Northern Great Plains Research Laboratory

NORTHERN GREAT PLAINS
INTEGRATOR
For environmentally and economically sound agro ecosystems for the northern Great Plains.

July 2012

A century of research

There's a patch of prairie pasture south of Mandan, N.D., on which the native grasses have been undisturbed, except by grazing cattle, since 1916.

For 96 years - through a gauntlet of extreme weather conditions - federal researchers have studied the pasture to see how many cattle it can accommodate without overgrazing.

John Hendrickson, a rangeland scientist, is one of the pasture's current stewards. On a warm, windy day in late June, he looks over the pasture's ankle-high grass and says, "We want a range and forage system that makes economic sense for producers and that also provides agricultural stability."

That approach is the hallmark of the Northern Great Plains Research Laboratory, which is celebrating its 100th anniversary this summer.

The lab, part of the U.S. Department of Agriculture's Agricultural Research Service, continues to search for ways to enhance and sustain agriculture in the Upper Midwest.

"We've always been about soils, sustainability and the survivability of family farms," says Cal Thorson, the lab's technical information specialist.

Today, the lab works on everything from crop diversity and cover crop practices to biofuels and the benefits of feeding flaxseed to beef cattle.

Most of the lab's work involves the Upper Great Plains, primarily North Dakota, South Dakota, Minnesota and eastern Montana.

The Agricultural Research Service, USDA's main in-house research arm, has more than 100 locations across the country.

Employees, perceptions

The Mandan lab has 33 year-round employees, including eight scientists, and about a dozen seasonal employees.

The lab's base funding comes from USDA, and the lab's scientists also compete with scientists elsewhere for USDA grants.

Matt Sanderson, a native of Willow City, N.D., has led the Mandan lab since 2010. He has a doctorate in crop production and physiology from Iowa State University. Before coming to Mandan, he conducted research at Texas A&M University and for the Agricultural Research Service in University Park, Pennsylvania.

Sanderson also works as a full-time scientist. His background is in forage grassland management, and he's collaborating with several scientists at the Mandan lab on research into rangeland management and forage management.

Many people in the Bismarck-Mandan area (Bismarck, N.D.'s capital, is separated from Mandan by the Missouri River) have little, if any, understanding of what the Mandan lab does, Sanderson and others at the lab say.

"But we want to be good neighbors. Visitors are always welcome," Sanderson says.

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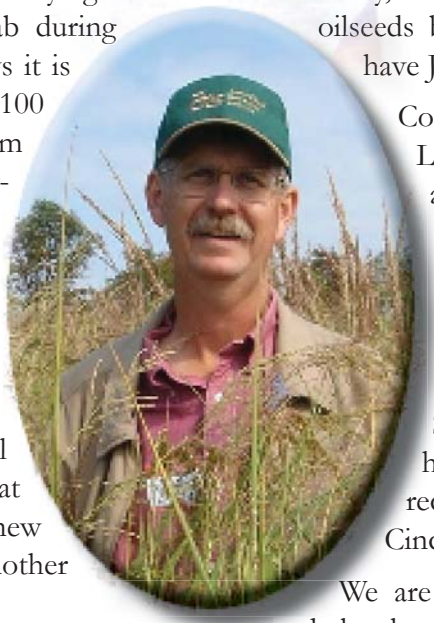
Inside:

Message from Matt



Welcome to a new century of research at the Northern Great Plains Research Laboratory. It is satisfying to look back at the accomplishments of the lab during the last 100 years; however, in many ways it is more exciting to look ahead to the next 100 years. Part of this excitement comes from our recent selection as one of 10 Long-Term Agroecosystem Research (LTAR) network sites within the USDA-ARS. One of the goals of this research network is to address the sustainability of agricultural systems for the next century. The 10 sites were chosen through a competitive process by a non-ARS scientific panel based on the quality of science. We at NGPRL are excited to be a part of this new network and look forward to delivering another century of excellent research.

As our new century of research begins, we welcome two new scientists to Mandan. Dr. Jonathan (Jay) Halvorson joined our scientific staff in June. Jay comes to us from the former USDA-ARS lab in Beaver, WV. Jay fills the position left vacant by the retirement of Don Tanaka. Dr. Joon Hee Lee is a new post-doctoral researcher working with David Archer. Joon comes to us from the ARS lab in Kimberly, ID and will spend the next two years on the oilseeds biofuels project. We are very pleased to have Jay and Joon on board.

Congratulations to Kris Nichols and Mark Liebig for recently receiving two prestigious awards. Kris Nichols will receive the Conservation Research Award from the International Society of Soil and Water Conservation at their annual meetings in Ft. Worth, TX this July. Mark Liebig has been selected as a Fellow of the Soil Science Society of America (one of the highest honors in the society) and will receive his award at their annual meetings in Cincinnati in October.

