroxybenzoate is fairly easy to clip off as a quite pure stream,” Ralph says.

From there, the researchers devised a short series of chemical reactions to convert the molecule into acetaminophen. The method is inexpensive and builds on a biomass pretreatment process previously developed at GLBRC.

In addition to charting a way to synthesize acetaminophen from a renewable, sustainable source

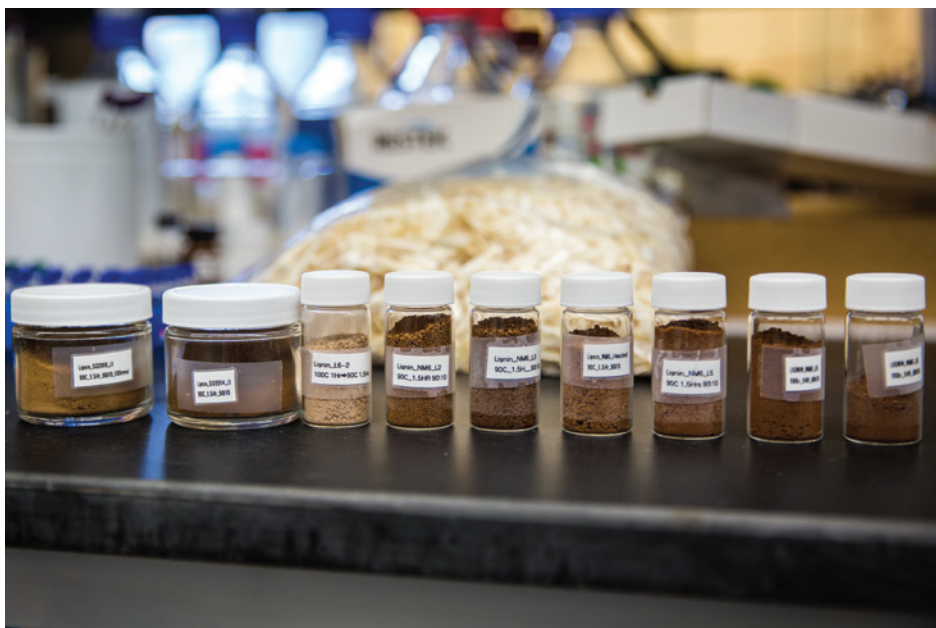


PHOTO BY CHELSEA MAMOTT

material, the newly patented process improves the overall bottom line for biorefining — that is, producing fuels and other industrial materials from plants.

“Making money off any side product helps drive the economics of the biorefinery,” Ralph explains. “In many cases, these products are even more valuable than the fuel.”

The plant material also offers the chemical advantage of starting from a molecule that already has some of the desired structure. More complex petrochemicals must first be stripped down to basic molecular backbones before being built back up into the desired compounds.

“As industries prepare to shift away from a fossil fuel-based economy, having biomass-based pathways at the ready will be an essential piece of that process,” Ralph says. “Here is an opportunity to make a high-demand, ‘green’ pharmaceutical from plants rather than from fossil fuels.”

Acetaminophen and related molecules are also useful as commodity chemicals, the industrial building blocks used to make products, including other pharmaceuticals, plastics, and fuels.

The researchers are now working on refining the process to improve the yield and purity of the plant-derived acetaminophen.

**Lignin samples in a lab at the Wisconsin Energy Institute, which houses the Great Lakes Bioenergy Research Center.**

This research was supported by a grant from the Department of Energy (DE-SC0018409).

—JILL SAKAI





## BORNEO AND PAPUA NEW GUINEA

### The Sounds of Biodiversity

It's said that a picture is worth a thousand words. To **Zuzana Burivalova**, an audio recording is worth a thousand pictures. That's the beauty of bioacoustics, Burivalova's area of focus as a new faculty member in the Department of Forest and Wildlife Ecology.

She's using the methods of this emerging science to better understand biodiversity in tropical forests.

"Bioacoustics and soundscape ecology are all about figuring out where biodiversity is and how it's changing using the sounds that animals make," says Burivalova, who also has an appointment with the UW Nelson Institute for Environmental Studies. "In a tropical forest, you don't see many animals, but you can hear a ton. At times you can hear 30 species within a minute."

The ability to hear biodiversity adds another implement to the conservation biology tool belt. Historically, scientists would visit a forest and count the species they could see, a time-consuming, costly effort that is prone to bias. Motion-detecting cameras, another tool, are great for capturing large animals on the ground but can miss smaller animals and those in the tree canopies.

"Scientists have really started leveraging the idea of bioacoustics as they try to develop ways to monitor biodiversity more cheaply and effectively — and with less bias," explains Burivalova. "We now have the computing power and data storage to do this work that we didn't have 10 years ago. Analyzing the data is really interdisciplinary, and I work with computer scientists and engineers to get the most out of it."

To capture this data, Burivalova visits tropical forests to place recorders that use small memory cards. They can be programmed to record at specific times, such as the morning or evening choruses, when many animals vocalize. They can also be left in the field over months or seasons to track daily and seasonal changes. Memory cards are then collected, and their recordings are uploaded into an online database for analysis.

"I listen for and analyze how filled up the frequency spectrum is with different kinds of sounds," says Burivalova. "If you think of an orchestra, you have instruments that play at different frequencies. If, let's say, the violinists didn't show up, we would see a gap in the soundscape. For me, those instruments are different species, and I can calculate how saturated

the soundscape is at any moment."

So far, Burivalova has recorded biodiversity in Papua New Guinea and Borneo, and she started a new project in Gabon in September. In Papua New Guinea, she found that even small disturbances in the forests can change the "signatures" of the soundscape.

For instance, she discovered that forest fragmentation, which can be caused by anything from planting a garden to clearing a small patch for a cacao plantation, leads to less vocalization during the dawn and dusk choruses. And after selective logging of single trees in Indonesia, soundscapes became more homogeneous and less saturated at various frequencies compared to untouched forests.



A bioacoustic recorder in Borneo's tropical forest is shown here in January 2019. The recorders are preprogrammed to capture all sounds in the environment on a weekly basis.



Zuzana Burivalova looks over the selective logging harvest plan with collaborators from a logging company and The Nature Conservancy to help decide where to place bioacoustic recorders.

PHOTO BY JUSTINE HAUSHEER, THE NATURE CONSERVANCY





These subtle differences might not be picked up by satellites or other survey methods, and opportunities to take note of them are disappearing.

“My dream project that I’m starting is to collect soundscape baselines from across different tropical forests around the world,” says Burivalova. “We still don’t know how tropical forest animal communities change naturally over days, months, or seasons. And we’re running out of time to collect baselines like this because there are almost no forests that are left untouched. So it’s an important time to be doing this.”

— CAROLINE SCHNEIDER MS’11



PHOTO BY ZUZANA BURIVALOVA (2)

In selective logging, as shown at left in Borneo in May 2018, individual, commercially important trees are removed while the rest of the forest is left intact. Bioacoustic studies have shown that even this relatively low level of human impact can cause changes in biodiversity.



# The Tuber Protector

To help growers defend their crops, Amanda Gevens monitors potato and other vegetable fields for destructive diseases

Interview by Nik Hawkins

In the Dairy State, it's easy for a humble vegetable like the potato to get lost amid all the talk of milk and cheese. Consequently, it's a little-known fact that Wisconsin is the third-largest tuber producer in the country, just behind Idaho and Washington. The state's growers plant around 70,000 acres of spuds each year, part of a \$340.8 million industry, so they stand to lose a great deal should anything go wrong with the crop. And plenty could go wrong.

Plant diseases such as late blight present a serious threat to potatoes, and a timely response to an outbreak can sometimes mean the difference between boom and bust. Fortunately for potato farmers, **Amanda Gevens** has their back.

As associate professor and chair of plant pathology, Gevens spends much of her time studying and tracking potentially devastating diseases in potatoes and other vegetable crops. She's also a potato and vegetable pathologist with the UW–Madison Division of Extension, so she's in constant communication with growers throughout the state, keeping them apprised of the presence of diseases and helping them make the best decisions in protecting their crops.

We asked Gevens about some of the pathogens she studies, how her research informs management recommendations for growers, and the methods she uses to get sound advice in the hands of those who need it most.

## WHAT IS THE MAIN PATHOGEN YOU STUDY, AND HOW DOES IT AFFECT POTATOES AND VEGETABLE CROPS?

*Phytophthora* is a genus of a group of highly aggressive plant pathogens that are referred to as water molds, or oomycetes. Most plant pathogens, particularly those that affect agricultural crops, are fungi. But we have a few unusual [nonfungal] pathogens that affect crops, and this group of water molds creates substantial damage. The Greek underpinning of the name is “plant destroyer.” One of the most infamous *Phytophthora* pathogens causes late blight, which played a big role in the Irish potato famine.

## HOW GREAT IS THE DAMAGE IT CAN CAUSE?

Globally, it's \$5 billion each year, and it poses a significant threat to food security. Here in Wisconsin, *Phytophthora* costs us about \$16 million a year. That's sort of a five-year rolling average that includes crop losses in both potato and tomato as well as additional fungicides required to limit the disease.

## THROUGH YOUR RESEARCH, WHAT HAVE YOU DISCOVERED ABOUT PHYTOPHTHORA'S RESISTANCE TO FUNGICIDES?

We monitor a particular water mold called *Phytophthora infestans* in this state, both in potatoes and tomatoes, and we essentially build a culture collection. With all of these samples, which we term “isolates,” we're closely examining the population. One of the things we do is assess the isolates for resistance to one of the most potentially effective fungicides, which is called mefenoxam or, its trade name, Ridomil. This fungicide is a tried-and-true, strong manager of the disease when it works. But it's important to know when resistance is present, because when it is, it's just like applying expensive water to the crop. Fortunately, there are several other fungicides that can be recommended when resistance is identified.

I also partner with the UW Plant Disease Diagnostics Clinic at CALS to offer free late blight diagnostics to all gardeners and growers in the state. Beyond the diagnostics, my lab conducts “strain typing,” which tells us what types of the late blight pathogen, or pathotypes, we're dealing with. We also offer this service on a national scale. So the recommendations are state-specific, but the information that comes out is used regionally and nationally as we learn about the pathotypes that are here. All of this informs our recommendations for disease management both in the near and long term.

## WHAT ARE SOME OF THESE RECOMMENDATIONS?

The first recommendation is always start with clean stock. Late blight is monitored and tracked by the Wisconsin Seed Potato Certification Program, which is a part of my department. The program is headquartered in Antigo, with additional offices in Rhinelander and Madison. It's important to note that certified seed potatoes meet the bar of containing no late blight pathogen. Starting with these seeds is a critical first step.

For tomatoes, it means generating transplants locally, where the pathogen is not known to overwinter and persist. Tomato seed doesn't harbor the late blight pathogen, so typically it's coming in on transplants from other places.

For both potato and tomato growers, we offer a disease forecasting tool through our real-time interactions with



Amanda Gevens

growers. It uses an algorithm based on the past four decades of research on environmental parameters — temperature, precipitation, etc. — to provide a risk rating for late blight on a daily basis. This is called a disease severity value, or DSV. Each day, you get up to four DSVs. When these accumulate up to a certain number, that's when growers know they have to start utilizing preventative fungicides to limit late blight in potatoes because most commercial varieties do not have substantial resistance to late blight. The tool is based on weather conditions within production potato plant canopies in multiple regions of the state.

