BREAKING GROUND

The people behind the science

Breaking Ground is a regular series featuring staff at CIMMYT

Breaking Ground series

Learn about the people behind the science at CIMMYT

The Breaking Ground series aims to give a human touch to our science by showing the people behind it and their stories. This series is our chance to highlight the great wealth of our organization: its people.

Our drive behind the Breaking Ground series is to support scientists by providing recognition for their work and to share knowledge and bring people together by learning about colleagues' activities and accomplishments.

We believe that Breaking Ground helps show the world our work and helps tell stories about what CIMMYT does it also helps to highlight our staff. Additionally, we are able to generate interest about diverse areas of work CIMMYT specializes in.

We are very proud of our scientists at CIMMYT and the stories we have been able to share from them in our Breaking Ground series up until this point. We hope to continue this series far into the future as new scientists continue to bring new and fresh perspectives to CIMMYT, driving our innovation forward to meet current challenges.

Geneviève Renard
Head, Corporate Communications

Scientist Deepmala Sehgal on the trail of novel wheat diversity

by **Mike Listman**

Deepmala Sehgal, wheat geneticist and molecular breeder at CIMMYT. Photo: M. Listman/CIMMYT.

EL BATAN, Mexico (CIMMYT) — Molecular analysis research by Deepmala Sehgal, a wheat geneticist and molecular breeder who joined the International Maize and Wheat Improvement Center (CIMMYT) as an associate scientist in 2013, has led to the discovery of novel genes for yield, disease resistance and climate resilience in previously little-used wheat genetic resources.

But getting to the point of applying cutting-edge DNA marker technology to support CIMMYT wheat breeding has involved a few dramatic moves for the New Delhi native, who studied botany throughout middle school and university. "I loved science and chose plant science, because I enjoyed the field trips and didn't like dissecting animals," Sehgal said, explaining her choice of profession.

It wasn't until she was studying for her Ph.D. at Delhi University in 2008 that she first used molecular markers, which are DNA segments near genes for traits of interest, like drought tolerance, and which can help breeders to develop improved crop varieties that feature those traits.

"For my thesis, I used molecular markers in a very basic way to analyze the diversity of safflower species that the U.S. Department of Agriculture had in its gene bank but didn't know how to classify. I found a place for some and, for several, had to establish completely new subspecies," Sehgal said.

Later, as a post-doctoral fellow at the University of Aberystwyth in Britain, Sehgal used an approach known as fine mapping of quantitative trait loci (QTL), for drought tolerance in pearl millet. "The aim of fine mapping is to get shorter QTL markers that are nearer to the actual gene involved," she explained, adding that this makes it easier to use the markers for breeding.

As it turned out, Sehgal's growing proficiency in molecular marker research for crops made her suited to work as a wheat geneticist at CIMMYT.

"By 2013, CIMMYT had generated a huge volume of new data through genotyping-by-sequencing research, but those data needed to be analyzed using an approach called "association mapping," to identify markers that breeders could use to select for specific traits. My experience handling such data and working with drought stress gave me an in with CIMMYT."

Based at CIMMYT's Mexico headquarters, Sehgal currently devotes 70 percent of her time to work for the CIMMYT global wheat program and the remainder for Seeds of Discovery, a CIMMYT-led project supported by Mexico's Ministry of Agriculture, Livestock, Fisheries and Food (SAGARPA), which aims to unlock new wheat genetic diversity able to address climate change challenges.

Over the last two years, she has served as lead author for two published studies and co-author for four others. One used genotyping-by-sequencing loci and gene-based markers to examine the diversity of more than 1,400 spring bread wheat seed collections from key wheat environments. Another applied genome-wide association analysis on a selection of landrace collections from Turkey.

"In the first, we discovered not only thousands of new DNA marker variations in landraces adapted to drought and heat, but a new allele for the vernalization gene, which influences the timing of wheat flowering, and new alleles for genes controlling grain quality, all in landraces from near wheat's center of origin in Asia and the Middle East."

Sehgal acknowledges the as-yet limited impact of molecular markers in wheat breeding. "Individual markers generally have small effects on genetically complex traits like yield or drought tolerance; moreover, many studies fail to account for "epistasis," the mutual influence genes have on one another, within a genome."

To address this, she and colleagues have carried out the first study to identify genomic regions with stable expression for grain yield and yield stability, as well as accounting for their individual epistatic interactions, in a large sample of elite wheat lines under multiple environments via genome wide association mapping. A paper on this work has been accepted for publication in *Nature Scientific Reports*.

Sehgal has found her experience at CIMMYT enriching. "I feel free here to pursue the work I truly enjoy and that can make a difference, helping our center's wheat breeders to create improved varieties with which farmers can feed a larger, more prosperous global population in the face of climate change and new, deadly crop diseases."

Jiafa Chen on improving maize and building partnerships

by **Katelyn Roett**

Jiafa Chen, a statistical and molecular geneticist at CIMMYT. Photo: CIMMYT.

Maize has always been an integral part of Jiafa Chen's life.

Chen, a statistical and molecular geneticist at the International Maize and Wheat Improvement Center (CIMMYT), has helped identify new genetic resources that have the potential to be used to breed new maize varieties that withstand a variety of environmental and biological stresses. He has also played a significant role in the development of a recent partnership between CIMMYT and Henan Agricultural University (HAU) in China.

Born in Henan – a province in the fertile Yellow River Valley known for its maize and wheat production – Chen's family grew maize, which was a major source of income and led to his interest in breeding the crop as a means to help small farmers in China. He went on to study agriculture at HAU, where he focused on maize at a molecular level throughout undergraduate and graduate school, then came to CIMMYT as a postdoctoral researcher in 2013.

"Coming to CIMMYT was natural for me," Chen said. "CIMMYT's genebank – which holds over 28,000 maize accessions – offered a wide array of genetic resources that could help to breed varieties resistant to disease and abiotic stress which are large challenges in my country."

Over Chen's four years at CIMMYT headquarters near Mexico City, he has helped characterize CIMMYT's entire maize genebank using DArTseq, a genetic fingerprinting method that can be used to help identify new genes related to traits like tolerance to heat under climate change, or resistance to disease. This research is being used to develop maize germplasm with new genetic variation for drought tolerance and resistance to tar spot complex disease.

"Conserving and utilizing biodiversity is crucial to ensure food security for future generations," Chen said. "For example, all modern maize varieties currently grown have narrow genetic diversity compared to CIMMYT's genebank, which holds some genetic diversity valuable to breed new varieties that suit future environments under climate change. CIMMYT and other genebanks, which contain numerous crop varieties, are our only resource that can offer the native diversity we need to achieve food security in the future."

Chen moved back to China this month to begin research at HAU as an assistant professor, where he will continue to focus on discovering new genes associated with resistance to different stresses. Chen was the first student from HAU to come to CIMMYT, and has served as a bridge between the institutions that officially launched a new joint Maize and Wheat Research Center during a signing ceremony last week.

The new center will focus on research and training, and will host four international senior scientists with expertise in genomics, informatics, physiology and crop management. It will be fully integrated into CIMMYT's global activities and CIMMYT's current collaboration in China with the Chinese Agricultural Academy of Sciences.

"I think through the new center, CIMMYT will offer HAU the opportunity to enhance agricultural systems in China, and will have a stronger impact at the farm level than ever before," Chen said. "I also think HAU will have more of an opportunity to be involved with more global agricultural research initiatives, and become a world-class university."