We are very grateful to the farmers, ranchers, and local communities for their support of the NGPRL during the last 100 years. With their support, the Northern Great Plains Research Laboratory has become an internationally recognized research location. We look forward to working with and serving our customers and stakeholders for the next century.

Research team uses new technology to help farmers

A scientific research team is using new technology to collect data which, in the long run, will help farmers.

Rebecca Phillips, a research plant physiologist at the Northern Great Plains Research Laboratory in Mandan, is using new scientific instruments to learn how a variety of factors, such as temperature, moisture and the time of day, affect the rate at which gases enter and leave the soil. The study is taking place in a 50-acre alfalfa field south of Mandan.

"What we're trying to do is model how emissions are affected by these different factors," she said.

Phillips said the study will run all year, possibly into 2013. She will analyze the study's findings and write recommendations, which will be available to the public. Farmers will be interested in the findings, she said, as they will be able to learn what conditions are most important to keeping carbon and nitrogen in the soil. The two elements lead to higher soil quality, more nutrients for plants and all around better growing conditions, she explained.

"Carbon and nitrogen are good stuff for your ground and you want to keep it in the ground if you can," she said.

Phillips has been researching greenhouse gases since the 1990s. The new technology allows her studies to be more specific than ever before. Previously, samples had to be taken manually once a day. Now, with a new laser funded by a NASA research grant, she is able to collect data continuously, 24 hours a day.

"I was always limited by technology ... we just didn't have the instruments. Now for the first time, I can see the things we always needed to see," she said.

Phillips and her research team will continue to take samples of the air and soil manually once a day in order to cross reference their data.

"We've been doing the manual stuff for so long ... that's our base," said Justin Feld, a biological technician with the Northern Great Plains Research Laboratory and a member of the research team. "We're taking what was standard and creating a new standard."

The laser is one of few of its kind in the country, Philips

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North Dakota vegetable research
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3 PM Research Tours
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Dow AgroSciences

A century of research *continued from page 1*

Past achievements

The lab, in its early days, focused on research to help homesteaders: raising vegetables for human consumption and planting trees to protect homesteads and livestock were two important areas of research.

By the early 1960s, the lab had introduced many new apple, apricot, plum, crabapple, tomato and sweet corn cultivars to the public.

The lab's research has shifted to meet the evolving needs of area agriculture.

A few examples: irrigation research began in the 1950s; research into reclaiming open-pit mined lands for crop production began in the 1970s; conservation tillage research was a priority in the 1980s.

In 1984, the lab launched the 400-acre Cooperative Research Farm in conjunction with the Area IV Soil Conservation District, which consists of the soil conservation districts in 11 North Dakota counties.

Matt Sanderson is laboratory director and research leader at the U.S. Department of Agriculture's Northern Great Plains Research Laboratory in Mandan, N.D.

The Cooperative Research Farm, about three miles from the Mandan lab, continues to operate. It conducts research into conservation tillage and cropping systems on farmer-sized fields rather than small test plots.

The Mandan lab controls about 2,400 acres, land that it either owns or rents.

Present priorities

Today, the lab is involved in a wide range of research. Here's a sampling of what's going on:

Kristine Nichols, a research soil microbiologist, is engaged in research on glomalin, fungi that help plants acquire nutrients.

Her work has found, among other things, that farmers can increase glomalin by planting cover crops to maintain living roots.

Hendrickson is involved in a five-year project to control Kentucky bluegrass, which is increasingly common in pastures across the region.

While cattle eat Kentucky bluegrass, the plant limits growth of native grasses. That can reduce forage production in mid- and late summer.

Rebecca Phillips, a plant physiologist, is working on remote agricultural sensing. The research can help ranchers determine how many cattle can graze a pasture given changing weather conditions.

Scott Kronberg, a research animal scientist, is working to improve the nutritional quality of red meat.

Dave Archer, agricultural research scientist, has looked at the use of oilseed crops for "green" jet fuels in the military.

A key focus is on what's known as "dynamic cropping systems," Sanderson says.

With the help of the lab's research, "Farmers are able to adjust their cropping systems, their crop rotation choices, not necessarily at the last minute, but to give themselves much more flexibility," he says.

Farmers already use their experience to make such choices, but dynamic cropping systems will make the process more scientific, Sanderson says.

Dynamic cropping systems also include cover crops and putting animals on the land.

"It seems to be a pretty good thing for a lot of producers around here. There's a lot of interest in it," Sanderson says.

On the road ahead

Biofuels, sustainability and so-called "integrated agriculture' - which combines crop and livestock production - likely will remain cornerstones of the Mandan lab's research in coming years, he says.

Earlier this year, the lab was named one of 10 ARS long-term Agro-Ecosystem Research sites nationwide.