We're always thinking about what we would term "pathogen ecology" — how these pathogens move, persist, and act within their environment. That's all part of what we've done to help build better management recommendations for growers.

#### **WHAT HAPPENS IF YOU HAVE A CROP THAT IS EXPERIENCING LATE BLIGHT AND THE PATHOGEN HAS FUNGICIDE RESISTANCE?**

When there is a first detection of late blight made in the state, within a day — usually within hours — we will identify what the pathotype is and whether or not it's resistant to mefenoxam. But that's not the only fungicide, right? We have about a dozen others that work well against late blight, so there are other options. That information helps growers make better prescriptive decisions.

Typically, if there's a hot spot for late blight identified in a field, they'll kill the plants there and then very aggressively manage the disease in the rest of that field, and all the surrounding fields will get placed on a more stringent fungicide program. So they'll be spraying more frequently, and they'll be using fungicide selections that have been more active against late blight if infection has occurred.

#### **HOW DO YOU ENSURE YOUR RECOMMENDATIONS GET IN THE HANDS OF THOSE WHO NEED THEM?**

We have multiple mechanisms. One of the most effective is the phone. When there is a first detection, I often spend several hours, if not days, on the phone talking to growers, crop consultants, and industry partners that are affected by the disease finding.

I also manage and write the weekly *Vegetable Crop Update* newsletter for the UW Division of Extension. Through this mechanism, growers can see those DSVs accumulate and know of risk that's coming. But if a disease is detected between issues, I also put out supplements and provide updates once we know the identity of the pathogen. We also have a Facebook

page and a Twitter account for program presence, but in terms of real-time information sharing for decision-making, it's by phone, text, or the newsletter.

**GROW ONLINE EXTRA**  
For additional questions and answers with Amanda Gevens, visit [grow.cals.wisc.edu](http://grow.cals.wisc.edu).

#### **YOURS IS PRIMARILY A RESEARCH AND EXTENSION APPOINTMENT, BUT WHAT ABOUT TEACHING?**

In all the work that I do in support of potato and vegetable production in Wisconsin and beyond, I aim to use the research questions as real-world case scenarios for graduate student training. Mentoring students and staff is tremendously rewarding and furthers good, useful studies while passing on critical research and outreach skills to the next generation of highly capable and much-needed agricultural scientists and practitioners. This is what ensures food security and economic stability.

To learn more about the Department of Plant Pathology's disease forecasting tool and disease severity values, visit [wivegdis.plantpath.wisc.edu](http://wivegdis.plantpath.wisc.edu).



Xuehua Zhong, associate professor of genetics, holds a flat of *Arabidopsis thaliana* (thale cress) in a basement grow room in the Genetics-Biotechnology Center Building on the UW-Madison campus.







# Deep in the Weeds

Close study of an ordinary plant's cellular mechanisms could lead to big advances in agriculture and medicine

BY NOLAN LENDVED : PHOTOS BY MICHAEL P. KING

If you were to come across a patch of thale cress poking through a crack in a parking lot, you might not think much of it. Its miniscule yellow flowers are little more impressive than its spindly stalk and rosette of leaves. You could eat those leaves in a salad, it just wouldn't be much of an epicurean experience. Yet thale cress just might be one of the most important weeds in the world.

This mustard relative, also known as *Arabidopsis thaliana*, has spread to habitats across the globe. And since the advent of genetics, it has taken root in science labs the world over. One such laboratory belongs to CALS genetics professor **Xuehua Zhong**, who discovered *Arabidopsis*'s utility early in her graduate career. Now she uses the plant to study epigenetics, a rapidly growing field concerned with how genes are turned on and off without changes to DNA sequences — in other words, how cells and organisms with the same DNA sequence can exhibit different traits.

Scientists are turning to epigenetics to understand everything from the development and treatment of cancer and other diseases to how crops become resilient to environmental stressors brought on by climate change. **Sarah Leichter**, a third-year genetics graduate student in Zhong's lab, sees a lot of possibilities through the lens of tiny molecules.

"If we can really understand how the mechanisms work, then perhaps we can manipulate them in a way that's favorable for precision agriculture," she says,

referring to efforts to use science to tailor farming practices to specific conditions. And the innovations won't be limited to the plant kingdom: Some of these processes also occur in mammals. "So discoveries first found in plants can help humans, too."

If precision agriculture and precision medicine are the future, then the field of epigenetics is helping make the map that leads there.

**X**uehua Zhong wasn't always a geneticist, nor was she always destined to become a scientist at all. But a deep-seated curiosity about the world, paired with a desire to find answers, laid her path.

"I grew up in a small town in the southeast of China," she says, "in a family without a science background." Her father, a businessman with a burdensome travel schedule, cultivated her inquisitive young mind. During long road trips, he indulged endless questions about trees, animals, and everything else.

When Zhong began middle school, her questions became more focused. On a day when she was home sick from school, she wondered why she, but not some of her classmates, got sick during the flu season. Her sixth-grade biology teacher was the first person to help her understand that science could hold the answers to her myriad questions. "Those early science classes really opened my eyes," she says. "I saw that some questions were already being answered. But the more that I learned, the more I realized that there is so much we still do not know and that maybe I could be one of the people to figure out the answers."



By the time Zhong arrived at Wuhan University, understanding human health and individual differences had become a passion. She majored in microbiology and immunology and found herself inside a laboratory for the first time during her sophomore year, barreling toward a career in medical research. But one thing was holding her back: her model organisms.

As a master's student, Zhong wondered if she could continue to study human diseases without the restraints — and emotional turbulence — of working with mammal models. Enter *Arabidopsis thaliana*. Thale cress is an excellent model for studying all kinds of biological problems because of a few key traits.

First, its life cycle is very short relative to animals and many other plants: It takes only about six weeks for the plant to go from a seed to a self-pollinating adult to the next generation. That's important when you want to study transgenerational changes — modifications that are preserved from one generation to the next.

Second, the *Arabidopsis* genome, or full DNA sequence, is comparatively tiny. At 135 million base pairs (the individual C-G and A-T pairs that make up DNA's double helix), its genetic catalog is among the shortest in the plant kingdom. That means that scientists can get a handle on the plant's genes and their functions with greater ease. In fact, in 2000, the *Arabidopsis* genome was the first to be entirely sequenced.

Finally, the plant is small enough to grow in large quantities inside a laboratory and produces plenty of seeds to support the next research study. Finding *Arabidopsis thaliana* was Zhong's ticket to an entirely new world of possibilities in biological research.

While Zhong was beginning her Ph.D. studies in plant virology at The Ohio State University in the early 2000s, ideas that had been around for the better part of the 20th century about how the same DNA can give rise to different traits were undergoing a renaissance. The term “epigenetics,” which has meant many things to various generations of scientists, was gaining ever-narrower definitions.

A few years earlier, in 1996, a group of researchers at the University of Rochester in New York made a pivotal breakthrough. They discovered that gene expression could be regulated by modifications to a substance called chromatin, a material — found inside the nucleus of a cell — that is made up of proteins, DNA, and other chemicals.

Scientists had been aware since the early days of DNA research that mechanisms must exist that determine which sections of an organism's genome are expressed, or activated. After all, every cell in a given organism's body has the exact same genome hidden away in its nucleus, and yet cells end up doing vastly different things. Cells must, therefore, have some way of reading only certain parts of the DNA code. A skin cell reads the sections that tell it how to be a skin cell, and a neuron reads

the parts that prescribe neurological functions.

The ability to sequence entire genomes and to “knock out” particular genes or regions of the DNA code presents all kinds of new possi-

bilities and allows scientists to identify many genes that play a role in regulating the expression of other genes. What the team at Rochester discovered was that one of those genes codes for a type of enzyme — a histone acetyltransferase — that modifies chromatin in a particular way to change gene expression without

changing the DNA sequence. The mechanism was one of the first thoroughly characterized examples of what today's experts call epigenetics.

“These things that we knew controlled gene expression are actually writing information on top of the genome,” explains **John Denu**, a professor of biomolecular chemistry at UW–Madison and one of Zhong's collaborators, “and that information is what is generally referred to as the epigenome.” Denu was starting his laboratory in 1996, characterizing enzymes and studying how information is transmitted into the nuclei of cells. He became fascinated by epigenetic factors and began trying to understand how they work at the molecular level.

A decade later, Denu was an expert in chromatin in the blossoming field of epigenetics and was on the lookout for colleagues who shared his passion about understanding the machinery of epigenetic changes. When UW–Madison announced the creation of a new collaborative research center, the Wisconsin Institute for Discovery, Denu submitted epigenetics as one of its potential research themes. Part of the proposal was to recruit new experts in the field.

Meanwhile, as a graduate student at Ohio State, Zhong was interested in how plants defend themselves against viruses. Viral invaders commonly carry their genetic information in single-stranded RNA rather than in the double-helical DNA that resides inside every cell of plants and animals. Viral RNA can be similar to the messenger RNA that plant cells use to transfer information from strands of DNA to ribosomes, where the information is read and proteins are made. Viruses can use that structural similarity to sneak from one cell to another and spread infection. Once inside a cell, viruses let the cell do the work of replication: The cell's own transcriptional machinery creates copies of the viral RNA.

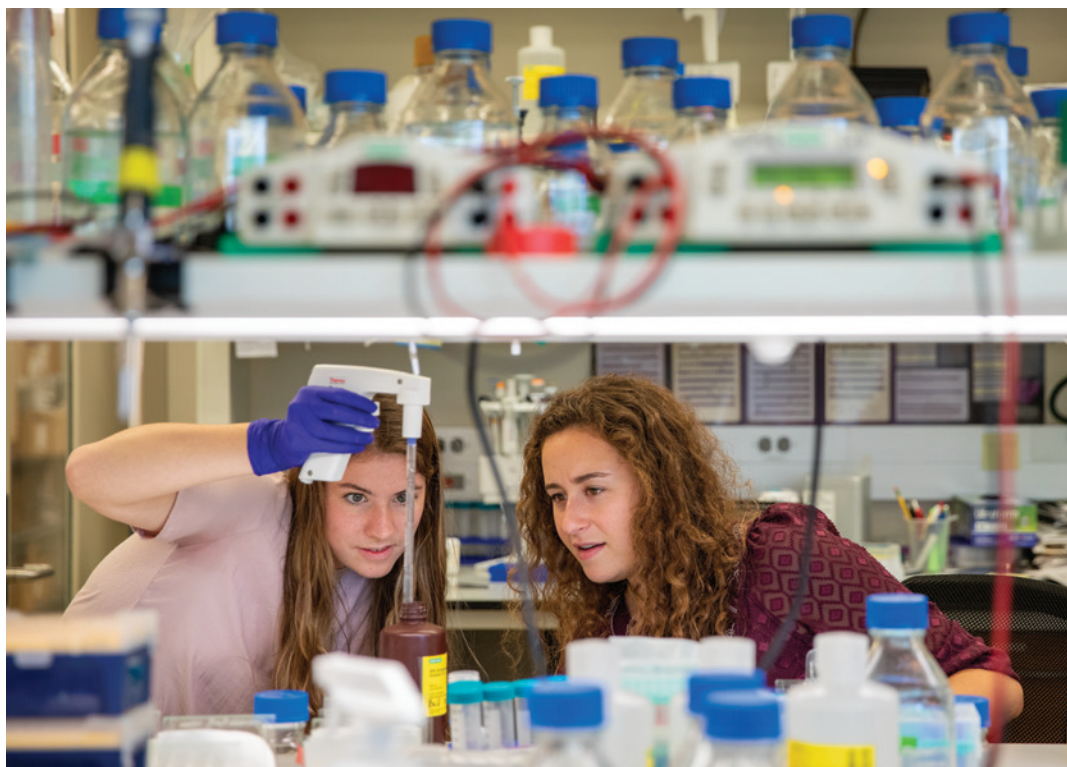
The plants, however, are not defenseless. Zhong and her Ph.D. adviser, **Biao Ding**, discovered that one way the plants

*If precision agriculture and precision medicine are the future, then the field of epigenetics is helping make the map that leads there.*

fight back is by silencing parts of the virus's RNA, turning off genes related to replication. In response, viruses have developed measures to silence plant genes that code for the silencers. So goes the biological arms race that drives evolution. That arms race also seems to be conserved across species, meaning similar defenses and counter defenses exist in the animal kingdom, too. The discovery was Zhong's introduction to epigenetic mechanisms.