Scientist L.M. Suresh uses new technology to fight maize lethal necrosis disease in eastern Africa

by **Bianca Beks**

Maize lethal necrosis (MLN) disease is putting maize production at risk in eastern Africa, escalating food insecurity in the region.

First reported in Kenya in 2011, it has subsequently spread rapidly to neighboring countries and has now been confirmed in six eastern African countries, including the Democratic Republic of Congo, Ethiopia, Rwanda, Tanzania and Uganda.

The disease, caused by a combination of the maize chlorotic mottle virus (MCMV) and sugarcane mosaic virus (SCMV), causes irreversible damage that kills maize plants before they can grow and yield grain. If a maize field is infected early in the cropping cycle, total yield losses may occur.

Scientist L.M. Suresh of the International Maize and Wheat Improvement Center (CIMMYT) plays a central role in efforts to keep the disease in check. He contributes significantly to the screening of maize germplasm against MLN/MCMV, and to the identification of maize hybrids with tolerance/resistance to the disease.

In 2013, CIMMYT and the Kenya Agricultural and Livestock Research Organization established an MLN screening facility in Naivasha, Kenya, northwest of the capital Nairobi. The center serves as a centralized platform for screening maize germplasm under artificial inoculation from CIMMYT as well as public and private sector partners.

Suresh joined CIMMYT in 2015 as maize pathologist for sub-Saharan Africa. He is also manager of the MLN screening facility. As almost all of the commercial maize varieties currently grown in eastern Africa are susceptible to MLN, it is crucial to identify and develop germplasm with tolerance/resistance to the disease.

His work involves identifying sources of resistance to MLN and its component viruses MCMV and SCMV, and he works closely with other scientists on the genetic basis of MLN resistance. In addition, he contributes to the identification of elite maize hybrids that offer tolerance/resistance to MLN.

The use of advanced phenotyping technology makes it possible to quickly make physical observations of the plants on a large scale without painstaking manual scoring.

Another major component of Suresh's work focuses on epidemiological factors related to MLN disease transmission, particularly seed transmission of MLN-causing viruses.

While focusing on MLN, he also works on other foliar – or leaf – diseases that are a threat to maize. As manager of the MLN screening facility, Suresh is responsible for the screening and indexing of about 84,000 rows of maize trials each year in three to four planting cycles at the Naivasha facility.

As of 2016, nearly 100,000 germplasm entries have been screened against MLN. To date, nine first generation MLN-tolerant elite maize hybrids have been released in East Africa. Several second-generation, CIMMYT-derived, MLN-resistant hybrids are currently being tested under national performance trials in Kenya, Tanzania and Uganda.

Born in Madasuru-Lingadahalli, a rural village in southern India, Suresh grew up on a farm where he worked in the fields during school holidays helping with weeding, picking areca nuts and harvesting.

In the 1970s and 1980s, his father was recognized by the State Department of Agriculture as a "progressive farmer" for undertaking various innovative approaches to increase rice paddy yields. However, the family continued to face several challenges, including low yielding varieties, diseases, pests, water scarcity and volatile prices.

To try and overcome some of these hardships, Suresh decided to further his education in agriculture.

"I believe that a deeper knowledge of science might offer alternatives, and that we should explore these options to help smallholder farmers like my father get better yields without increasing costs," Suresh said. "My family always supported me to pursue higher education in the field of agriculture."

Suresh earned undergraduate and master's degrees at the University of Agricultural Sciences in Bangalore. During that time, Professor and emeritus scientist Varagur Ganesan Malathi from the Indian Agricultural Research Institute was his mentor and guide, also supervising him while he completed his Ph.D. at Kuvempu University in Karnataka.

Before joining CIMMYT, Suresh worked for 19 years at seed companies, including 14 years for Monsanto in India, where he led a team of plant health scientists focusing on diseases in vegetables. Additionally, he supported teams working on maize and cotton to harmonize various disease screening protocols.

"Working in agriculture gives me the best opportunity to contribute to efforts to help smallholder farmers improve their livelihoods," Suresh said. "CIMMYT is a place full of scientific rigor and experts who work collaboratively with partners and thus bring impact. A major disease like MLN brings researchers from various organizations and institutions from different parts of the world together to accelerate efforts to not only understand the disease and establish effective surveillance, but also to engage stakeholders to commercially scale up disease-resistant hybrids developed by CIMMYT."

The MLN web information portal, to which Suresh contributes, provides comprehensive information on various initiatives to tackle the MLN challenge. This website and information management system was developed with the objective of providing a one-stop resource for all the relevant information on MLN to interested stakeholders.

Caixia Lan on identifying building blocks for rust resistant wheat

by **Matthew O'Leary**

CIMMYT scientist Caixia Lan. Photo: Courtesy of Caixia Lan.

Support for research into breeding crops resistant to wheat rust is essential to manage the spread of the deadly disease, which has caused billions of dollars of yield losses globally in recent years, said Caixia Lan, a wheat rust expert at the International Maize and Wheat Improvement Center (CIMMYT).

Rust disease has historically been a menace to wheat production worldwide. Although agricultural scientists manage the disease by breeding wheat varieties with rust resistant traits, the emergence of new races hinders progress and demands continued research, said the scientist.

With outbreaks of new strands reported in Europe, Africa and Central Asia, wheat rust presents an intensifying threat to the over 1 billion people in the developing world who rely on the crop as a source of food and for their livelihoods.

One of the most recent rust races, Ug99, was detected in 1998 and has since spread across 13 countries, alone causing crop losses of $3 billion in Africa, the Middle East and South Asia, said Lan.

Working with CIMMYT's Global Wheat Program Lan is identifying and mapping adult-plant resistance genes to different races of rust (leaf, stripe, and stem) in bread and durum wheat and transferring them into new varieties that help secure farmer's production.

Growing up in an area dependent on agriculture in rural China, Lan knows all too well the impact crop disease and natural disaster has on family food security and livelihoods. The struggles of smallholder farmers to feed and support their families motivated her to pursue a career in agriculture for development, but it was not until university that she became inspired by the improvements made to crop yield through genetic manipulation and breeding, she said.

After completing her doctoral degree at the Chinese Academy of Agricultural Sciences, and working as a wheat molecular breeding lecturer at Huazhong Agricultural University, Lan was named the_Borlaug Global Rust Initiative Women in Technology Early Career Winner in 2011. Lan joined CIMMYT in a post-doctoral position and currently works as a scientist to improve wheat's resistance to rust.

Rust is a fungal disease that uses wheat plants as a host, sucking vital nutrients and sugars from the plant leaving it to wither and die. Without intervention, wheat rust spreads due to the release of billions of spores, which travel by wind to other plants, crops, regions or countries. Spores have the potential to start new infection, ravage crops and threaten global food security.

The science behind building genetic resistance takes two forms known as major (or race-specific) genes and adult-plant resistance based on minor genes. Major resistance genes protect the wheat plants from infection by specific strains of rust. While adult plant resistance, Lan's area of specialization, stunts the pathogen by reducing the infection frequency and limiting its nutrient intake from the host wheat plant. Some of the longer-lasting adult-plant resistance genes have been shown to provide protection against multiple diseases for decades and have not succumbed to a mutated strain of rust so far.

Replacing wheat crops for varieties bred with several rust-resistant genes acts as a safeguard for occasions when the pathogen mutates to overcome one resistant gene as the others continue the defense, Lan said.

Lan has identified a number of rust resistant genes in CIMMYT germplasm and developed molecular markers, which are fragments of DNA associated with a specific location in the genome. However, as new races of the disease emerge and old ones continue to spread, research identifying durable and multiple rust resistant genes and breeding them into crops is of high importance, she said.