The 10 sites are focused on looking at "agriculture at a much larger scale," Sanderson says.

The idea is designing research for 50 to 100 years that involve large areas such as watersheds, he says.

"What we're focusing on is, what are the things we need to measure now that still will be relevant 50 to 100 years down the road? Things such as productivity, soil baseline measurements," he says.

The lab's budget was cut by roughly $500,000 last year. As a result, two vacant scientist positions and two vacant technical positions were eliminated.

Sanderson is optimistic that the lab's current annual budget of $3.4 million won't be cut.

Focus on the 'customer'

The Mandan lab's research is intended to fit the evolving needs of area agriculture, Sanderson says.

A customer focus group of about 60 members helps the Mandan lab determine what direction its research should take.

"We get that group together twice a year and we talk to them about our research and research results. We get feedback from them on our research. Sometimes they say, 'That's great stuff.' Sometimes they say, 'Why on Earth are you working on that?'" Sanderson says.

John Hendrickson stands in prairie pasture south of Mandan, N.D., on which the native grasses have been undisturbed, except by grazing cattle, since 1916.

"And we ask them, 'What are your needs? What type of research would benefit you?' And they give us a lot of input. Some things we can do, some things we can't," he says.

LeAnn Harner, director of the Area IV Soil Conservation District, is a member of the Mandan lab's customer focus group.

She says the lab listens carefully to the focus group and takes its input seriously.

Sirens, humor and tragedy

Albert Frank, a retired plant physiologist at the Mandan lab, wrote "The Taming of the Prairie: A Century of Agricultural Research at Northern Great Plains Research Laboratory."

Among the information he uncovered:

For many years at the lab, sirens rang four times daily: at 8 a.m. to start the work day, at noon to signal lunchtime, at 1 p.m. to call staffers back to work and at 5 p.m. to end the work day.

In the lab's early years, scientists in Mandan became suspicious that USDA officials in faraway Washington, D.C., weren't reviewing the North Dakota research before publishing it in USDA bulletins. So one Mandan scientist prepared a preliminary bulletin stating that jackrabbit damage to fruit trees could be controlled by flying kites over orchards at night. The claim was nonsense, but the USDA officials in Washington published the bulletin anyway. The Mandan scientist, having proved his point, destroyed the faulty bulletins.

Tragedy has struck the lab four times through the years. In 1915, a seasonal worker was killed while pulling trees to clear land. In the mid-1930s, a worker was killed when he was hit in the head by an engine crank. In 1952, two people drowned in the rain-swelled Heart River. In 1991, a seasonal worker was killed in a tractor rollover.

Frank, who lives in Bismarck, tells Agweek that he volunteered to write the history.

He worked at the Mandan lab from 1969 to 2004. When he started, he worked with, and learned from, some outstanding scientists who had been at the facility for many years, he says.

In 1996, there were plans to close the Mandan lab because of funding problems. Frank thought he would be transferred to Fargo, N.D., and even looked for housing there.

"That was a tough time on everybody," he says.

Ultimately, pressure from farmers and others led Congress to provide enough funding for the Mandan lab to remain open.

'100 lifetimes' of work

Mark Liebig, a soil scientist at the Mandan lab, likes to tell people that's he's "working on national security."

He smiles and says, "If you tell them that you work with soils, you can see them go to sleep. But you get their attention when you say 'national security.' And, really, when you think about it, healthy soils are part of our national security."

He and other scientists build on what previous generations of scientists have learned. Likewise, scientists of the future will build on what Liebig and other scientists are learning today, he says.

"You figure out one piece of the puzzle and then the attention shifts to another piece," he says.

A century of research at the Mandan lab has just scratched the surface, he says.

"There's still enough work here for 100 lifetimes," he says.

By: Jonathan Knutson, Agweek; Photos by John Brose

Research team uses new technology to help farmers *continued from page 2*

Adam Tollefsrud, a student at Bismarck State University, collects a sample of air surrounding an alfalfa plant

said. Researchers from the Woods Hole Research Center located in Massachusetts tested the laser in a natural forest in Maine. The laser was then deployed to North Dakota for a full-fledged study.

"It's pretty darn new in this level of accuracy and precision," Phillips said. "It's going to open up our understanding, I think, a great deal."

Students expand their knowledge

Adam Tollefsrud, a Bismarck State College student studying geographic information systems, and James Norton, a spring 2012 graduate of the same program, are interning with Phillips this summer.

In the geographic information systems program, the two men learned to use software to organize information in a visual way, such as creating maps or charts.

Angie Milakovic, assistant professor of geographic information systems at BSC, said the internship is a great opportunity for her students. Many of the students participate in some kind of internship, she said, but the hands on opportunity to learn about science is unique.