Zhong now studies the machinery of suppressing gene expression by way of methylation. Enzymes called DNA methyltransferases attach methyl groups — bunches of  $\text{CH}_3$ , one carbon atom bonded to three hydrogen atoms — to specific sites on DNA, changing how that section is expressed. “Methyltransferases are really ancient proteins,” says Zhong, “and because their structure and function are conserved between plants and mammals, we can gain important information about DNA methylation in humans by studying flowering plants, such as *Arabidopsis*.”

In 2013, Denu partnered with the Department of Genetics to bring Zhong's research program — and her model organism — to UW–Madison. “She brought with her a very strong genetic background and a good knowledge of the model organism *Arabidopsis* to study fundamental processes of the epigenome,” says Denu, who has been impressed with Zhong's success since her arrival in Wisconsin. Zhong has been honored with an Early Career Development Award from the National Science Foundation, the Alfred Toepfer Faculty Fellow Award from CALS for research benefiting agricultural activities, a Maximizing Investigators' Research Award from the National Institutes of Health, and, most recently, a Vilas Early Career Investigator Award from UW–Madison recognizing research and teaching excellence. She has also published her research in prestigious journals and cultivated collaborations throughout Wisconsin and beyond.



**B**elow the sunlight-drenched glass windows, bustling labs, and Mesozoic gardens of the Discovery Building on the UW–Madison campus sits a portion of Zhong's crop of *Arabidopsis thaliana*, a ragtag collection of plants at various stages of the life cycle growing in a windowless basement corner. Freshly germinated green sprouts can be found on a shelf next to brittle, brown bunches of seeds. Across University Avenue beneath the Biotechnology Center, thousands more specimens of the plant fill carefully climate-controlled walk-in rooms and stand-up growth chambers. At a given time, Zhong's lab is cultivating around 30,000 individual plants that may be part of dozens of different experiments.

Leichter, backlit by meticulously calibrated lights, uses a small forceps to pollinate the delicate yellow flower of an *Arabidopsis* plant. She's a details person. The processes she tries to understand occur at the molecular level. She studies one particular enzyme, a DNA methyltransferase called DRM2, that

Undergraduate genetics and genomics major Katie Klimpel, left, and research assistant Sarah Leichter work in the Xuehua Zhong epigenetics lab in the Discovery Building at UW–Madison.

is responsible for depositing epigenetic modifications in *Arabidopsis*'s genome. DRM2 is choosy. It lays down methyl groups at very specific sites on DNA, usually silencing those regions. But Leichter is not satisfied only knowing what DRM2 does — she wants to know exactly how it does it.

“Getting down to the precise, nitty-gritty mechanism is what makes me so excited about it,” she says. “What are the properties of the amino acids within the enzyme that targets DNA? What's the biochemistry of the DNA that allows this interaction to occur?” Answering those questions means building collaborations with structural biologists, biophysicists, computational modelers, and other experts. “We're trying to study this in a way that's very multidisciplinary and that pushes me outside of my comfort zone as a scientist,” she says.



## ScienceOutreach

### A Versatile Training Tool

Genetics professor Xuehua Zhong is a true believer in the power of outreach to instill a love of science in young people and develop mentoring skills in her students. To her delight, she has found an opportunity to do both.

Every July, hundreds of high school students from across Wisconsin descend on the Discovery Building at UW–Madison for Summer Science Camps run by the Morgridge Institute for Research and the Wisconsin Alumni Research Foundation. Over the course of a week, many of the participants are introduced to *Arabidopsis thaliana*, epigenetics, and members of Zhong's laboratory group.

Graduate students Sarah Leichter and Ray Scheid BS'16 lead the high schoolers through a molecular biology experiment to investigate the

difference between two types of plants: the wild-type, or "normal," plant and a mutant stripped of its ability to methylate DNA. The students extract DNA from the plants using the same tools and techniques Leichter and Scheid use in their own experiments.

Next, they go on a molecular treasure hunt for DNA methylation using a special enzyme that cuts methylated DNA and a technique called PCR, which makes copies of sections of DNA to make it visible on agarose gel. At the end of the week, they talk about what their experimental results mean for the plants with whose DNA they have been tinkering.

Many of the students may never have encountered a centrifuge or micropipette, but Leichter is impressed with how quickly the young minds take to science. "I like

seeing the kids problem-solve and work together as they go through the protocol, and I'm really surprised at how naturally good they are at molecular biology techniques," she says. "I find that they ask really good questions about science beyond what we are doing for the experiment in the lab."

The camps are just one instrument in Zhong's arsenal of outreach activities, but she sees them as a unique opportunity to impact not only the students but also their teachers. "The idea is that the influence of a science teacher could be very big," she says, recalling that her own sixth-grade teacher was responsible for cultivating her early interest in science. "The students go home and influence their friends and local communities and talk about their research experience at UW–Madison, but the teachers can also have a huge impact on an entire generation of future scientists."

The benefits don't end there. Zhong's own students learn valuable mentoring skills by participating in camps, lab internship programs, and other outreach opportunities. Those abilities, says Zhong, are just as important as the laboratory skills they develop on the way to receiving their degrees.

"Eventually, they're going to be leaders and mentors somewhere, and these are great opportunities for them to learn how to mentor junior students and to model what scientists look like."

Delving into the nitty-gritty is a common theme for Zhong's research group. One project, for example, is focused on understanding how plants sense environmental threats, such as ultraviolet (UV) radiation from sunlight, which can alter the epigenetic landscape. That means teasing apart every aspect of UV radiation's effect on a single plant enzyme, from the photo-receptors that sense the UV light to the plant's ability to develop and survive.

Zhong and postdoctoral researcher **Jianjun Jiang** have discovered that extra doses of UV light cause the DNA methyltransferase DRM2 to malfunction, leaving typically silenced regions of *Arabidopsis*'s genome unmethylated and thus activating genes associated with stress and defense responses. Zhong's enthusiasm about the discovery is palpable.

"This is big because it's the first time we are able to link a signaling pathway directly with epigenetic components in a way that we understand the precise mechanism," she says.

Fully appreciating the mechanisms underlying epigenetic changes is critical, according to Zhong, because such understanding might be the key to turning epigenetics into a powerful tool. If UV light is a potent inhibitor of DNA methylation, it might be an effective means of changing gene expression in a less invasive, less enduring way.


"If we want to change a phenotype," she says, "perhaps we can just use UV light rather than chemicals or other permanent methods like genetic transformation."

The epigenome, it turns out, is very responsive to environmental cues not only in plants but also in mammals. Zhong and Denu are part of a campus-wide Epigenetics Hub with researchers who are studying how multitudes of external factors, from lifestyle and diet to trauma and early life experiences, can influence chromatin to cause changes in which genes are turned on or off. Denu, for example, has linked



Xuehua Zhong, associate professor of genetics, and high school summer science camp participant Sadiq Wanyaka look at a solution of supernatant and isopropanol during a DNA extraction experiment at the Morgridge Institute for Research at the Discovery Building on the UW–Madison campus.





diet to gene expression and health, a relationship that is moderated by gut microbes, metabolism, and epigenetic mechanisms, such as methylation.

The more the mechanics of epigenetics are understood, the easier it is to see the big picture. What might be possible if we could harness the biochemistry of chromatin and bend it to our will? Modifying the genomes of organisms has become a common practice in science and industry. Humans have been making tweaks to the genetic codes of plants and animals using selective breeding since long before the discovery of DNA. Today, nearly all of the soy, sugar beets, canola, and corn grown in the United States has been genetically engineered through various forms of biotechnology to be resistant to disease, drought, and other environmental threats.

That resistance, though, is not necessarily responsive to present and ever-changing conditions, and creating transgenic crops can take several generations. What if crops could be made more resilient more quickly but without permanent edits to their DNA?

Zhong thinks epigenetics has a big role to play in the future of agriculture, and she has one big environmental factor on her mind: climate change. As the planet warms up, plants are facing new and intense challenges, such as less predictable growing seasons and skyrocketing temperatures. **Jaini Chen**, another of Zhong's postdoctoral collaborators, is investigating how *Arabidopsis* responds to increasing temperatures, the kind

that crops around the world are experiencing as a result of climate change.

Since setting up shop in Madison, Zhong and her collaborators have built an extensive library of *Arabidopsis* mutants with various genes deleted from their genomes. Chen noticed that when the genes that code for the DNA methyltransferase are mutated, the plants start to struggle to beat the heat: Their stalks grow shorter and their leaves curl, providing less surface area for photosynthesis.

"We started to think that maybe DNA methylation is involved in heat stress," Chen says.

Chen, who cranks the growing chamber temperatures from 23 degrees Celsius (a comfortable mid-70s Fahrenheit) to a scorching 44 degrees

(over 110 degrees Fahrenheit), has spent the last year teasing apart the pathways and processes between the temperature of the environment, the epigenetic response, and the ultimate effects on the plants' health and fortitude. She's found, for example, that a gene related to curling leaves is typically methylated and silenced, but without the DNA methyltransferase, it is expressed. Now

she's trying to determine whether the methylation-related consequences of heat stress are passed from one generation to the next. After a few generations of high temperatures, she'll compare the methylation profile and health of the plants in the experimental lineage to the wild-type controls.


"When we see the difference, we'll go deeper to study the precise mechanism

**"If we can understand how it works in a model plant system and then transfer that knowledge out to agricultural plants that need to adapt to the changing environment, we can develop strategies to maintain a sustainable yield in heat-stressed environments."**

behind this transgenerational inheritance," she says.

When it comes to the effects of heat, it's another case of uncovering the nitty-gritty with an eye toward manipulating the epigenome. Zhong and her group believe that if they can understand how plants use epigenetic mechanisms such as methylation to adapt to heat, they might be able to activate those same mechanisms to help them adapt even better as conditions change.

"If we can understand how it works in a model plant system and then transfer that knowledge out to agricultural plants that need to adapt to the changing environment, we can develop strategies to maintain a sustainable yield in heat-stressed environments," says Leichter.