Cesar Petroli on data-driven use of maize genetic diversity

by **Miriam Shindler**

Access to genetic data can revolutionize research partnerships and lead to major benefits for crop breeders aiming to help smallholder farmers boost yields, according to Argentinian geneticist Cesar Petroli.

Hailing from Reconquista in Santa Fe Province, Petroli now works for the MasAgro program at the International Maize and Wheat Improvement Center (CIMMYT) and is funded by Mexico's Ministry of Agriculture (SAGARPA). He first became curious about genetics in the mid-1990s when it was a relatively new field in Argentina and the National University of Misiones offered the only bachelor's degree in the country. Petroli initially focused on cattle and sheep genetics, which gave him his first introduction to molecular markers, which shed light on characteristics of the organism.

His interest in data and plant genetics took root while he was a student. While completing his doctoral degree at the University of Brasilia in partnership with EMBRAPA, Brazil's agricultural research body, Petroli began to work on the eucalyptus tree with Diversity Arrays Technology (DArT), an Australian enterprise specializing in developing technologies for whole genome profiling.

At that time, CIMMYT wanted to create what was subsequently to become the Genetic Analysis Service for Agriculture (SAGA) using a platform based on the DArT method. Petroli was the perfect fit. Not only did he bring expertise in sequencing and low-cost DNA fingerprinting, he also brought experience of application of large amounts of data in research; in particular, his experience in eucalyptus.

At the heart of operations at the SAGA laboratory is the Illumina HiSeq 2500 sequencing system, one of only three in Mexico, where CIMMYT is headquartered. Petroli and his team have the capacity to determine the genetic make-up up to 2,500 maize samples per week for both CIMMYT and its partners, generating vast quantities of data in the process.

"We determine the genetic make-up maize and wheat varieties and collections," Petroli said. "This can help maize breeders to identify patterns in the DNA which are associated with characteristics such as drought and heat tolerance. These patterns or molecular signposts can then be used to help select the best materials for breeding," he added, explaining that heat and drought resistant maize and wheat varieties not only help present-day farmers, but could also mitigate potential future risks to global food security from the impacts of climate change.

The data generated when fingerprinting thousands of maize and wheat samples provide opportunities for scientific exploration and synergies; while one team may be exploring heat and drought tolerance, another team can use the same DNA fingerprint data to explore other characteristics such as disease tolerance.

"Sharing data for use by interested breeders broadens collaboration and maximizes benefits to smallholder farmers," Petroli said, describing his enthusiasm for making data publicly available. "Accessible data increases the impact of our research and allows the global public to benefit from the wealth of knowledge we generate."

In the first six years of the MasAgro program, more than 2 billion genotypic data have been made available in the Germinate and Dataverse platforms. Petroli's work forms part of bigger efforts at CIMMYT to study and characterize genetic diversity for use in breeding programs.

Xuecai Zhang prepares future generation of crop breeders

by **Katelyn Roett**

Xuecai Zhang wants to merge traditional maize breeding methods with new software and other tools to help improve farmers' yields faster than ever.

"In the next three decades we need to increase agricultural production by 70 percent to meet projected food demand," said Zhang, a maize genomic selection breeder at the International Maize and Wheat Improvement Center (CIMMYT). "However, crop yields, while improving, are not increasing quickly enough to meet this challenge. We must explore new methods and technologies that can speed up our crop breeding processes if we hope to feed a world with over 2.3 billion more people by 2050."

Growing up in Henan province, China, Zhang's mother was a teacher who instilled a love of science in him from a young age.

"I loved exploring outside and seeing how plants grew — I always wanted to know how they worked," said Zhang. "Maize was naturally interesting to me because it's the second most grown crop in Henan, and is becoming a very important crop in China overall."

Zhang first arrived at CIMMYT in 2009 while completing a doctorate in applied quantitative genetics. He subsequently returned as a postdoctoral fellow in 2011 to undertake molecular breeding and coordinate CIMMYT's maize genomic selection program.

Since his return, he has focused mainly on helping breeders and statisticians work together to create new tools that can help accelerate the breeding process through genomic selection.

"It's crucial that as breeders, we're able to use genomic selection in our work," Zhang said. "Not only does it speed up the breeding process to deliver better, faster results to farmers in the field, applied well it's also a more cost-effective option."

Conventional plant breeding is dependent on a researcher going into the field, observing the characteristics of a plant based on how its genotype interacts with the environment, then painstakingly selecting and combining those materials that show such favorable traits such as high yield or drought resistance. This process is repeated again and again to develop new varieties.

Genomic selection adds DNA markers to the breeder's toolkit. After initial field evaluation breeders are able to use DNA markers and advanced computing applications to select the best plants and predict the best combinations of plants without having to wait to evaluate every generation in the field. This speeds up the development of new varieties as more cycles of selection and recombination can be conducted in a year compared with field selection alone.

The cost of hiring a human to go and collect phenotypic data for conventional breeding is increasing, while conversely the costs associated with genomic selection are getting lower as genotyping and computing technology becomes more affordable, according to Zhang.

"Breeders need to think about where the technology is pushing our field," he said. "They will increasingly have to be versed statisticians and computer scientists to effectively apply genomic selection to their work, and I want to help ensure they have the skills and tools to make the most of the technology."

Zhang has helped demonstrate to breeders in Latin America, Africa and Asia of the value of genomic selection by showing that the technique can improve the prediction accuracy of successful varieties in comparison to conventional breeding.

He also credits joint efforts like the GOBII project, a large-scale public-sector effort supported by the Bill & Melinda Gates Foundation, to apply genomic selection techniques to crop breeding programs across the developing world, as key towards curating the necessary data for genomic breeding programs.

"In the future, I hope to continue to help build better tools for breeders to move towards genomic selection," Zhang said. "I chose to breed maize because of the potential impact it has to help smallholder farmers globally. Compared with other crops the yield potential of maize is very high, so I want to ensure we are using the best resources available that will help maize reach its full potential."

Carolina Sansaloni explores and unlocks genetic potential from wheat genebanks

by **Katie Lutz**

Carolina Sansaloni's passion for genetics began when she was at Universidad de Misiones in Posadas, Misiones, Argentina, an interest that grew as she moved on to receive her master's and doctoral degrees in molecular biology at Universidad de Brasilia in Brazil.

While completing her doctorate degree, Sansaloni travelled to Canberra, Australia to research the genomic structure of the eucalyptus tree at Diversity Arrays Technology (DArT), learning the ins and outs of sequencing technology.

In 2012, the International Maize and Wheat Improvement Center (CIMMYT) wanted to introduce the DArT genotyping technologies to Mexico to serve the needs of the Mexican maize and wheat research communities, and once Sansaloni finished her doctoral degree, she was an obvious choice to lead this initiative.

Working under the MasAgro Biodiversidad project in partnership with DArT, INIFAP and CIMMYT, Sansaloni helped to build the Genetic Analysis Service for Agriculture (SAGA in Spanish) from the ground up.

The service, managed by the CIMMYT-based Seeds of Discovery (SeeD) initiative, brings cutting edge genotyping capacity and genetic analysis capability to Mexico. The facility provides unique insights into the genetic variation of wheat and maize at a "sequence level." Use of the vast quantities of data generated help understand genetic control of characteristics evaluated at a plant or crop level for example, height variations among wheat varieties.