"North Dakota is such an agriculturally-based state that having the opportunity to be able to work with a project like this is such good experience," she said.

Norton said he has no background in biology or chemistry.

"It's new for me and it's a great learning opportunity," he said.

Rebecca Phillips, a research plant physiologist at the Northern Great Plains Research Laboratory near Mandan, is using new technology to learn how factors such as temperature, moisture and time of day affect the rate that gases enter and leave the soil.

Tollefsrud and Norton's duties include collecting air, soil and plant samples manually, mapping out areas similar to the alfalfa field and learning to maintain and run the instruments, Phillips said.

Tollefsrud is looking forward to creating a database out of the information he will help to collect.

"GSI is all about spatial analysis ... it's taking information and putting it on a map," he said. "The experience of turning that data into something that can be used ... is something that I can take with me."

Tollefsrud is excited to intern with the team full time this summer.

"I haven't been there long, but the work Phillips is doing is so cutting edge and worthwhile," he said.

By Mara Van Ells, Bismarck Tribune

NGPRL news

Dr. Kris Nichols has been seleted to receive the Conservation Research Award from the International Soil and Water Conservation Society. The Conservation Research Award is conferred on SWCS society members or teams of members whose research has led to exceptional improvements in soil conservation, water conservation, and/or related natural resources research. This award is given for research excellence first and foremost. The award may be given for research excellence or results of the research that have led to significant conservation improvements. Nichols will receive the award at the annual meeting of the SWCS in Ft. Worth, Texas later in July.

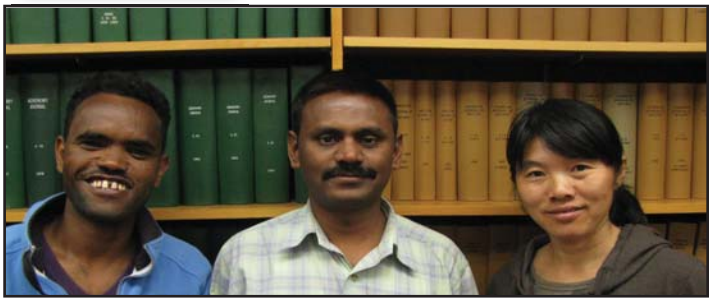
Dr. Mark Liebig has been selected to receive the award of Fellow of the Soil Science Society of America. This is one of the highest awards in the SSSA. Liebig will receive the award at the annual meetings in Cincinnati this October.

Dr. Donald Tanaka, former NGPRL Research Soil Scientist, was presented with the Northern Pulse Growers Researcher Excellence Award. The Northern Pulse Grower's Association Researcher Excellence Award is given to a researcher who has spent a tremendous amount of time and effort promoting and supporting the pulse industry. Tanaka retired from his 31-year career at year end 2011.

Dr. Jonathan Halvorson, Research Soil Scientist, has joined the staff of the Northern Great Plains Research Laboratory. Jay has been with the Appalachian Farming Systems Research Center in Beaver, West Virginia for the past 12 years. His research has centered on the impact of plant-derived chemicals on soil function, especially the use of tannins and other plant phenolic compounds to manage soil organic matter and nutrient cycling. He is a recognized authority on spatial statistics and legume effects on soil organic matter accumulation in highly disturbed early successional sites. He recently participated in studies of temperate bamboo for forage and biofuel. Halverson has bachelor's degrees in Soil & Water Science and Horticulture from the University of Arizona, a masters in Environmental Science and Ph.D. in Botany, both from Washington State University.

Dr. Jonathan Aguilar, NGPRL PostDoc Agricultural Scientist gets the photo credit for the March 2012 cover of Agronomy Journal. The experimental plots (Cook Agronomy Farm, Washington State University) in Pullman, WA, after the harvest season of 2010 depicts the complexity of remotely assessing the landscape in terms of crop residues. Note the different light effects due to cloud shadow; different crops, and the different positions of the stubble.

Dr. Joon Hee Lee joined the staff of the Northern Great Plains Research Laboratory in July. Dr. Lee is a headquarters-funded postdoc working on the oilseed to jet fuel project (see page 8). He previously worked on the Upper Snake River CEAP focusing on erosion simulation within irrigated crop areas with the USDA-ARS in Kimberly, Idaho.



Haregot Haile Zerom, Dr. Igathi Cannayan, and Manlu Yu of NDSU

Haregot Haile Zerom, an Eritrean international master student of Agricultural and Bioresource Engineering in The Netherlands Wageningen University, has been a "Visiting Scholar" under the direction of NDSU Assistant Professor Dr. Igathinathane Cannayen at the Northern Great Plains Research Laboratory.