As new ways of modifying chromatin — such as UV light and heat — are carefully characterized, they could become powerful tools for fine-tuning the epigenomes of crops and their responses to environmental stresses. And those alterations could be passed on to future generations of more resilient plants. 



Researchers expand a powerful  
computer simulation tool to study  
and address nitrate contamination  
in Wisconsin's groundwater

# A MODEL SOLUTION

BY NICOLE MILLER MS'06

PHOTOS BY MICHAEL P. KING

**W**hen agronomy professor Chris Kucharik and his wife, Amy, moved into a subdivision in the Town of Burke in 2006, they weren't surprised to learn their well water contained quite a bit of nitrate. Nitrate is the most widespread groundwater contaminant in Wisconsin, and it's often associated with agriculture. Their home, located in rural Dane County, is surrounded by current and former farmlands.

Their nitrate level was around 9 parts per million (ppm), below the maximum contaminant level of 10 ppm set by the Environmental Protection Agency. But that still felt too high for them. Fortunately, the house came with a reverse osmosis system that filters out around 70% of the nitrate in their drinking water. Besides changing the filter annually, they didn't think about it much. Set it and forget it.

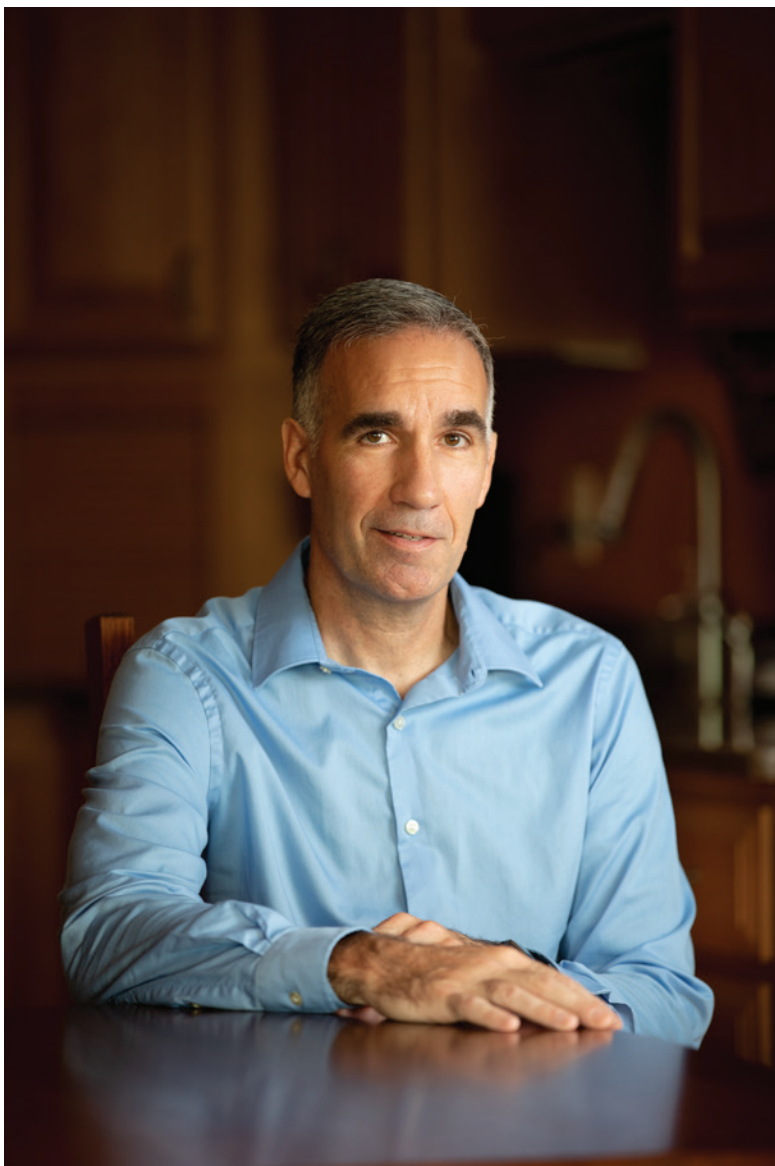
Then, in 2013, Amy became pregnant, and they were jolted out of their complacency. It was time to get their drinking water tested again.

"That was at the top of our list of things to do," recalls Kucharik, a professor of agronomy at CALS. "We rechecked the water samples to make sure the reverse osmosis system was still functioning correctly."

High levels of nitrate are known to cause health problems in pregnant women and infants, including the life-threatening condition known as blue baby syndrome. In adults, long-term consumption appears to be linked to certain cancers, thyroid problems, and diabetes.

Fortunately for the Kuchariks, their system was doing its job. Unfortunately, nitrate contamination is still a big issue in Wisconsin. There are more than 800,000 private wells in the state, and around 10% of these wells are estimated to have nitrate concentrations exceeding the EPA's maximum contamination level. In certain agricultural regions, that percentage is reported to be much higher — up near 20–30%.

This issue is one of the reasons why Gov. **Tony Evers** declared 2019 the Year of Clean Drinking Water in Wisconsin, and it's why, around the same time, state Assembly Speaker **Robin Vos** established the Speaker's Water Quality Task Force. Last summer,



**Professor of agronomy Chris Kucharik at his kitchen table in his Town of Burke, Wis., home.**

**The plumbing system in the Kuchariks' home features a reverse osmosis treatment system, which removes contaminants, such as nitrate.**

Evers specifically called for new rules to help limit nitrate losses from agricultural fields. The goal is to address the source of the nitrate problem — to help understand it and solve it.

It's a goal Kucharik shares.

"I've been worried about this for years," he says. "Water quality has always been an issue, but it's coming to a head in many places because more and more residents are becoming concerned that they can't trust their tap water."

Kucharik is the developer and steward of a powerful computer model known as Agro-IBIS, which enables him to explore the complex challenges that arise where the interconnected demands for food, water, and energy collide. It can also factor in climate change, a moving target that compounds these challenges.

"Models are tools," says Kucharik. "They are



good for asking big questions. They are good for playing out scenarios of the what-ifs. Using models, we are able to conduct experiments that we can't conduct in the field [because of the complexity or scale]."

For more than 15 years, Kucharik has been using Agro-IBIS to explore all kinds of difficult questions related to agricultural resiliency and environmental protection. He's used it to look at the impact of the federal Energy Independence and Security Act of 2007 — which ramped up corn production for ethanol — on the hypoxic area, or dead zone, in the Gulf of Mexico. And he recently wrapped up a big project where his team scrutinized phosphorus levels in the state's Yahara River watershed.

In recent years, he's been preparing to bring the model to bear on Wisconsin's nitrate problem. The project involves field research in the Central Sands region, the state's "vegetable basket," to improve the model's ability to simulate how nitrate flows through the environment.

"We're trying to understand how the system works, how the nutrient cycles work, a bit better so that we can take that information and use it as validation and calibration data for the model," says Kucharik. "Then we can look at, if growers irrigate this way, or if they apply fertilizer this way, what is that going to mean to crop production as well as to how much nitrate is being lost out of the system. The model can be used as a tool to understand how different types of management might impact those things at a [regional or statewide] scale as well as under a changing climate."

Kucharik hopes to provide information that can help guide farmers and policymakers as they develop adaptation strategies to meet water quality goals.

"That's a big part of what we're trying to do here," he says, "to find better solutions for the production of food."





**THE IDEA TO DEVELOP AGRO-IBIS** marked a key crossroads on Kucharik's career path.

Kucharik grew up in West Allis and Slinger, Wisconsin, where, from a young age, he knew he wanted to be a meteorologist. He followed his aspiration to UW–Madison, where he earned bachelor's and doctoral degrees in atmospheric and oceanic sciences in 1992 and 1997.

During a postdoctoral position at UW–Madison, he worked on a model of global ecosystems and carbon cycling. The model — called IBIS — only included natural landscapes, such as grasslands and forests. Near the end of his postdoc, it struck Kucharik that something was missing.

"There were five or six groups around the world that were doing this [ecosystem] modeling, but nobody was factoring in agriculture, which covers 35–40% of the earth's ice-free land surface," says Kucharik.

He then began building his own integrated model of agroecosystems, bringing together traditional crop models and ecosystems models. It was the first model of its kind, notes Kucharik. Before Agro-IBIS, as it came to be known, he could never have predicted that agriculture would be such an integral part of his research program.

"At that point in my career, I had never had a class in agronomy. I didn't know anything, really, about cropping systems," notes Kucharik, who is now the chair of the agronomy department. He is also affiliated with other campus units, including the Nelson Institute for Environmental Studies and the Wisconsin Energy Institute.

Agro-IBIS is a process-based model, meaning it tries to account for everything happening in the system, down to the small details. It seeks to simulate all of the processes taking place across the landscape — on both natural and managed lands — factoring in things such as weather, soil type, plant cover type, plant growth rates, irrigation, fertilizer applications, nutrient losses, and surface water and groundwater flow.

"Many [processes in the model] are run at an hourly time step, which means every hour the model is producing new data," explains **Tracy Campbell MS'18**, a doctoral student in Kucharik's lab. "We have to study plant photosynthesis [for a new crop type] over the course of the day, hour by hour, and across a variety of environmental conditions so the model's simulations can best mimic crop behavior at such a fine temporal scale."

Agro-IBIS is ideal for studying complex interacting effects, such as the combined impacts of



**Tracy Campbell** (left), a research assistant in the Department of Agronomy, and research intern **Emily Marrs** install funnel systems to collect irrigation water in a pea field at Isherwood Farm near Plover, Wis.



**Sensors are shown at various depths of soil in a field at Isherwood Farm. A clear line is visible between the fertile top soil and the beginning of the sand layer.**

land management and climate change, and how those interactions can affect crop yields, water quality, soil erosion, and other factors of interest. It can assess these impacts on a field level or on regional, state, and national scales. It can also look at short time frames or long stretches.

"If you're running a simulation into the future or doing a historical run of 50, 60, 70, or 100 years, it can take a week or two [for the model to complete the run]," notes Kucharik.

The model has grown over time, as Kucharik and his graduate students and scientific collaborators have expanded it to incorporate more phenomena. Over the years, they've added new crops (potatoes) and new nutrients (phosphorus), and they've integrated it with other helpful models (hydrology).

Today, Agro-IBIS consists of around 50,000 lines of code written in FORTRAN 90. The code looks like concise poetry — with plenty of line



Water samples containing nitrate are examined at a testing tent at the Midwest Renewable Energy Association's Energy Fair in Custer, Wis.



Kevin Masarik, a doctoral student in the Kucharik Agroecology Lab, injects a dye into his model while giving a presentation on Wisconsin groundwater at the Midwest Renewable Energy Association's Energy Fair.

breaks and white space — written in some kind of futuristic language that features a lot of numbers and symbols. It seems impenetrable, but it's not hard to grasp the big picture.

"The code is largely equations that represent the physics, the chemistry, the biophysics, the biogeochemistry that represent our understanding of how the system works," says Kucharik. The laws of nature, so to speak.

The code also includes the instructions needed to run a simulation. In other words, to query the model with a research question.

"That's where all the fun starts, when the model starts spitting out data," says Kucharik.

For years now, Kucharik has been gathering the information needed to ask Agro-IBIS more in-depth questions about nitrate in Wisconsin. To that end, his team is actively involved in three research projects in the Central Sands. They're gathering field measurements, which are needed to increase their understanding of these agroecosystems on sandy soils, so they can improve and expand the model in this area.