SAGA's services are available for all CIMMYT scientists, universities, national agriculture research programs and private companies. Worldwide, few other platforms produce this kind of data and most are inaccessible to scientists working at publicly funded institutions because their economic or logistics difficulties.

"When it comes to genotyping technology, it doesn't matter what type of organism you are working with. It could be wheat, eucalyptus or chicken – the machine will work the same way," explained Sansaloni.

Sansaloni has also been focusing her time on the wheat Global Diversity Analysis, which characterizes and analyzes seeds in genebanks at both CIMMYT and the International Center for Agricultural Research in Dry Areas (ICARDA). Her team has characterized approximately 100,000 wheat accessions including 40 percent of the CIMMYT genebank and almost 100 percent of the ICARDA genebank wheat collection. This is an incredible and unique resource for wheat scientists providing a genetic framework to facilitate selection of the most relevant accessions for breeding.

"Currently only five to eight percent of materials in the genebank are being used in the breeding programs," Sansaloni said. "The Global Diversity Analysis could have huge impacts on the future of wheat yields. It is like discovering the pieces of a puzzle, and then beginning to understand how these pieces can fit together to build excellent varieties of wheat."

Sansaloni's goal is to combine information from CIMMYT and ICARDA, making the information accessible to the entire wheat community and eventually enhancing breeding programs across the globe.

"Working at CIMMYT has been an invaluable experience," Sansaloni said. "I've had the opportunity to work and collaborate with so many different people, and it's brought me from the laboratory into the wheat fields, which really brings me closer to my work."

Akhter Ali helps transform agriculture sector in Pakistan

by **Katelyn Roett**

Akhter Ali always knew he wanted to have an impact on the livelihoods of farmers in Pakistan.

"I come from a farmer family – the poverty and inequality of rural communities always disturbed me," said Ali, who was born in Multan district, Pakistan. "I knew from a young age I wanted to do something to help my community and the rural poor throughout my country."

Ali, an agricultural economist at the International Maize and Wheat Improvement Center (CIMMYT), is working to sustainably increase agricultural productivity and incomes for farmers through the Agricultural Innovation Program (AIP), an initiative funded by the U.S. Agency for International Development to build up the country's agriculture sector through the development and dissemination of new agriculture technologies.

"Agriculture supports nearly half of Pakistan's population – more than two thirds for those living in rural areas – and accounts for over 20 percent of Pakistan's gross domestic product" Ali said. "Strengthening this sector by connecting and addressing the needs of different actors in rural markets is key to poverty reduction and achieving food security."

Despite the significant role of agriculture to the economy, the sector has only grown 2.8 percent in recent years due to weak market structures, resource depletion and other challenges. Ali, along with other researchers, is analyzing how maize and wheat farmers can access the best seed, technology and practices to sustainably increase crop yields across the country.

"If we want to boost farmer livelihoods, we need to change how farmers work by ensuring they know how to sustainably manage their land, water and other resources," Ali said. "We then need to ensure that the markets in which these farmers operate are stable so that they have easier access to agricultural inputs like seed."

Ali's research over the past four years at CIMMYT has focused on making these goals a reality, from conducting comprehensive surveys, which are expected to help develop the durum wheat market in Pakistan, to adoption and impact studies of such sustainable technology as zero tillage machines and precision land levelers, now used by thousands of farmers throughout Pakistan.

"There are 80,000 farmers – 20 percent of which are women, whose numbers are growing – working with AIP who have adopted these new, sustainable technologies," said Ali. In the future, Ali hopes to see his work continue to be used as a tool by policy makers, extension workers and others.

"We still face challenges with farmer access to seed, from engaging women to market constraints, so it's critical we create policies that facilitate sustainable development in rural communities," Ali said.

Shifting trends in Pakistan from urbanization to climate change will make it even more necessary to understand how rural communities operate in the coming years, he said, adding that policies supporting its development will be key to feeding the country and alleviating rural poverty.

Closing the circle: Kanwarpal Dhugga works at CIMMYT

by **Mike Listman**

Growing up on a small farm in India's northwest Punjab state, Kanwarpal Dhugga was a young boy when the first Green Revolution wheat varieties arrived in his village. Now stationed in Mexico as Principal Scientist and head of biotechnology for agricultural development at the International Maize and Wheat Improvement Center (CIMMYT), Dhugga has witnessed vast changes in his boyhood community.

"It was tight for families there, living from season to season with no extra money to spend," Dhugga said, reflecting on the period during the 1960s before new high-yielding, disease resistant wheat varieties began to reshape agricultural potential throughout Asia. "Farmers used to plant a mixture of wheat and chickpeas. If rains were good, you got good wheat yield; if there was a drought, you got at least chickpeas."

The use by farmers of the new, high-yielding wheat varieties developed by the late Nobel Peace Prize laureate Norman Borlaug, who was head of the wheat program at CIMMYT headquarters in Mexico, coincided with the introduction of electric power to Dhugga's area. Electricity enabled pumping underground water for irrigation, making farming more predictable. Within a couple of years, everyone was growing new, more resilient semi-dwarf wheat varieties and yields had increased substantially.

The community was poor and without many educational resources. Dhugga recalls sitting on the ground at elementary school in India and carrying his books in a satchel along with a burlap gunnysack, which he used as a mat to sit on. Despite challenges, his perseverance and determination eventually took him to Punjab Agricultural University, where he earned a master's degree in plant breeding, then to the University of California, Riverside for a doctoral degree in botany and plant genetics, and finally for a post-graduate degree at Stanford University, where he worked directly with Peter Ray, renowned biologist and now a Stanford emeritus professor.

"I started in genetics and finished in biochemistry," Dhugga explained. "Science grew on me and I became so fixated that I couldn't live without it, and that after I had no clue growing up what I wanted to become in life. The vision extended only as far as the next year."

From 1996 through 2014, he worked at DuPont-Pioneer, the multinational seed producer, where his work included leading research on expressing high-value industrial polymers in maize grains and soybean seeds, developing in-field screening tools to screen maize hybrids for stalk strength, improving nitrogen use efficiency in maize, and on developing a combined genetic marker x metabolites model for predicting maize grain yield, demonstrating that the combined model was more effective than genetic markers alone.

"I was a developer and supplier of advanced plant genetics for a company that was providing high-quality maize seed to farmers around the world, but I felt like something was missing – a social component," Dhugga said.

Taking a job at CIMMYT, where the focus is on helping improve food security for poor smallholder farmers in the developing world, satisfied this urge, according to Dhugga. "It felt like completing a circle, given where I came from and the role of CIMMYT in improving farmers' food security and incomes."

At CIMMYT, he is leading work to apply a recent technology for what is commonly called "gene editing." Known as the CRISPR-Cas9 system, it allows researchers to enhance or turn off the expression of "native" genes as well as modify the properties of the translated proteins in crops like maize or wheat more simply and effectively than with other methods, including transgenics.

"To deactivate a gene and thus learn about what it does used to be a major undertaking that took years, and even then you didn't find some of the things you wanted to," Dhugga explained. "With the new technology, you can find what you're looking for in much less time. That's the main focus of my work right now."

CIMMYT is collaborating with DuPont-Pioneer to fine map, isolate and validate a major gene in maize for resistance to maize lethal necrosis, which appeared in sub-Saharan Africa in 2011 and has caused major losses to maize crops, decreasing food security and the ability of the smallholder farmers to provide for their families.

"We already know a locus that confers high levels of resistance against the combination of viruses that cause the disease," he said. "Once we have the specific gene, we can edit it directly in elite maize lines used for hybrid production in Africa, eliminating the need for generations of expensive crosses to get uniform lines with that gene."