He has been working on his thesis entitled "Estimation of mesh size and starch content of potatoes by machine vision." While searching for a potential opportunity in the machine vision applications, he investigated the research of Dr. Cannayen in biomass preprocessing and came to North Dakota to learn from him. Completing his four-month internship, Heregot will return to the Netherlands in August.

Oilseeds to jet fuel

Both commercial and military aviation have expressed interest in using renewable jet fuels as a part of their overall fuel supply. There are multiple reasons for this interest including national security, fuel cost, and the environment. By diversifying sources of jet fuel, the aviation industry hopes to reduce the potential for fuel disruptions, buffer against price shocks, and reduce their carbon footprint. These fuels are designed to be nearly identical to traditional jet fuel, allowing them to be used as drop-in fuels without need for engine modifications or major changes in storage and distribution infrastructure. There are many potential sources for renewable jet fuels, one of which is oil from oilseed crops like sunflower, soybean, or canola. A key consideration is that these fuels be cost competitive with conventional jet fuel so that they are economically viable for the aviation industry and are a fiscally responsible fuel source for the military.

Scientists at the Northern Great Plains Research Laboratory are participating in a joint USDA-ARS and Department of Navy-Office of Naval Research project evaluating the production potential of oilseeds, farmer profitability for growing these crops, and identifying areas where oilseeds are most likely to serve as economically viable sources of feedstocks for the jet fuel industry. This project is looking at the primary wheat producing areas of the U.S. (Figure 1) as locations where oilseeds are most likely to fit into crop rotations and be profitable for producers to grow. These regions include the Inland Pacific Northwest, the Central Great Plains, and the Northern Great Plains. The project is focusing primarily on Brassicas like canola, industrial rapeseed, and mustards, but also will look at camelina (Figure 2), safflower, and sunflower. The project will include effects of transportation costs, value of co-products (for example the value of the oilseed meal left after oil extraction for livestock production), and factors affecting the willingness of producers to grow these crops including contracting terms and market influences.

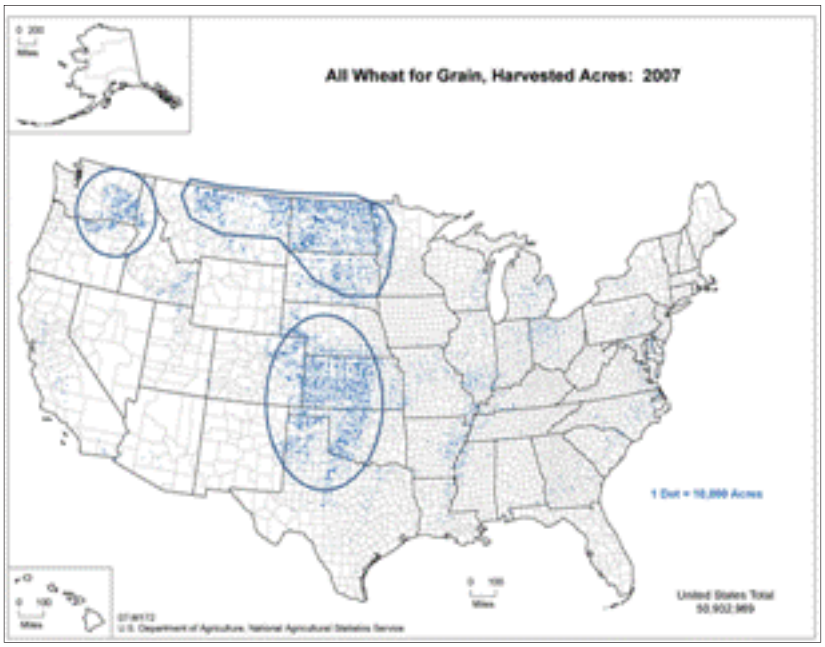


Figure 1. Primary wheat producing areas of the U.S.

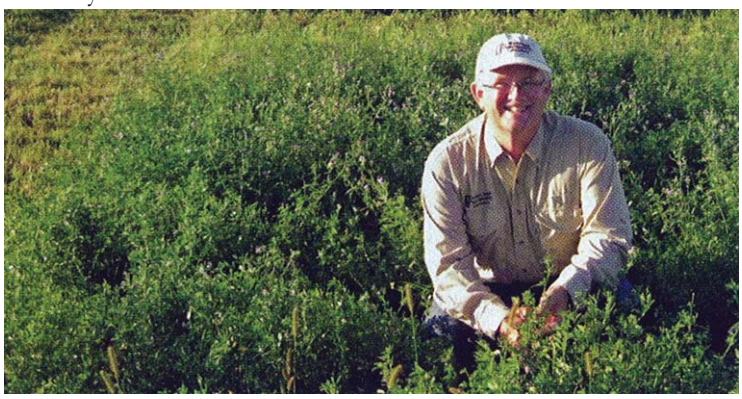
Figure 2. Winter camelina field plots at the Area IV SCD Cooperative Research Farm.