**ISHERWOOD FARM SITS ON A FLAT** expanse of land near Plover, Wisconsin, in the Central Sands. **Justin Isherwood**, a sixth-generation potato and vegetable farmer, runs the operation with his son, **Isaac**. A published author with a longtime interest in agriculture and sustainability, the elder Isherwood has been welcoming research on his land since the early 1970s.

"I believe in the place of science, how it alters our methods and improves our lives," Isherwood says. "It's been the boon of agriculture."

That's why Isherwood allowed Kucharik and his research team to install 25 lysimeters deep in the sandy soil below his farm fields over the years. The instruments collect the moisture — from irrigation and rain — that soaks down past the root zone of his crop plants.

The Central Sands is one of the nation's top potato and vegetable producing areas. Encompassing portions of eight counties in the center of the state, the land features a shallow layer of fertile topsoil — just 10 or 12 inches on Isherwood Farm — underlaid with a large volume of sand and gravel deposited by the state's most recent glaciers. Water permeates the sand and gravel, creating a large, rain-fed aquifer that farmers utilize to irrigate their crops.

The region is great for growing food, but it's not without its challenges. The Central Sands has faced serious water quantity problems in the past, and concern is mounting about water quality. Potato and corn require relatively large amounts of nitrogen-based fertilizer, and some of these nutrients leach down through the soil into the groundwater in the form of nitrate. Nitrate is considered mobile in the soil — it tends to flush through.

"The challenge is the top foot," says **Kevin Masarik** MS'03, a doctoral student in Kucharik's lab. "We need to figure out how to keep nutrients in the top foot of the soil, where plants can take them up and utilize them and prevent them from leaching into the groundwater."





**Agronomy research assistant Tracy Campbell uses a portable photosynthesis system to assess the growth of potato plants in a research plot at Hancock Agricultural Research Station in Hancock, Wis.**

Masarik is also the state's groundwater education specialist with the UW–Madison Division of Extension. Through this position, based at UW–Stevens Point, Masarik helps citizens test their well water and advises them on how to address contamination problems. He has access to 30 years of water quality data from private wells around the state. To learn how to deal with such a large data set, he joined Kucharik's lab, in part, to expand his skills in data analytics and statistics.

"Plus, Chris has been looking at nitrate for a long time," says Masarik. "That's one of the reasons why I was excited to work with him."

On a regular basis, Masarik or his student assistant stops by Isherwood Farm — as well as other participating farms and the Hancock Agricultural Research Station — to pump out the lab's lysimeters and send the water samples for nitrate testing. The data provide quantitative information about how much nitrate is leaching in various situations, given different crop types, soil properties, nutrient applications, irrigation schedules, and weather events.

This project, now in its fourth year of data collection, has revealed a surprise. The findings show that crops do a pretty good job of capturing nitrate in the root zone during seasons when precipitation is normal to below average. However, wet years still pose challenges.

"A significant portion of nitrate is actually lost during the period after harvest all the way up until planting the following year," says Masarik. "During that time, there's a large portion of nitrogen that's returned to the soil because of the crop residue [breaking down]."

This was big news to Isherwood, who is excited about this unexpected (and welcome) opportunity for growers to do better.

"Maybe there's some material that could be sprayed on the residue to slow down its biological decay [until the next growing season]," says

Isherwood. "When the problem is revealed, that's when ingenuity can come into play to help solve it."

Last summer, Campbell, who joined Kucharik's lab in 2016, helped launch a new research project at the Hancock station. On most days throughout the growing season, she could be spotted there lugging around a portable LI-COR photosynthesis system. The instrument measures a plant's rate of photosynthesis — a quantitative way to assess plant growth at a given moment — at various CO<sub>2</sub> and light levels.

"It's nondestructive," says Campbell. "You just clamp [the leaf chamber] onto a leaf, and it takes around 45 minutes to do the measurements."

Campbell's project piggybacked on a field study, led by horticulture assistant professor **Yi Wang** PhD'12, that is testing out three promising new varieties of potatoes developed through the UW's potato breeding program. Growers are excited about the new varieties, says Wang, so they will likely be grown on more acreage in the future. She is testing their productivity at five different nitrogen application rates, comparing them to some more widely grown varieties.

"For this project, I am working to find the optimal 'N' rate to grow these varieties," says Wang. "The hope is maybe these new varieties will need less nitrogen to achieve a good yield compared to their standard counterparts. So that's the primary objective of the project." In a related study, she is looking at different irrigation rates for these same varieties.

For Campbell, the goal is to gather information — which she can turn into new parameters and equations and add to Agro-IBIS — about how the new varieties respond to various treatments. At this point, the model already has equations that represent a "generic potato" grown in ideal conditions. When the project is complete, it will be able to answer questions about specific potato varieties under different growing conditions.

"Those experiments and that data that Tracy's

collecting are the things that we need to put into our models so we can scale up from a plot level to ask, okay, if we started growing one of these new varieties across the whole Central Sands, and managing nitrogen and water this way, these are the large-scale impacts that it would have on water quality,” says Kucharik.

A third project involves looking at how much nitrate is present in irrigation water and whether farmers can factor that into how much nitrogen fertilizer they apply.

“When growers pump groundwater to the surface to irrigate their fields, in a way they’re recycling some of the nitrogen that has been lost earlier, and this is not something new,” says Kucharik. “Now we want to try to credit that so they can maybe reduce the amount of other fertilizer that they’re applying to the crop.”

So far, with data from more than 23 wells, they have found nitrate concentrations ranging from 6 ppm all the way up to 32 ppm, which is quite high and has the potential to make a significant contribution to a crop’s nitrogen needs. Now they are trying to figure out if nitrate levels for wells are consistent over time so farmers can count on this contribution.

“In the future, we may be able to develop guidance on how much N application rates should be reduced based on irrigation water nitrate concentration,” says soil science professor **Carrie Laboski**, who puts together crop nutrient recommendations for Wisconsin farmers. “We need more data on the consistency of nitrate levels over time along with field trials validating this practice on farms.”



**OVER THE COURSE OF HIS CAREER**, it has become more urgent for Kucharik to solve relevant problems and share his results with groups that could benefit.

“Early on, it was satisfying for me to publish my research in journals, and scientists would read that,” says Kucharik. “But it’s very unsatisfying now to know that the people who could actually apply the findings are not really reading that information, so we’re trying to do things to better interface with them.”

Kucharik is now involved in outreach to the state’s growers, a group he finds is constantly motivated to “understand how to do things better.” His goal is to help them envision the future and encourage them to start heading in that direction now, so they won’t be caught off guard by things like new fertilizer regulations or altered weather patterns down the line.

“Chris has made numerous presentations to our grower group,” says Isherwood. “He’s been wanting to take the group in directions that climate science is leading us. That’s very daring, and I’m sure I’m not the only one who appreciates that.”

Kucharik also plans to make himself — and his model — available as a resource to support the state’s water quality efforts during the Year of Clean Drinking Water and beyond, including Gov. Evers’s call for new rules to limit nitrate losses from agricultural fields. To that end, Kucharik has met several times this past year with staff from the Wisconsin Department of Natural Resources (DNR) and the Department of Agriculture, Trade and Consumer Protection to discuss state water quality issues, and he was among a group of CALS researchers who met with DNR Secretary **Preston Cole** this spring to discuss their water-focused research.

“I want to be as involved as possible,” says Kucharik. “I want the process to be as informed [by science] as possible. Decision-makers and legislators need to make policy at the watershed, region, or state level. A great way that we can help is by sharing model results at broader scales that have some policy relevance to them.”

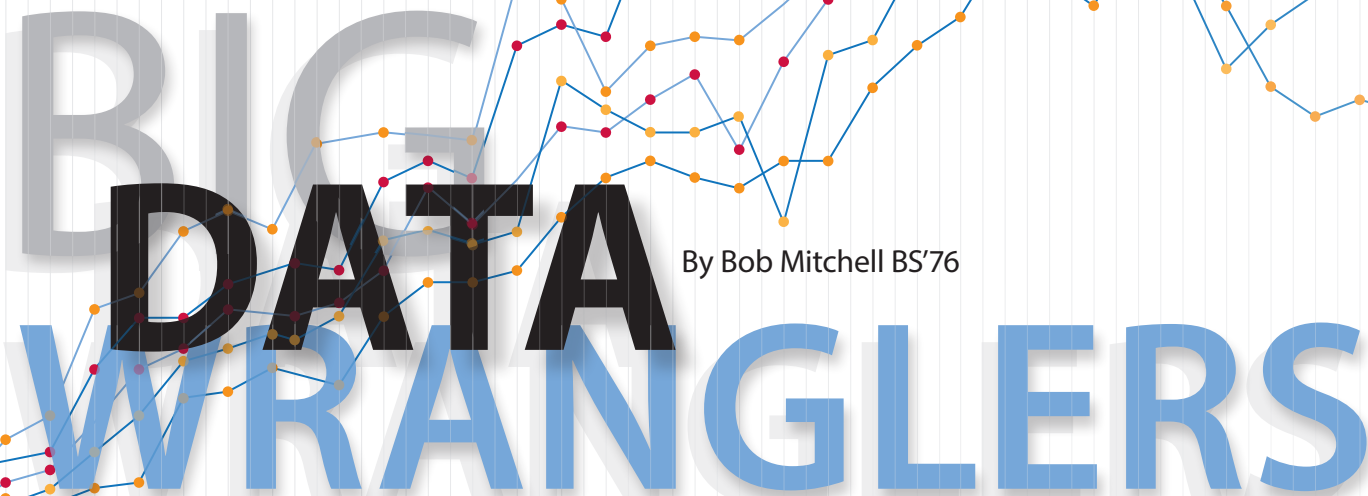
There’s wide agreement that it won’t be easy to solve the state’s nitrate problem. Kucharik believes it will take a significant transformation of our agricultural systems, including more perennial vegetation on the landscape, such as perennial crops, cover crops, and grasses, as well as reductions in fertilizer applications.

For farmers around the state, there won’t be a one-size-fits-all solution. Adaptations will need to be tailored to individual farms based on their cropping systems, soil, local weather patterns, topography, and hydrology. Solutions may involve adjusting nutrient or irrigation approaches, switching to “low nitrogen” crop varieties, managing crop residues, or crediting nitrate in irrigation water. In most cases, it will likely take a number of things combined.

Kucharik is excited to use Agro-IBIS to help assess which changes will have the biggest impacts — now and into the future — and show the best path forward. The goal, says Kucharik, is twofold: farm resiliency and clean water.

“The model,” he says, “will help us understand the impacts of decision-making and climate change on these goods and services that we rely on as a society.”





# BIG DATA WRANGLERS

By Bob Mitchell BS'76

**From computer vision to cloud computing, CALS scientists are finding ways to gather and analyze massive amounts of information for better farm management**

The video clip shows some very colorful calves. It's an overhead view of five young Holsteins, but none of them is black and white. They are either red, green, yellow, indigo, or sky blue, and they keep changing color as they move about the pen.

These are six-week-old calves as seen by a computer — one that's been trained to identify each animal by the pattern of her coat and to recognize and record what she's doing. Each color signifies a different behavior: standing, lying down, drinking water, drinking milk, or eating.