Dhugga greatly respects living systems and, rather than viewing his work as inventing new methods, believes he is drawing out the best potential of nature.

"The biology for these processes is already there in nature; we just need to rediscover and apply it to benefit farmers and ensure food security," he said.

Hands on experience gives Carolina Camacho insight into farming best practices

by **Matthew O'Leary**

Tending her own crops gives Carolina Camacho insights into the challenges farmers face that she could never have learned in a classroom.

Growing up in the metropolis of Mexico City, the historical and political importance of agriculture was never lost on Camacho, who works as a principal researcher at the International Maize and Wheat Improvement Center (CIMMYT).

"As a teenager, I would debate my sister over the most pressing issue that faced our country, Mexico. For me it was always in agriculture," Camacho said. "I strongly believe if we are to improve our country, we must improve the lives of our campesinos (smallholder farmers)."

With no knowledge of farming, but with a passion to bring about change, she took to the field, studying crop science at Chapingo University, on the outskirts of the city in the State of Mexico. Having to brave early morning starts, she learned the basics of agriculture, and a love for the genetic diversity of maize.

Mexico, considered the birthplace of maize, is home to a rich diversity of varieties that has evolved over years of domestication by farmers. Camacho was introduced to this diversity firsthand, interning at CIMMYT's maize germplasm bank as an undergraduate.

Interested in discovering how conserving maize diversity played out in farmers' fields she gravitated towards an on-farm conservation project in rural Mexico. Working with indigenous farmers, Camacho learned how traditional knowledge and practices relate to environmental management, agricultural production and the diversity of native maize varieties.

After earning a master's degree in the conservation and utilization of genetic resources, Camacho felt that crop science was isolated from the daily life of farmers. Thus, in a move to study the relationship between humans and plants, she embarked on a multidisciplinary doctoral in the sociology of rural development at Wageningen University in the Netherlands.

While conducting her research, Camacho lived with indigenous farmers in Mexico's Lacandon rainforest in the state of Chiapas. Alongside local Mayan farmers she cultivated her own *milpa* – a farming system used by indigenous farmers in Latin America, which typically involves intercropping maize, beans and squash. Her hands-on fieldwork allowed her to study cultivation practices outside the scope of purely agronomic activities, but also as political, social and cultural actions.

"Farming alongside the Tzeltal people, I saw how my own cultivation practices were interwoven with everyday life," said Camacho. "Farming was influenced by religious ceremonies, health and family affairs as well as political struggles for land. It had to cope, adapt and overcome these challenges."

Today, these lessons learned guide Camacho as she investigates how agricultural innovations, including drought-tolerant crops, fertilizer and land management approaches can be farmer inclusive and tailored to local contexts as part of CIMMYT's sustainable intensification strategy for Latin America.

Sustainable intensification aims to enhance the productivity of labor, land and capital. They offer the potential to simultaneously address a number of pressing development objectives, including unlocking the agricultural potential to adapt production systems to climate change, sustainably manage land, soil, nutrient and water resources, improved food and nutrition security, and ultimately reduce rural poverty.

CIMMYT principal researcher Carolina Camacho studies how agricultural innovations are promoted and adopted in different regions to aid their smooth delivery to farmers and community members from different genders, ethnicities and ages. Photo: CIMMYT/ Courtesy of Carolina Camacho.

Smallholder farmers, who manage small plots of land and handle limited amounts of productive resources, produce 80 percent of the world's food. The United Nations calls on these farmers to adopt agricultural innovations in order to sustainably increase food production and help achieve the "Zero Hunger" U.N. Sustainable Development Goal. However, these farmers seldom benefit from new techniques to shore up efforts to meet the goal.

"An agricultural scientist can tell a farmer when and how to plant for optimal results, but they do not farm in a bubble, their practice is affected by the ups and downs of daily life – not only by climate and agronomy but also by social and cultural complexities," Camacho said.

"One of the biggest challenge is to recognize the heterogeneity of farmers and leave behind the idea of one size solution to their diverse problems and needs," said Camacho. By understanding a farmer's lifestyle, including access to resources and information, levels of decision making in the community and the role of agriculture in their livelihood strategy, researchers can best identify complementary farming practices and techniques that not only boost productivity but also improve livelihoods.

"It's important to think about agricultural innovations as social processes for change in which technologies, like improved seeds or agronomic practices, are only one element," said Camacho. "It is key that we recognize that changes will not only occur in the farmer's field but also in the behavior of other actors in the value chain, such as input suppliers, traders, government officials and even researchers."

Camacho studies how innovations are promoted and adopted in different regions to aid their smooth delivery to farmers and community members from different genders, ethnicities and ages.

When working with indigenous communities, she ensures cultural values of the milpa system are taken into account, thus promoting the agricultural tools and techniques that do not detract from the importance of the traditions associated with the milpa practice.

"The milpa system is a clear example of how agriculture in general and maize in particular contribute to the construction of the cultural identities of indigenous people. We should be aware of the consequences that innovations will have not only for environmental sustainability but also for the sustainability of the Mayan Culture," she said.

"Let's not forget, we can't separate culture from agriculture," Camacho finished.

David Guerena transfers world-class science to smallholder farmers

by **Bianca Beks**

David Guerena is fascinated by what he learns from smallholder farmers about the interactions between agriculture and the environment.

He recently joined the International Maize and Wheat Improvement Center (CIMMYT), where, as soil scientist-systems agronomist, he leads the soils/nutrient management activities for the Nepal Seed and Fertilizer Project, funded by the U.S. Agency for International Development's (USAID) Feed the Future Program.

Guerena's work involves the strategic planning and execution of multidisciplinary spatial agronomy programs across complex ecologies. In addition to strict biophysical work, which involves integrating chemistry, biology, and physics into agricultural systems, he also engages in socio-economic and market facilitation dynamics research.

"Humanity has been eking out a cultivated living from the earth for around 10,000 years," Guerena said. "Smallholder farmers are the direct link to this collective knowledge, which has shaped and defined human history. I really enjoy witnessing farmers reap satisfying harvests from their own efforts, but via outputs from agronomic systems research of which I have been a part."

"Agriculture is intensely satisfying. A seed, fertile soil, water and sunshine eventually turn into food. This is such a simple process, yet millions of people around the world don't get enough to eat. I draw inspiration from being a part of positively changing this dynamic."

Originally from Santa Barbara, California, Guerena has always been fascinated by the natural sciences and international travel. He decided to pursue a career in international agriculture by obtaining his Ph.D. from Cornell University, specializing in crop and soil science. Prior to joining CIMMYT, he worked as a soil scientist and agriculture innovations manager at One Acre Fund, served as an international research fellow with the World Agroforestry Center and a Borlaug Fellow in international food security.

CIMMYT provided a unique opportunity for Guerena to work on global food systems. "Together, maize and wheat make up a significant proportion of the global food supply – maize and wheat research is a globally important mandate," he said. "CIMMYT has also left an indelible mark on human history through facilitating the Green Revolution."

Currently, Guerena is working on spatial agronomy programs, focusing on questions such as how to move from blanketed to site-specific agronomic recommendations across complex agro-ecologies in the developing world. Guerena will also investigate how digital technologies like SMS, smartphones, image recognition, and remote sensing data can be used and integrated into agronomy programming for smallholder farmers living in poverty.

Precision agronomy, a farming management concept based on observing, measuring, and responding to inter- and intra-field variability in crops, is already transforming agricultural efficiency in the developed world, but these advancements have not yet reached the developing world.