Dr. David Archer - david.archer@ars.usda.gov - 701 667- 3048

Feel free to pass on this issue of Northern Great Plains Integrator to others interested in agricultural research in the northern Great Plains. Northern Great Plains Integrator is published and distributed by the USDA-ARS, Northern Great Plains Research Laboratory, PO Box 459, 1701 10th Avenue S.W., Mandan, ND 58554. Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at 202-720-2600 (voice and TDD). The United States Department of Agriculture prohibits discrimination in all its programs and activities on the basis of race, color, national origin, gender, religion, age, disability, political beliefs, sexual orientation, and marital and family status. To file a complaint of discrimination, write USDA, Director, Office of Civil Rights, Room 326-W, Whitten Building, 14th and Independence, SW, Washington, DC 20250-9410 or call 202-720-5964 (voice or TDD). USDA is an equal opportunity provider and employer. Mention of trade or manufacturer names is provided for information only and does not constitute endorsement by USDA-ARS. To be added to our mailing list, request a copy through our website or contact editor: Cal Thorson, Technical Information Specialist, USDA-ARS Northern Great Plains Research Laboratory, 1701 10th Ave., S.W., Mandan, ND 58554. Office:701 667-3018 FAX:701 667-3077 Email: cal.thorson@ars.usda.gov

Rotating perennials with wheat

Preliminaly results of an ongoing study suggest that a mix of switchgrass-alfalfa planted as a previous crop produces competitive wheat yields as well as good hay yields. Researchers at the USDA Agricultural Research Service Northern Great Plains Research Laboratory in Mandan, North Dakota, are examining the effects of five perennial treatments on subsequent spring wheat performance. They include intermediate wheatgrass, switchgrass, alfalfa, intermediate wheatgrass-alfalfa, and switchgrass-alfalfa.



John Hendrickson says an intermediate wheatgrass-alfalfa mixture can spark both competitive wheat and hay yields.

The straight alfalfa and switchgrass-alfalfa mix benefitted spring wheat yields the most. After three years of alfalfa, a field strip of unfertilized spring wheat yielded 37 bushels per acre. Unfertilized spring wheat following a three-year strip of a switchgrass and alfalfa mix yielded 35 bushels per acre. By contrast, fertilized continuous spring wheat yielded 28 bushels per acre.

The intermediate wheatgrass-alfalfa moderately boosted spring wheat yields. After three years of the grass-legume, a field plot of unfertilized spring wheat yielded 25 bushels per acre, slightly less than fertilized wheat.

Still, yields exceeded the 23-bushel-per-acre yield of the continuously cropped unfertilized spring wheat.

Along with annually producing a crop of harvested forage, the alfalfa and grass-alfalfa mixes effectively replaced 60 pounds per acre of purchased nitrogen applied to fertilized spring wheat. Over three years, purchased nitrogen costs averaged about $30 per acre. Subsequent wheat yields will show the carryover effect of the soil fertility left by the legume. Perennials also help to reduce weed pressure. "Perennials can shift weed populations," says John Hendrickson, rangeland scientist at the Northern Great Plains Research Laboratory. "Having a fast-growing perennial such as intermediate wheatgrass in a field for two or three years will help control weeds."

Soil improvement is yet another benefit. "Legumes, of course, add nitrogen. And some studies show that switchgrass, for instance, puts carbon into the lower soil zone," says Hendrickson.

Including perennials in rotations also offers opportunities to integrate livestock with crop production by providing options for both grazing and haying.

While intermediate wheatgrass-alfalfa mix makes particularly good-quality hay, forage harvested from the straight switchgrass stand yielded the most. In the study's third year, the straight switchgrass plot outyielded the straight alfalfa by 4,000 pounds per acre.

"But both grasses need time to get established," says Hendrickson. In the trial's second year, for instance, alfalfa yielded the most, producing 6,200 pounds per acre. Straight switchgrass yielded 4,500 pounds per acre, while switchgrass alfalfa produced 2,100 pounds per acre.

Researchers used a staged process of establishing grass-alfalfa mixes. Planning to grow the alfalfa and grass in alternate rows, they began establishing the forage by first planting grass along with field peas in alternate rows. This system let them offset initial seed costs by harvesting the peas as an annual cash crop.

"The next year, we seeded alfalfa into the rows where the peas had been, and we got good establishment of the alfalfa," says Hendrickson.

Adding grass or alfalfa to a rotation offers flexibility and risk management. Perennial systems are better able to withstand drought and erosion from wind and water. "The cost-savings from the nitrogen provided by alfalfa could be increasingly significant, too, depending on future prices of nitrogen," he says.