This is valuable information for a dairy farmer, says CALS dairy scientist **João Dórea**. A calf's behavior tells the farmer a lot. Just like a human child, a calf that's beginning to get sick is lethargic and doesn't have much appetite. A parent with two or three kids might notice these changes, but for a farmer who's raising dozens or hundreds of calves, it's not so easy.

"It's a tiny change that's hard to spot," Dórea says. "By the time the farmer notices it, it's often too late."

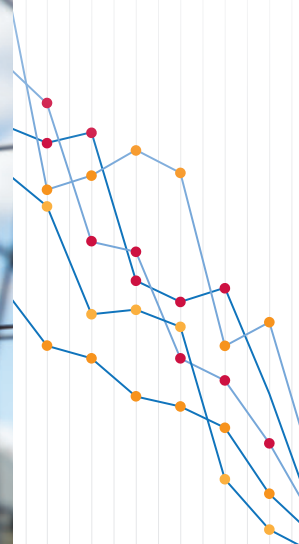
A team of CALS researchers is working to change that. They're building an automated system that uses computer vision technologies — akin to what guides Google cars and lets your photo app match faces to names — to watch calves 24 hours a day. Their system will not only warn

a farmer if a calf is getting sick but also track her growth and predict her future success as a milking cow and mother.

The idea for this system was hatched on the fourth floor of the UW–Madison Animal Sciences Building in the lab of animal sciences professor **Guilherme Rosa**. Rosa and Dórea (who worked in Rosa's lab until he joined the dairy science faculty in July 2019) and their students and postdocs wrangle "big data" — a term that refers to the vast volumes of complex information now being generated and streamed continuously from many sources in many forms. They use artificial intelligence, cloud computing, and sophisticated statistical tools to dig deep into mountains of farm data, searching for patterns that can help farmers better understand what is happening with their animals.

These researchers work at two very different scales. Some projects zoom in on individual animals, using sensor technology to collect and analyze data in real time about each animal's health, growth, feeding, and behavior. "We can use this information for individualized management practices — so-called precision livestock farming, similar to personalized medicine in humans," says Rosa, who is also affiliated with the Department of Biostatistics and Medical Informatics in the UW School of Medicine and Public Health.

◀ João Dórea, assistant professor of dairy science (right), and animal sciences graduate student Arthur Fernandes set up a camera over a calf hutch at Arlington Agricultural Research Station in Arlington, Wis.





Others take a wide-angle approach, poring through huge data sets assembled from records of hundreds or thousands of farms. “Farms collect vast amounts of data on feeding, health, genetics, reproduction, but they mostly use it only for day-to-day decisions,” Rosa says. “We mine this data to develop predictive models to help farmers optimize production, animal welfare, their environmental footprint, everything.”

Rosa, Dórea, and their collaborators are putting this blend of data and animal science to work in myriad ways.

### SWINE STRESS REDUCTION

There are a lot of pigs on Iowa’s highways. The state produces 50 million hogs a year, and they all end up on trucks headed for packing plants. For a few of them, it’s a rough trip.

In 2016, Ph.D. candidate **Tiago Passafaro** undertook a major data-mining project in collaboration with Iowa Select Farms, the state’s largest hog producer. Part of the project looked at transportation losses. He examined more than 26,000 shipments from 520 farms, totaling about 4.5 million animals, and found that 0.76% of the pigs didn’t survive the trip.

“Obviously, this is a very big welfare concern,” Rosa says, “and also a big economic one.” Valued at about \$150 per pig, the 34,715 nonsurvivors in their study represent a loss of about \$5.2 million.

Passafaro used a sophisticated statistical model to integrate a wide range of data — where the trip began and ended, the date traveled, weather conditions, shipment size, weight of the pigs, and so forth. Some of his findings were expected: There was a direct relationship between heat, humidity, and transportation losses. But there were also surprises.

“A pig is more likely to die on a shorter trip — up to 150 kilometers or so — than a longer one,” Rosa says. “The largest stress comes from loading and unloading. On a longer trip, the pigs



PHOTO BY MICHAEL P. KING

Guilherme Rosa, professor of animal sciences, visits the Emmons Blaine Dairy Cattle Research Center at Arlington Agricultural Research Station.

have time to recover from the loading stress prior to the unloading. Another surprise was that when the truck driver is the owner of the truck, the likelihood of a pig dying is much lower.”

This dive into the data shows how complicated it can be to make a sound management decision, Rosa says. It’s not enough, for example, to rank trucking companies by pig mortality and hire the one with the best record. There is a complex interdependence of factors to consider.

“Maybe one company was used more in the summer and another more in the winter,” Rosa says. “Or maybe a company does only long-distance hauling. You have to sort all that out. It’s not something you can analyze with an Excel spreadsheet. Our model takes all of these confounding factors into account.”

Iowa Select Farms lost no time in incorporating the study’s findings into its management protocol, says **Noel Williams**, the firm’s chief operating officer. “Results from this analysis allowed us to discover the potential causes of transportation losses,” he says. “Now we’re implementing processes that



PHOTO COURTESY IOWA SELECT FARMS

Pigs at one of Iowa Select Farms’ 800 locations move toward a transport truck. CALS researchers used a sophisticated statistical model to find ways to reduce stress among swine. They found that the largest stress comes during loading and unloading.

mitigate transport loss and improve our system's economic performance and care for our animals."

### A FORECAST FOR BEEF QUALITY

Another of Rosa's students is mining data to help dairy farmers maximize returns from selling culled cows to beef processors. Some 2.5 million U.S. dairy cows are sold for beef each year, providing farmers with a much-needed secondary income — roughly 10% of dairy farm revenue — and about 12% of the nation's beef supply. But these animals often bring disappointingly low prices, and carcass quality is uneven.

Dairy farmers would like to know how they can do better, says graduate student **Ligia da Cunha Moreira**.

"My objective is to investigate how what's happening during the cow's lifetime can help predict her carcass quality and the price she'll bring when she's sold," she says.

Moreira is collecting data from four farms, a cattle auction company, and a meatpacking plant. The farms furnish detailed records on each cow's milk production, health history, and reproductive performance. The auction barn and packing plant provide the sale price and data about carcass quality.

"I'm organizing and integrating the data and testing different statistical models to see which one best predicts price and carcass quality," she says.

The project is funded partly by the Baldwin Wisconsin Idea Endowment, which supports UW partnerships with off-campus groups — in this case, Professional Dairy Producers of Wisconsin (PDPW).

"Research that helps us make better decisions to produce higher quality dairy beef is good for everybody in the food chain," says **Jay Heeg**, PDPW's board president. "With milk prices being [as low as] they've been, anything that can help us make more off of dairy beef is another opportunity to help make dairy viable."

### NO HUNGRY CATTLE, NO WASTED FEED

Feed is to livestock as fuel is to cars — the raw material that makes them go and the biggest operating cost by far. So feed efficiency is key to a healthy bottom line.

Rosa and Dórea are combining computer vision and data streaming in a system that tells beef feedlot managers exactly how much fodder to put in their feed bunks.

"Quite often, feed bunks get checked once a day," Dórea says. "If there is feed left over, you know you fed too much. But if the feed bunk is empty, maybe you put out the right amount, or maybe you put out too little and the cattle are hungry."

The system uses solar-powered cameras to monitor the feed in the bunk and the behavior of the animals. The



PHOTO BY NIK HAWKINS

Animal sciences graduate student **Ligia da Cunha Moreira** analyzes samples of beef at the Meat and Muscle Biology Lab at UW–Madison. Moreira is collecting and analyzing data from four farms, a cattle auction company, and a meatpacking plant to investigate how what happens during a cow's lifetime can help predict the quality of meat and price she will provide.





researchers used thousands of images to train an algorithm to tell if a bunk is empty, full, or half full and to distinguish animals that are waiting for feed from those that have had enough.

“The strategy is, if the bunk is empty but the animals are lying down, they are not hungry, so exactly the right amount of feed was offered,” says Rosa. “If the bunk is empty but animals are standing by it, you need to put out more on the next round. The model makes this assessment not once a day but 24/7.”

The model also factors in the local weather forecast to account for impending rain, which could ruin the feed before it’s eaten, or extreme heat, which curbs the cattle’s appetite.

“It combines these pieces of information — the weather, what happened with the last round of feeding, and the behavior of the animals — and tells the farmer precisely how much feed to put out,” Rosa says.

### MILK TELLS THE DIET TALE

In addition to mining image data to help create an efficient feeding system, Dórea is digging into data from milk to help farmers identify efficient cows.

“We need animals that are efficient at converting feed into animal products,”

says Dórea. “That’s one of the keys to sustainable livestock production.”

But measuring a cow’s feed efficiency is challenging. It requires knowing both how much milk she produces and how much she eats. The milk part is easy. Her output is weighed when she’s milked. But measuring any one cow’s feed consumption — her dry matter intake, or DMI — is a problem because cows eat together from a common bunk.

“We can measure it with a few cows in a research setting using electronic gates that identify individual cows and weigh how much they eat,” Dórea says. “But that’s very expensive. On a commercial farm, it isn’t practical.”

As a workaround, researchers use models that predict a cow’s DMI based on her weight, milk production, and “days in milk” (in other words, how far along she is in her 305-day lactation). Now Dórea has developed a more accurate model by extracting data from an additional source: the cow’s milk.

Dórea is a dairy nutritionist as well as a precision agriculture specialist; he is practiced at analyzing the components of milk using a mid-infrared spectrometer, which shines infrared light on a sample of milk and measures which wavelengths are absorbed. Different

▲  
**A dairy cow eats from a feeder at Arlington Agricultural Research Station. To prevent waste, CALS researchers developed a system that uses solar-powered cameras to monitor the feed in the bunk and animal behavior.**

wavelengths are associated with specific chemical components, and Dórea suspected an additional association between wavelengths and DMI.

To test this, he ran trials using 310 cows at the UW Arlington Agricultural Research Station. He recorded how much each cow ate and how long she spent at the feeder as well as her body weight, milk yield, days in milk, and milk MIR spectra reading. He analyzed the data using an artificial neural network — a data mining tool that mimics the human brain — to identify 33 wavelengths closely associated with DMI. Adding the wavelength data to the DMI prediction model significantly improved its accuracy.

This approach is logistically feasible for a commercial farm, Dórea says. Dairy operations already get milk samples tested for protein, fat, and other components, and the same labs could also run spectra analyses. Data from those tests could be incorporated into whole-farm decision-making software

to help identify which cows are yielding a good return on investment.

"If you know that some cows eat a lot but produce less milk, you probably don't want those animals on the farm," Dórea says.

## A VIRTUAL SCALE

The idea of using computer vision to monitor dairy calves started with an effort to "weigh" fish. In 2015, graduate student **Arthur Fernandes**, new to Rosa's lab at the time, tried using computer vision to predict the size and quality of tilapia filets based on images of live fish.

"Some people from a pig breeding company heard about the project and proposed a collaborative research project to use images to predict pig body weight," Rosa recalls.

Fernandes took up the challenge as his Ph.D. project. The end result was a fully automated system that uses a 3D camera to draw what is basically a topographical map of a pig. By gauging the distance from the camera to various parts of the pig, the system calculates the pig's surface area, volume, length, width, and height at multiple points along the body. The system analyzed a lot of images and tested dozens of predictive models to come up with one that can estimate a pig's weight with remarkable accuracy.