This is of the utmost importance, as worldwide, the vast majority of farmers are smallholders producing most of the global food supply. CIMMYT is not only looking at ways to put its top-level science into the hands of farmers, but also at ways to use these technologies to turn farmers themselves into world-class agronomists. This approach may be a way to bypass cumbersome agricultural knowledge generation and dissemination systems and reach farmers directly, at scale.

Vijay Chaikam develops doubled haploid lines to accelerate maize breeding

by **Jennifer Johnson**

As a child helping out on his family's farm in rural India, Vijay Chaikam dreamed of helping farmers increase the hard won returns of their agricultural labor to improve their livelihoods. Today, he works as a scientist and manager at the International Maize and Wheat Improvement Center (CIMMYT) doubled haploid (DH) facility in Kiboko, Kenya.

He produces DH maize lines, which are highly uniform, genetically pure and stable, making the maize breeding process more intuitive and efficient by simplifying logistics. The outcome of this work is that breeders can develop improved maize varieties faster than ever before so that they can be delivered to the smallholder farmers that need them the most.

"I grew up in a rural village in the state of Andhra Pradesh, India, where my family depended on agriculture for their livelihood," Chaikam said. "During my childhood, I used to work in the fields, planting, weeding and harvesting alongside my family members to save labor costs. I realized that despite their backbreaking work, most farming families suffer economically. This inspired me to pursue a career in agriculture that would allow me to contribute to reduce the efforts of the farmers and increase their farm income."

After receiving his doctorate in genetics at West Virginia University in the United States, Chaikam worked at Purdue University and then moved to CIMMYT headquarters in Mexico in 2011 as an associate scientist. His work involved conducting research on developing and implementing maize DH production technology for tropical breeding programs.

In 2016, he moved to CIMMYT's office in Kenya to manage the Maize DH Facility at KALRO-Kiboko Center, where he assists maize scientists from CIMMYT and partner organizations in the development of DH lines. The efficiency of the DH procedure in maize cuts the time it takes to develop parental lines from six to eight seasons to just two or three seasons.

"My work allows farmers to receive improved maize varieties much quicker," Chaikam said. "Time is of the essence for farmers planting improved maize varieties in regions affected by stresses such as drought or maize lethal necrosis (MLN). DH technology can drastically cut short the time it takes to derive parental lines in a hybrid maize breeding program."

CIMMYT's work on DH has greatly expanded in the past few years. Between 2012 and 2016, CIMMYT scientists produced over 100,000 DH lines, up from less than 5,000 in 2011. However, adoption of the technology is lagging behind in tropical maize breeding programs due to the lack of adapted haploid inducers with high haploid induction rates. The haploid inducers enable generations of haploids – maize varieties containing only one set of chromosomes instead of the usual two sets of chromosomes found in normal diploid maize – at a high frequency. These haploids are then detected using a color marker on the kernel, and the chromosome complement is doubled artificially using treatment with a chromosome doubling agent to derive doubled haploid plants, and consequently seed from those plants.

Chaikam's current research is aimed at improving the adoption of DH technology in tropical maize breeding programs by developing improved haploid inducers for tropical maize breeding programs, developing novel methods of haploid identification and efficient protocols for chromosomal doubling, and optimizing the agronomic management for deriving doubled haploids. He works closely with breeders to develop ways of using DH lines more efficiently in maize breeding programs. This research could be valuable in the development and deployment of improved maize varieties that benefit smallholder farmers in the developing world. In addition to his work in the DH facility, Chaikam has published several journal articles and book chapters. He has also coordinated scientific training courses.

"I always wanted my work to be relevant to the needs of farmers," he said, explaining the factors that drew him to work at CIMMYT. "CIMMYT offered such an incredible opportunity, where my day-to-day activities have a direct impact on the development and deployment of improved maize varieties needed by farming communities. I also enjoy working with, talking to and listening to my passionate colleagues who love the work they do to improve the livelihoods of smallholder farmers."

Monica Mezzalama keeps vital check on seed health and biosafety

by **Matthew O'Leary**

Monica Mezzalama, head of CIMMYT's Seed Health Laboratory. Photo: Xochiquetzal Fonseca/CIMMYT.

At the International Maize and Wheat Improvement Center (CIMMYT) it all starts with a seed. Each year, the non-profit receives requests and sends more than 700,000 packets of seed to researchers, agricultural organizations and farmers around the world from its headquarters near Mexico City. These seeds stand up to climate change, produce higher yields with fewer resources and provide the nutrition a growing global population needs.

However, before each seed travels across an international border, it is essential to ensure that each one has a clean bill of health, free from virus, fungus and bacteria pathogens. Infected seeds must be controlled or there is a risk that plant pathogens will spread, affecting crop health and potentially threatening food security.

That is where plant pathology expert Monica Mezzalama, head of CIMMYT's Seed Health Laboratory, gets involved.

"Seed movement around the world is regulated to limit the spread of pathogens across international borders," said the senior scientist. "I coordinate and supervise seed health testing to ensure all seeds that pass through CIMMYT meet these international standards and do not pose a risk."

Securing the health of seeds ensures that researchers, breeders and partner organizations don't encounter infected seed and is essential to maintaining efficient agricultural research that has impact, she added.

Since taking the helm of the Seed Health Laboratory 15 years ago, all seed that has been inspected on its way out of CIMMYT must meet certification. If unhealthy seed is found it must be quarantined and destroyed under the law, explained Mezzalama.

Seeds arriving from partner organizations, researchers or farmers are also tested for disease and granted a "seed release" by Mezzalama and her team. Authorized seed then moves on to CIMMYT researchers to be studied for disease resistance, heat tolerance and micronutrient content and added into international breeding programs. Others are placed in the maize and wheat germplasm bank, where over 175,000 different varieties are preserved on behalf of humanity and are freely available to all upon request.

A curiosity for disease and a passion to cure led Mezzalama to a career as a plant pathologist. While studying for an undergraduate degree in agronomy in her hometown of Turin, Italy, she visited nearby vineyards to study plant pathogens for the first time.

"It was working in the vineyards where I first saw plant pathogens at work and where I saw the impact they have on farmers, and what it means for their livelihoods," she said.

After graduating in 1986, Mezzalama began her first job at CIMMYT working alongside virologist Peter Burnett on a project dedicated to barley yellow dwarf (BYD) virus, which effects barley, wheat, maize, rice and other grasses worldwide. The experience opened her mind to a new world where she learned the inner workings of plant pathogens and started to study for a doctoral degree in plant pathology in Italy.

Since returning to CIMMYT in 2001, Mezzalama has led the Seed Health Laboratory, set institutional biosafety protocols to protect against harmful incidents, which include regular reviews of the biosafety in laboratory settings, as well as well as guidelines to follow, and participated in several research projects. Most recently, she joined a project to control the spread of Maize Lethal Necrosis (MLN), a devastating virus that poses a severe risk to food security in eastern Africa.

The complex disease results from the infection of two deadly viruses, maize chlorotic mottle virus and sugar cane mosaic virus. It spreads through infected maize seed and insect pests. Mezzalama's skill in plant pathology detection was called upon to organize the opening of seed health laboratories in Kenya and Zimbabwe and also train staff on how to detect seed infected with MLN or the two associated viruses.

Currently, Mezzalama is in the final stages of developing a standard of detection protocol, providing the agriculture industry with knowledge of best practices and affordable tools to detect MLN infected maize seed.

"There are several products and methods that may be used for MLN detection in seed, these must be tested to see which obtain the most accurate results efficiently while taking into price into account," she said.