By Raylene Nichel, Successful Farmer, Photo by Andrea Fischer

Long-Term Agroecosystem Research network

The USDA Agricultural Research Service (ARS) is coordinating 10 of its well-established research watersheds and rangelands as a Long-Term Agro-ecosystem Research Network. These locations will engage in synergistic, network-wide research to address questions related to the condition, trends, and sustainability of agricultural systems and resources on large scales of space and time. Sustainable agricultural systems that provide a safe, nutritious, ample, and reliable food supply; produce bio-energy; provide essential ecosystem services; and mitigate climate change are needed for the well-being and welfare of future generations.

One of the sites in the Long-Term Agro-ecosystem Research Network is coordinated by the Northern Great Plains Research Laboratory at Mandan, ND. Strategically located in the center of the northern Great Plains, the NGPRL has a 100-year legacy of research for the unique environment of the cold, semiarid northern Great Plains. The Northern Great Plains Research Laboratory is one of the few ARS laboratories with crop, soils, rangeland, and livestock research capacity at the field and herd scale which is complemented by agricultural economics research expertise.

Estimating the volume of fruits and vegetables by machine vision

Automated and accurate determination of volume would aid grading, packaging, and other post harvest processes. Automated measurements reduce mechanical handling injury to the materials handled as well as the time involved, if measured manually. Volume of fruits and vegetables is an essential attribute that is reflective of their quality. The noncontact method employed in this research is a cost-effective machine vision method. In this method, a digital scanner captured the input image and a developed image-processing program (ImageJ plugin) evaluated the volume using the mathematical principle of "solids of revolution" from the projected images. Five agricultural produce, namely, lemon, pear, orange, cucumber and potato were tested (Fig. 1).

Fig. 1. Fruits and vegetatbles (lemon, pear, orange, cucumber, and potato) samples used in volume measurement

Color images of the samples were obtained using a digital document scanner. Three resolutions 127, 254, and 508 dots per inch (DPI) were used in imaging to study their effect. Color images were converted into binary (black and white) images by appropriate thresholds using the Fiji standard commands. Binary images serve as the basic input on which the plugin operates and determines the volume from the two-dimensional images. Various steps involved in the algorithm used in the plugin for volume determination are: i) obtaining the coordinates of the profile of the object, ii) establishing the major-axis as the axis of revolution, iii) rotating the profile so that the axis of revolution becomes horizontal, iv) interpolation and data smoothing so that data were generated at every pixel on the profile along the horizontal direction, while avoiding multiple pixels along the vertical direction, v) determining the profile points (discs) vertical distance orthogonal to axis of revolution along every pixel on the axis, vi) revolving such discs and determining their volume using the diameter (vertical distance) and the thickness (1 pixel), and vii) assembling of individual discs and determining the object volume by adding all the individual discs volume. This plugin algorithm was implemented using the Fiji (ImageJ), an open source, free image processing software (Fig. 2). Pixel units were suitably converted to physical units using the DPI information of the image from the user inputs.

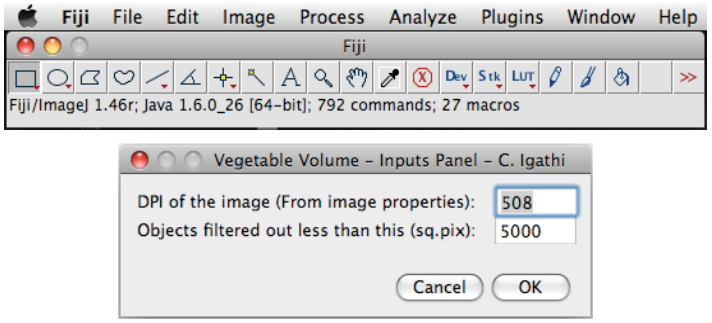


Fig. 2. Fiji/ImageJ image processing software and front panel of the developed volume estimation plugin program

Binary images of object represented in two-dimensional projected area were revolved along the length axis to obtain the volume mathematically using the plugin (Fig. 3). Rotation of the profile and data smoothing makes it easy for calculations as all measurements (discs) were only in the vertical direction.

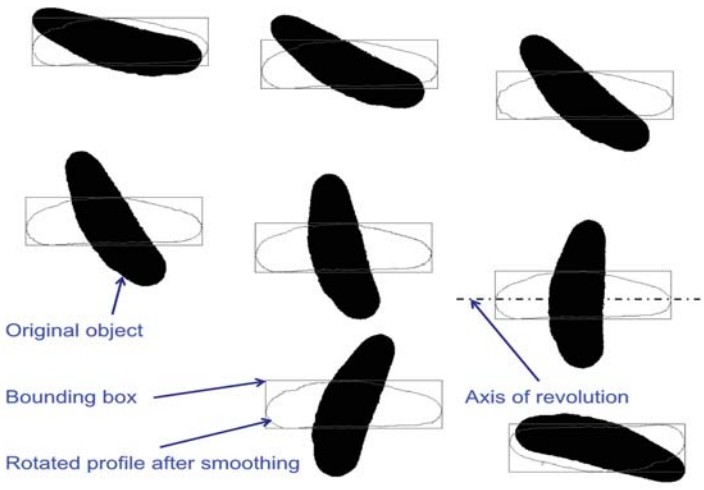


Fig. 3. Volume estimation of cucumber sample at several orientaion showing original cucumber binary image, smoothed rotated profile representing about 240 discs, bouding box, and axis of revolution