Dórea had assisted on the pig project, and now he, Fernandes, and others are adapting the idea to calves.

"You can't weigh calves even on a weekly basis. It's stressful for the calf and very labor-intensive," he says. "But you need frequent measurements in order to track individual growth curves."

He also wants to find out where the calf is putting the

pounds on its body. "I want to know if it's getting fatter and more circular or if it's skeletal growth," Dórea says. "If you understand how the calf is growing, you could adjust the nutritional strategy, if needed."

You could also peek into her future. There's a correlation between how a calf develops and how she does as an adult cow. So Dórea plans to follow each calf through her first lactation, collecting data on her milk yield, milk composition, and reproductive success.

"The cost of replacement heifers is significant," he says. "If we can use the calf's development to predict her performance as a cow, this can help farmers do a better job of selecting the heifers to improve profitability and reproductive performance."

## EARLY WARNING SYSTEM FOR SICK CALVES

Tracking a calf's weight and shape can help predict her future, but it's not as useful for telling if she's getting sick. Illness might stem her growth, but other symptoms show up much sooner.

"Animals change behavior when they're sick," Dórea says. For example, calves that have gut ailments related to *E. coli* spend more time lying down. Calves with pneumonia take fewer steps.

"We need to be able to pick up these little differences because, by the time you see the obvious symptoms that a calf is sick, it's probably too late," Dórea says.

"When a calf is a little bit sick, it's a very tiny change that is easy to miss in a large operation. If you have 100 calves, it's hard to notice if one is acting lethargic."

But it's not so hard for a trained camera. Dórea and his colleagues are working on a computer vision system that uses both conventional and infrared cameras to monitor calves' behavior around the clock.

"We presented the computer with hundreds of images of calves standing or drinking or lying down, and the system extracted the features associated with each behavior," Dórea says.

Of course, to make this work, the computer has to know which calf it's looking at. The team is also training the system to recognize each animal's distinctive markings — the bovine version of facial recognition.

Seed funding for the calf behavior monitoring project came from a Microsoft initiative called Artificial Intelligence for Earth, which funds research that addresses global environmental challenges. The investment is recognition that this kind of technology could have a significant impact. A tool that helps keep animals healthy with fewer antibiotics is a step toward more sustainable food production.

Rosa thinks that bringing big data science and artificial intelligence to the farm will also help sustain agriculture in another way: It will attract smart, innovative young people to the business.

"These kinds of things are going to interest young people who might think,

"I don't want to work on the farm, I want to go into a technology field," he says. "But we are using these technologies on the farm — the same technologies used for things like self-driving cars and facial recognition. I think that's an important message."

**A 3D camera was used to create this representation of a calf surface, which helps predict the animal's weight.**

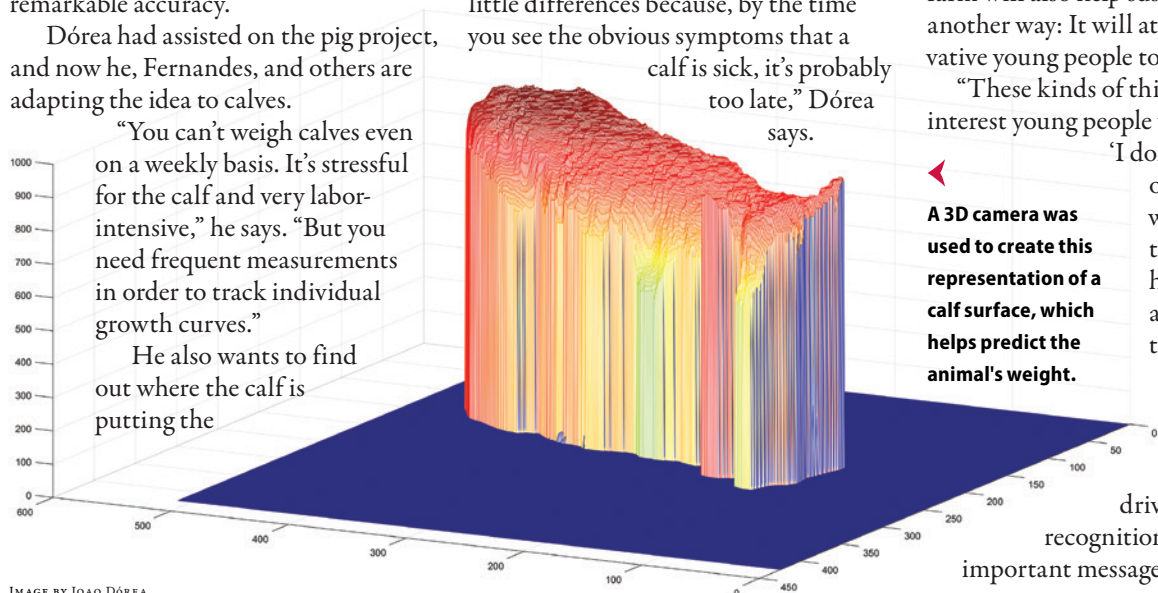


IMAGE BY JOAO DÓREA



## in the field

BY STEPHANIE HOFF BS'19

**BEN FEHR** BS'15

**Ben Fehr** works as an environmental scientist in Minneapolis for WSB, a design and consulting firm that specializes in engineering, community planning, and environmental and construction services. Fehr completes projects associated with the Minnesota Department of Transportation, the Minnesota Pollution Control Agency's Voluntary Brownfield Programs, and the Minnesota Petrofund Program, which aims to prevent groundwater pollution stemming from petroleum tank leaks. "I am primarily involved with assisting clients to redevelop Brownfield sites with petroleum impacts to soil and groundwater," says Fehr. "I enjoy assisting local communities to prevent, assess, safely clean up, and ultimately be able to reuse contaminated properties." Fehr has worked on a large variety of projects. He's traveled to Houston to assist with mold remediation efforts associated with Hurricane Harvey and has completed endangered and threatened bat surveys in Tennessee. "CALS not only provided me with the technical skills needed to succeed as an environmental consultant but also the professional and interpersonal skills necessary for delivering clear and innovative solutions to complex environmental problems," Fehr says.

**KELLEN MCSWEENEY** BS'15

"Energy efficiency was not always the field I thought I'd end up in, but it has been a fantastic area of sustainability to dive into," says **Kellen McSweeney**. She was able to see many different aspects of the environmental studies field during her time at CALS, from geology to cartography to field research. "I've been able to grab skills from specific classes to help me succeed in the work that I do," McSweeney says. "I recently had the opportunity to use skills I learned from cartography and geographic information system courses to work on a new project." She says she has always been drawn to nonprofits that work in sustainability and energy efficiency because their employees show great passion for their work. McSweeney is now a project manager at one of these nonprofits: Slipstream, a national organization that designs energy efficiency programs. She primarily works on the utility program implementation with ComEd New Construction and a new pilot program with BIT Building, which aims to bring building energy efficiency to underserved communities. "My favorite part of my work is that I have the opportunity to build relationships with all sorts of individuals in the energy efficiency industry," says McSweeney. On a typical day, she could speak with an architect, a commercial building developer, a workforce development agency, and a city planner. "I love learning about the innovations occurring all across the industry," she says.

**ALLISON STRUSS** BS'15

Growing up, **Allison Struss** showered with buckets to conserve water and picked up trash on the side of the road just for fun. Doing her part to address global warming and the human impact on the environment was important to her at an early age. She knew that simplifying sustainability was the first step in finding a solution, and that's what steered her toward Leadership in Energy and Environmental Design (LEED), a green building rating system and certification of sustainability. Struss started working on LEED projects as an intern at Madison Environmental Group during her freshman year, and she rounded out her senior year by earning her LEED Accredited Professional credential. Today, Struss continues her involvement with LEED projects as a consultant for Chicago-based tech company Goby. She works with people who run and operate commercial buildings to understand their sustainability plans — and then help make them happen. "My favorite part about my job is seeing my clients' sustainability progress year after year and helping them achieve their goals in the easiest, most cost-effective way," Struss says. She thanks an early push from CALS for her dream job. "During my freshman year, CALS required that we meet with professors to talk about our future goals and that we start looking into internships," Struss says. "Without this . . . I would not have been so motivated to start searching for opportunities immediately." After the first internship, opportunities came easier, and she started building her resume. "It just takes one experience to shape all the rest, and CALS instilled that in me from the start," Struss says.

**THE ENVIRONMENTAL SCIENCES MAJOR** at UW–Madison is a rigorous, science-based interdisciplinary major offered through both CALS and the College of Letters & Science (L&S). It promotes critical thinking and emphasizes environmental problem solving in service to society. More at [envirosoci.wisc.edu](http://envirosoci.wisc.edu).

## Alumni making a difference through ENVIRONMENTAL SCIENCES



**CAITLIN BERGSTROM BS'14**

**Caitlin Bergstrom's** time at CALS prepared her to engage with people from all fields. It's a skill that proves valuable in her role as a public affairs analyst at the American Geophysical Union, an organization that promotes earth and space science for the benefit of humanity. Her job includes engaging with Congress and the public to share the value of earth and space science. "Before I began this work, I thought you needed to have a political science degree to make a difference in policy, but I work with so many experienced scientists who want to bring their expertise to the table to help craft well-informed policy," Bergstrom says. She also advocates for federal science funding. "My undergraduate research was funded by the Department of Energy, so I was able to understand firsthand how impactful federally funded research can be," Bergstrom says. She spent two years as an entomology lab assistant studying insect-ecosystem interactions. "As a researcher, I was always looking for ways to make my science accessible outside of a lab," Bergstrom says. It was in an environmental policy course her senior year that she realized fighting for fair environmental laws and practices was a perfect blend of her skills and passions. "The interdisciplinary education I received at CALS has been invaluable," she says. "I work with geoscientists, oceanographers, and policymakers, and I always seek new ways to learn."



**KEVIN THEIMER BS'17**

**Kevin Theimer** is an assistant environmental scientist in the water and environmental sector of WSP, an engineering company in Madison that plans, designs, and manages solutions to environmental problems. He is primarily involved with environmental due diligence work; his job is to conduct environmental site assessments (ESAs). This includes researching historical use of property to see how soil or groundwater has been affected (Phase I assessments) and collecting soil and groundwater samples to test for contamination (Phase II assessments). He is also a part of a large environmental response team that deals with spills, explosions, environmental remediation, and construction projects. "My favorite is Phase I and II ESAs. I enjoy the opportunities to travel the country as well as the unpredictability that each site may bring," says Theimer, who travels about 60% of the time. For him, the world's environmental challenges became more real as he progressed in his environmental sciences coursework. "I became eager to learn more and use my analytical skills to contribute to solutions to some of these issues," Theimer says. "CALS provided me with the tools, framework, and fundamentals to be highly successful in many fields of work. I use knowledge directly obtained from CALS coursework on a regular basis, including courses that didn't seem applicable at the time." Theimer believes that surrounding himself with individuals in CALS helped him develop strong communication and collaboration skills that are highly marketable in any workplace. "I am grateful for the many opportunities and networks I obtained through CALS, as it was actually a CALS alumnus who was recruiting for my position and helped establish the connections that allowed me to start my career with WSP," he says.