Accuracy, time and cost are important factors when developing MLN detection protocols as common practice, implemented by partners in Kenya and other impacted countries, she explained.

Crop simulation models help Balwinder Singh predict future challenges

by **Jennifer Johnson**

Balwinder Singh uses crop simulation models to help smallholder farmers in South Asia prepare for future climates and unexpected challenges.

Despite improvements in agricultural technology in the past few decades, crop yield gaps persist globally. As climate patterns change, farmers are at risk of crop loss and reduced yields due to unforeseen weather events such as drought, heat or extreme rains.

Singh, a cropping system simulation modeler at the International Maize and Wheat Improvement Center (CIMMYT) based in New Delhi, India, uses crop simulation models—software that can estimate crop yield as a function of weather conditions, soil conditions, and choice of crop management practices—to develop future climate predictions that can help farmers reduce risk, overcome labor and resource constraints, intensify productivity and boost profitability.

"Using future climate data, simulation modelling allows researchers to develop hypotheses about future agricultural systems," said Singh. "This can help predict and proactively mitigate potentially catastrophic scenarios from challenges such as shrinking natural resources, climate change and the increasing cost of agricultural production."

A specific focus is on how to best quantify, map and diagnose the causes of the gap between potential yields and actual yields achieved by cereal farmers in the Indo-Gangetic Plain. "My research combines field experimentation, participatory engagement, and cropping systems modelling and spatial data to identify promising technologies for increasing crop productivity and appropriate geographical areas for out scaling," he said.

For example, Singh and a team of scientists have used simulation tools to find out why wheat productivity is low in the Eastern Gangetic Plains, for example, late sowing, suboptimal crop mangement and terminal heat stress. This process identified various potential techniques to raise wheat productivity, such as early sowing, zero tillage, or short duration rice varieties to facilitate early harvest and field vacation. Geospatial data and tools were used to identify the potential target zones for deployment of these promising technologies.

"The research is helping farmers increase agricultural productivity and to manage climate-related crop production risk and increase the use of agricultural decision support systems," Singh said. "My research towards improving cereal production systems in South Asia contributes to the knowledge, process understanding and modelling tools needed to underpin recommendations for more productive and sustainable production systems."

Growing up in rural India in a farming family, Singh viewed firsthand the uncertainty that smallholder farmers can face.

"I was brought up and studied in northwestern India – the region where the green revolution occurred known as the food basket of India," Singh said.

"I grew up playing in wheat and cotton fields, watching the sowing, growing and harvesting of crops, so an interest in agricultural science came naturally to me and I have never regretted choosing agriculture as a career."

While studying for his bachelor's and master's degrees in agronomy at Punjab Agricultural University (PAU) in Ludhiana, India, a chance encounter helped shape his career.

"Dr. Norman Borlaug came to PAU in 2005 and he happened to visit my field experiment on bed planting wheat. I had a very inspiring conversation with him which made me decide to pursue a career in agricultural research and work for the farming community."

Singh went on to earn a Ph.D. from Charles Sturt University in Australia through the John Allwright Fellowshipfunded by the Australian Center for International Agriculture Research (ACIAR). He started work for CIMMYT in 2013 as associate scientist based in New Delhi working with the Cereal Systems Initiative for South Asia(CSISA) project, which aims to improve food security and the livelihoods of more than 8 million farmers in South Asia by 2020.

Since 2014, Singh has led the CIMMYT participation in the Agricultural Model Intercomparison and Improvement Project (AgMIP) as part of the Indo-Gangetic Basin team, conducting integrated assessments of the effects of climate change on global and regional food production and security, analyzing adaptation and mitigation measures.

Apart from collaborating with CIMMYT colleagues and other advanced research institutes from across the world to build weather and soil databases or working on simulation models, Singh enjoys interacting with farmers in their own fields and collecting data for crop simulation models to generate useable information for research and extension.

He also holds training sessions to aid in developing the capacity of CIMMYT's national agricultural partners in system simulation modelling to create awareness of the proper use of simulation tools for research and extension.

"The most rewarding aspect of my work is to see my simulation results working in farmers' fields," Singh said. "There's a proverb that says: 'When a person is full they have a thousand wishes, but a hungry person has only one.' There is no nobler task than that of being able to feed people. Some of us are not even aware of how many people are starving every day," he said.

"It gives me great satisfaction to be a part of CIMMYT, an organization that works beyond political boundaries to safeguard future food security, improve livelihoods and carry on the legacy of Dr. Borlaug who fed billions."

AbduRahman Beshir is revitalizing Pakistan's maize sector

by **Bianca Beks**

In Pakistan, maize is the third most important cereal crop after wheat and rice and it is the first in productivity among all the cereals. However, Pakistan imports about 90 percent of the hybrid seeds used to produce the crop, costing the country as much as $60 million annually. Furthermore, the genetic diversity of the currently available maize varieties is not diverse enough to adapt to the varied agro ecologies of Pakistan.

To address these issues, AbduRahman Beshir, maize improvement and seed systems specialist with the International Maize and Wheat Improvement Center (CIMMYT), and his team, working under the U.S. Agency for International Development (USAID)-funded Agricultural Innovation Program (AIP) for Pakistan, are developing climate-resilient, biofortified and biotic stress-tolerant maize to enhance the maize seed sector.

"Pakistan can be considered as a new frontier for CIMMYT's maize impacts," Beshir said. "Except for some limited maize activities in the early 1980s, there were no coordinated research activities in the past 32 years. I am glad to revitalize and breathe new life into Pakistan's maize sector."

Almost half of children under age 5 are reportedly malnourished, Beshir said, adding that protein, vitamin A, and other micronutrient deficiencies in Pakistan are rampant, while the mortality rate is among the highest in South Asia.

Beshir's work targets these underprivileged groups and in the foreseeable future, he hopes to see nutritional benefits improve significantly.

Throughout his life, Beshir has witnessed how small scale farmers are often unable to fulfill their basic needs as they struggle to get fair market prices for produce, in part due to middlemen and a lack of information in the market.

He grew up in Ethiopia, a country where agriculture is the mainstay of the economy, accounting for 80 percent of employment, according to UNDP. The livelihoods of Beshir's grandparents and most of his relatives were dependent on agriculture, but his parents switched to a sideline business selling agricultural and food related products.

"I was brought up observing my parents' entrepreneurial skills and efforts, but they wanted their children to pursue a career in science," Beshir said, explaining how his parents encouraged him to attend university. "My father used to call me 'doctor' when I was a fourth grade pupil to inspire me in my education."

Earning an undergraduate degree in agriculture and plant sciences was a life changing experience for Beshir, serving as an eye opener to the dire need for educated agricultural professionals to transform the livelihoods of rural farmers.

"Since then, I developed a passion on how to increase profits for rural farmers through technology promotion and targeted intervention."

Beshir earned a Ph.D. in plant breeding from the University of the Free State, Bloemfontein, in South Africa, and was awarded a gold medal for his research project highlighting the severity of malnutrition in parts of sub-Saharan Africa and the ways quality protein maize seeks to address the issue.

Before joining CIMMYT in 2013, Beshir was the national partner in Ethiopia for a CIMMYT-led project on quality protein maize development and drought-tolerant maize for Africa.

"My involvement in these projects gave me a good grasp of how CIMMYT's impact-oriented interventions practically change the life of farmers and brought a maize revolution in my country, in partnership with local institutions," he said.