Machine vision volume results were compared with two experimental water displacement methods, 1) water-

overflow (collecting the volume of water over flown by dipping the object), and 2) water-fill (filling the container with the object so that the water reaches a given level while noting the volume of water used). These water displacement methods were calibrated by using geometrical objects (cylinder, annular cylinder, cube, and sphere) of known volume. Calibration results indicated the water-fill method (1.69% deviation) was more efficient water-overflow method (8.20% deviation), hence water-fill method was used to compare the machine vision results. Thus, it is interesting to note there are practical difficulties and inaccuracies associated with standard water displacement method available for volume measurement of irregular objects. Based on the observed deviations (1.69%), the water-fill method results of fruits and vegetables were updated for evaluating results of machine vision.

Before applying to images of actual samples, the plugin was tested with manually drawn images of geometrical objects using Fiji command for which exact volumes can be obtained using analytical formulas. Ellipses and circles of various dimensions starting from 24 pixels minimum dimension were tested. Percent deviation of the machine vision method varied from -4.05% to 2.18%, giving a mean absolute deviation of 1.86%. It should be noted that the analytical method assumes a perfect smooth profile, while the digital images are formed by square pixels of definite dimensions. Thus, any curved profile is approximated as rectangular steps, and this would contributes to the observed deviation.

Mean separation statistical analysis revealed that orange and potato samples had similar volumes, while the other produce were significantly different. Volumes followed the small to big order of lemon, pear, orange, potato, and cucumber. Among the produce, significant differences were not found among the six replications and they can be clubbed into only two groups. Orientation of a produce image at different angles (Fig. 3) produced only a small deviation of about 0.61% from the mean volume among volumes estimated. Image resolutions 254 and 508 DPI were not significantly different, but 127 and 508 DPI were different. Therefore, 508 DPI was selected for all further analysis and reporting.

Ratios of means of machine vision to water-fill method volumes for 508 DPI found to vary from 0.87 to 1.02 for individual produce and an overall mean of 0.88895 for all produce. These correction factors were used to update the machine vision method results so that they will be equivalent to water-fill method estimations. Absolute percent deviation between updated machine vision and water-fill methods volumes evaluated the performance of machine vision method. Mean value of this deviation was 10.80% when the overall ratio of 0.88895 was applied, and this was 4.36% when individual fruits and vegetables based ratios were applied.

Updated machine vision measurements of fruits and vegetables correlated well (r = 0.92) with the updated water-fill method, after removing the two outliers. Linear regression fit (Fig. 4) predicting the water-fill volume from machine vision method volume produced a good performance (R^2 = 0.85).

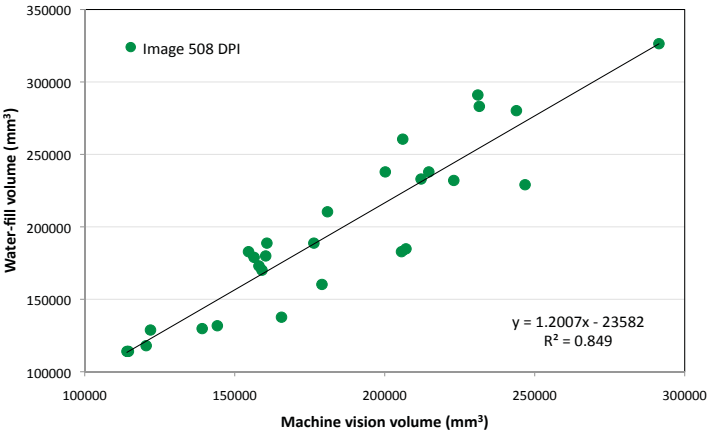


Fig. 4. Correlation and regression between machine vision and water-fill methods volume estimation

The ratio result indicate that the machine vision method can be more efficient when individual ratios were utilized to update the volume estimates. This means for calibration purposes, necessary number of samples of a specific produce should be measured using both machine vision and water-fill methods to determine the ratio, and the ratio can be later applied to update all machine vision measurements. It can be concluded that the machine vision method can be used as an efficient noncontact volume measurement method for irregular three-dimensional objects, such as fruits, vegetable and other similar products.

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