**MADALYN LUPINEK BS'17**

At Cardno, a company that builds new infrastructure to improve the standard of living in communities, **Madalyn Lupinek** works on environmental solutions that preserve natural resources and promotes sustainable economic development in developing countries. Some days Lupinek is in the office corresponding with the Wisconsin Department of Natural Resources or the U.S. Army Corps of Engineers about permits; setting up ArcGIS web maps, which are interactive displays of geographic information; or looking at aerial imagery for project sites. Other days she's in the field monitoring construction sites for protected species, keeping an eye on erosion control, or helping determine the exact border of wetlands to figure out what types of permits might be needed or how much wetland disturbance might occur as a result of a project. "I really like that the work allows me to be in the office and in the field," Lupinek says. "I also like that it's fast-paced and requires me to talk to many different types of people." She found out about environmental consulting after completing an internship during her junior and senior years with the Environmental Department at American Transmission Company in Madison. "My experiences at CALS really expanded my point of view on what's out there," Lupinek says. "There are so many possibilities, and everyone's path is different in some way. There's so much to learn, and I take each day as an opportunity for learning and growth."



## Catch up with...

**Kristin Kohlmann** BS'13

Genetics and Global Health Certificate

**K**ristin Kohlmann has a passion for keeping children healthy and well-fed. And to make it happen, she found the perfect partner with Project Peanut Butter, a nonprofit that works to treat the most extreme form of malnutrition in children in Sub-Saharan Africa.

Kohlmann first connected with Project Peanut Butter in 2016 while working for Washington University as a field research coordinator in Ghana and then in Malawi. There, she saw firsthand how effective food therapy can help kids grow and stay healthy.

Project Peanut Butter uses ready-to-use therapeutic food (RUTF) — a protein-rich, peanut butter-like paste that can be employed in homes — as an affordable treatment for malnutrition. RUTF has higher success rates than traditional milk-based formulas and has been instrumental in Kohlmann's work. For her efforts, Kohlmann received a 2019 Forward Under 40 Award from the Wisconsin Alumni Association.



Kohlmann is now in Germany finishing her master's degree in international health at Heidelberg University. She is studying how the maternal diet at the time of conception can influence children's susceptibility to certain diseases in adulthood. In the future, she plans to resume her research in the field of acute malnutrition and is considering pursuing a Ph.D.

### WHAT HAVE YOU LEARNED ABOUT ADDRESSING MALNUTRITION FROM YOUR RESEARCH AND WORK?

There is a common misconception that acute malnutrition in children is caused primarily by famine or humanitarian emergencies. But actually, malnutrition is primarily a condition of poverty. Children are especially vulnerable because of a combination of social and economic factors that are exacerbated during times of acute hardship. Of the millions of children who have severe malnutrition, only 20–25% of them are able to access treatment. One of the ways to make treatment more accessible and affordable is through local RUTF production.

Our project in Ghana was to evaluate locally produced alternative RUTF in a clinical equivalency trial. My work has taught me the importance of cooperation in approaching these immense global health challenges. Our project would not have been possible without our collaborators at the University of Ghana and Ghana Health Service. Future projects and programs need to leverage these kinds of partnerships and to be designed with complex societal and economic situations in mind.

### WHAT ARE SOME OTHER STEPS THAT NEED TO BE TAKEN TO SOLVE GLOBAL HEALTH ISSUES?

Children today are more likely to live through infancy, to survive past the age of five, and to be given the opportunity to lead healthy lives than ever before. However, this progress has been uneven, and large inequalities between and within countries still exist. I think that we are finally acknowledging the complexities of addressing global public health problems. We're recognizing that the health impacts of climate change, discrimination, and extremism are relevant to people from across the globe but have the greatest effect on the most impoverished and marginalized people, whether they live in Chicago or rural Malawi. And these types of huge challenges require a global response that focuses on reaching the most vulnerable people regardless of where they live.

### WHAT MOTIVATES YOU TO HELP CHILDREN IN NEED?

It's easy to stay motivated when you've seen how acutely malnourished children change as they recover. When a child begins to recover, a light comes back into her eyes. With every visit, she has more energy to smile, to laugh, and to cry. The people on the front lines of fighting against malnutrition also motivate me, especially clinic nurses who work hard in demanding conditions to give children the best possible futures. The sacrifices mothers make for their children also resonate with me and inspire me to use my talents to help children have healthy futures.

—ANDREW PEARCE

## 'I Wonder What I Can Do?'

From the Dairy Cattle Center to the Multicultural Student Center, from DNA to proteins to flavor perception. These were among the wide-ranging locales and topics offered to more than 30 Chicago and Milwaukee-area high school students who participated in the inaugural 2019 CALS Agricultural Experience, an immersive visit to the college and greater UW–Madison campus. The program, held April 11-13, was made possible in large part by a generous donation from Chicago real estate developer **Elzie Higginbottom** BS'65.

Higginbottom, an NCAA all-American track and field athlete, earned his degree in agricultural and applied economics and took his business acumen to the Windy City, first at the firm of Baird & Warner before starting his own — East Lake Management & Development Co. — in 1975.

"Having worked with groups like After School Matters in Chicago, I believe that exposure to the extraordinary opportunities available in programs like CALS will motivate high school freshmen and sophomores to work hard and achieve," he says.

**Kalyanna Williams** MS'17, a dairy science faculty associate who helped coordinate the program, knows just how quickly a student can be captivated by something new. During an internship at Iowa State University, Williams was temporarily assigned to a dairy project. It was her first experience with dairy animals, but it inspired her to go to graduate school and ultimately teach in the field.

"When I think about that, I think about these students," she says. "It just takes that one opportunity, that one exposure for these students to say, 'I wonder what I can do?'"



PHOTO BY MICHAEL P. KING

The students — hailing from Chicago High School for Agricultural Sciences, Milwaukee Vincent High School, and the After School Matters and Chicago Scholars after-school programs — participated in a variety of hands-on workshops. They explored the rumen of a cannulated dairy cow at the Dairy Cattle Center, tested zucchini plants for an aphid-borne virus at D.C. Smith Greenhouse, learned about flavor perception at Babcock Hall (and got an obligatory taste of ice cream), and viewed three-dimensional models of proteins at the Microbial Sciences Building.

To Higginbottom, inclusion for students of color is a critical component of college success. "As a minority student, that's one of the things that you're concerned about," he says. "We overcome the economic considerations. We overcome the academic considerations. But the consideration of feeling included is very important."

**Thomas Browne**, CALS senior assistant dean for academic affairs, agrees. He notes that the program's unstructured time at the Multicultural Student Center, Black Cultural Center, and The Sett at Union South is valuable and necessary.

"We really wanted participants to have interactions with our current students that they could relate to here, so they could see people from similar

**Chicago high school student Paige Smylie reaches into the rumen of a cannulated dairy cow at the Dairy Cattle Center during the CALS Agricultural Experience weekend.**

backgrounds actually doing what we hope that they would do, and show them it's not impossible," he says. "A lot of us have the privilege to do college visits before we apply — a lot of these students don't. It makes it real. The possibility of it. Anyone who gets to step on this campus, or any other campus, is getting a leg up on most of the people that they grew up with."

The 2019 CALS Agricultural Experience was also made possible with funding from the Morgridge Center for Public Service's Wisconsin Idea Fellowship program and the Wisconsin Agricultural and Life Sciences Alumni Association, as well as assistance from **Abigail Catania** BS'19 through the UW–Madison chapter of Minorities in Agriculture, Natural Resources and Related Sciences. And thanks to Higginbottom's gift, the program will continue in the 2019–20 school year, giving dozens more students "a leg up" on success.

—MICHAEL P. KING

To donate to the CALS Agricultural Experience, contact Brooke Mulvaney at [brooke.mulvaney@supportuw.org](mailto:brooke.mulvaney@supportuw.org) or 608-308-5330.





Continue to be part of the story.  
Join fellow Badgers in keeping the  
UW headed in a positive direction  
through the most ambitious fundraising  
campaign in the university's 170-year history.

[AllWaysForward.org](http://AllWaysForward.org)

# FORWARD



STUDENT SUPPORT | FACULTY EXCELLENCE | WISCONSIN EXPERIENCE | EUREKA MOMENTS

## Take the Final Exam

FALL 2019

Fill out your answers online. Ace our quiz and we'll enter you in a drawing for a gift box of Babcock Hall cheese. To participate, go to [grow.cals.wisc.edu](http://grow.cals.wisc.edu) and look for the Final Exam.

## NUTRITIONAL SCIENCES

1. Which of the following symptoms of dehydration is the first to occur?

- a) increased pulse rate
- b) difficulty concentrating
- c) thirst
- d) decreased blood volume
- e) failing kidney function

## PLANT PATHOLOGY

2. Natural selection can keep most traits in a population or species quite stable and similar over thousands or even millions of years. The type of natural selection that promotes this scenario is called

- a) directional selection.
- b) divergent selection.
- c) stabilizing selection.
- d) solidifying selection.

## SOIL SCIENCE

3. If leaves on corn plants develop a reddish or purple color early in the growing season, the corn is probably deficient in

- a) phosphorous.
- b) potassium.
- c) zinc.
- d) boron.

## FOREST AND WILDLIFE ECOLOGY

4. The pathogen that causes Lyme disease is a

- a) tick.
- b) bacterium.
- c) protozoan.
- d) virus.

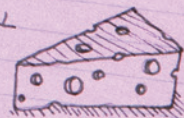
## ANIMAL SCIENCE

5. *Tapetum lucidum* is responsible for improved

- a) hearing.
- b) sense of smell.
- c) night vision.
- d) sense of taste.
- e) tactile sense.

LAST ISSUE'S  
ANSWERS WERE | 1:A • 2:D • 3:B • 4:B • 5:C

CONGRATULATIONS TO MADELYN FALK BSx'21,  
WHO WAS RANDOMLY SELECTED FROM AMONG  
31 PEOPLE WHO CORRECTLY ANSWERED ALL FIVE  
QUESTIONS. SHE WINS A GIFT BOX OF  
CHEESE FROM THE BABCOCK HALL  
DAIRY STORE!



## EXAMPLE

WRONG

1 A B C D E

WRONG

2 A B C D E

WRONG

3 A B C D E

RIGHT

4 A B C D E

121 A B C D E

T F

122 A B C D E

T F

123 A B C D E

T F

124 A B C D E

T F

125 A B C D E

T F

126 A B C D E

T F

127 A B C D E

T F

128 A B C D E

T F

129 A B C D E

T F

130 A B C D E

T F

131 A B C D E

T F

132 A B C D E

T F

133 A B C D E

T F

134 A B C D E

T F

135 A B C D E

T F

136 A B C D E

T F

137 A B C D E

T F

138 A B C D E

T F

139 A B C D E

T F

140 A B C D E

T F



College of Agricultural and Life Sciences  
University of Wisconsin–Madison  
136 Agricultural Hall, 1450 Linden Drive  
Madison, WI 53706

Nonprofit Org.  
U.S. Postage  
PAID  
Madison, WI  
Permit No. 658

## SPUD BUG

A Colorado potato beetle makes a meal of a potato plant leaf in a test plot at Hancock Agricultural Research Station in Hancock, Wis. Scientists at the station test potato varieties for adaptability to Wisconsin's soil and climate.

PHOTO BY MICHAEL P. KING