His current work in Pakistan mainly involves extensive testing of various maize products sourced from CIMMYT breeding hubs in Colombia, Mexico, Zimbabwe and the International Institute of Tropical Agriculture (IITA). Since 2014, more than 2,200 maize entries have been tested through the project.

Test samples consist of biofortified maize, as well as maize varieties that can tolerate major biotic and abiotic stresses, and they have been evaluated on more than 300 different sites in Pakistan. Such large scale testing is unprecedented in the history of maize in Pakistan.

Beshir's led efforts resulted in the allocation of 49 market ready maize products (hybrids and OPVs) to partners in less than three years, a process that would otherwise have taken eight to 10 years to develop even a single product. The allocation of the new maize products has also given partners access to CIMMYT's parental lines and breeder seeds, so that they can continue to lead sustainable seed businesses even after the project ends.

"Our intervention is the first program in Pakistan to introduce and identify biofortified maize, including pro-vitamin A, quality protein maize, and zinc-enriched hybrids/open pollinated varieties suitable for Pakistan," Beshir said, adding that the research also led to the inauguration of the first maize stem borer mass rearing facility in Pakistan.

The facility will help national programs develop maize germplasm tolerant to maize stem borer attacks.

"As imported hybrid seeds are simply unaffordable to millions of small scale maize farmers, our research will enable local companies to provide affordable options to farmers," he said.

More data on gender roles key for a food secure world, says Anya Umantseva

by **Katelyn Roett**

Social inequality, including gender discrimination, hinders the potential for economic development, a key focus of the agriculture for development community.

Women in developing countries make up more than 40 percent of waged farmworkers, a percentage that is even higher if unwaged farm work is included, according to the U.N. Food and Agriculture Organization. Despite their significant representation in the sector, women often experience acute poverty due to unequal access to seeds, fertilizer, land and other agricultural necessities.

The challenges are great, but the aim of achieving gender equality and empowering all women and girls everywhere by 2030 is entrenched in the international development framework by the U.N. Sustainable Development Goals (SDGs).

Spurred on by the SDGs, gender has become a key agricultural research and policy focus for the International Maize and Wheat Improvement Center (CIMMYT) and the CGIAR system research programs in recent years.

"Despite improvement, there are still several opportunities which could significantly decrease inequality between men and women," said CIMMYT gender researcher Anya Umantseva. "Little data exists on gender roles in rural communities and most importantly, a systematic integration of social components like gender into scientific, data-based research could really help expand outcomes and impacts to more women as well as men.

"Women in rural communities often face very strict gender norms," said Umantseva, referring to local women's and men's expected roles and behaviors. "What we're trying to do is see how these norms influence the way men and women adopt agricultural innovations, and how adoption of different innovations affects gender norms across different communities."

Umantseva is one of many researchers working on GENNOVATE – a global comparative research initiative, which addresses the question of how gender norms influence men, women and youth to adopt innovation in agriculture and natural resource management.

Gender norms include restricted access to land and financial resources, or even the social taboo of walking alone as a woman, can make it difficult to have equal access to agricultural trainings and other farming inputs, she explained.

Umantseva grew up in Yurga, Russia during the country's economic transition to capitalism after the fall of the Soviet Union. "Witnessing the abrupt change of political-economic regimes, and the impact it had on society, shaped my interest in social sciences and anthropology," she said. "I decided that I wanted to study how social norms and culture are historically constructed."

"Gender in agricultural research for development is not an isolated topic; it is deeply intertwined with social inclusion of disadvantaged groups in general," Umantseva said. "Gender is not just about men and women, but who these men and women are. Through GENNOVATE we want to go deep into their stories, their socio-economic status, religion, position in the family and more."

Around 8,000 rural study participants of different ages and socioeconomic backgrounds reflected on gender norms and how these social rules affect their ability to access, adapt and benefit from innovations in agricultural and natural resource management.

"GENNOVATE is the first attempt of this scale providing this type of gender-based data for agricultural research for development initiatives," said Umantseva. "But most importantly, we want to convince the research for development community of the important opportunities, that insights from this kind of data, can bring. It might not always be easy to integrate gender into research, and may require us to do certain things a little differently, but it is necessary if we want to have inclusive development impact."

Along with other researchers, Umantseva is analyzing GENNOVATE data to produce a series of reports, journal articles and other products so researchers and project managers can begin incorporating GENNOVATE's findings into their work.

"Right now we're looking at men and women who have successfully adopted agricultural innovations and what factors their success might have in common, and how men and women differ in adoption. We hope to produce a paper on these findings sometime this year," said Umantseva.

Umantseva received her bachelor's degree in linguistics and translation from Russia's Tomsk State University. She then went on to pursue a master's at the Catholic University of Leuven in Belgium, where she studied minority policies, ethnic relations and gender norms.

Before she joined CIMMYT in 2016, she worked at the United Nations Office on Drugs and Crime, focusing on human trafficking and migration. She currently lives in Mexico City and is based at CIMMYT's Headquarters in El Batan, outside Mexico City.

Mainassara Zaman-Allah uses remote sensing to expedite phenotyping

by **Jennifer Johnson**

Remote sensing technology is on track to make crop breeding faster and more efficient, ensuring smallholder farmers get the improved maize varieties they need.

Field phenotyping – the comprehensive physical assessment of plants for desired traits – is an integral part of the crop breeding process but can create a costly and time-consuming bottleneck, according to Mainassara Zaman-Allah, abiotic stress phenotyping specialist at the International Maize and Wheat Improvement Center (CIMMYT).

Now, technological advances such as proximal or aerial sensing allow scientists to quickly collect information from plants to develop improved varieties.

"Previously, we used to measure maize height with a stick, and manually capture the data" he said. "Now we use proximal sensing—a laser distance meter connected to your phone or tablet that automatically captures data —to measure plant height 2 to 3 times faster for half of the labor. We also use digital ear imaging to analyze maize ear and kernel attributes including grain yields without having to shell the cobs, saving time and money on labor. This will be helpful particularly to most of our partners who do not own the machinery required for shelling after harvest"

Zaman-Allah also works with aerial sensing, using unmanned aerial vehicles equipped with sensors to fly over crop fields and collect images that are later processed to extract crop phenotypic data. "Aerial phenotyping platforms enable us to collect data from 1,000 plots in 10 minutes or less, a task that might take eight hours to do manually," he said.

This means that developing improved maize varieties with tolerance to heat and drought, as well as devastating diseases such as maize lethal necrosis (MLN), could become faster and more cost-effective than ever before. Application of aerial and proximal sensing technology for high-throughput phenotyping, in which large amounts of data are processed simultaneously, provides high-resolution measurements for research plots that can enable the rapid identification of stress tolerant varieties, speeding up the breeding process.

The time and money saved by using these technologies allow researchers to develop and deploy improved varieties more quickly to the smallholder farmers that need them most, which is especially important as climate change begins to change growing environments faster than traditional varieties can adapt.

For Zaman-Allah, this interest in improving agriculture for all is "in the blood," he said. While growing up in Niger, his family had to move to a different city every three years due to his father's job. "Everywhere we moved; my father made sure that we rented or bought a small farm, where I would be involved in crop production every year during the long vacations over the rainy season. That was a wonderful experience as I learned a lot regarding crop production, drought and soil fertility management."

He would take this first-hand experience in agriculture to the next level while earning undergraduate and postgraduate degrees at the University of Carthage in Tunisia and conducting research for his Ph.D. in plant eco-physiology at the French National Institute for Agricultural Research (INRA) through a grant from the French Agency for International Cooperation.

Zaman-Allah joined CIMMYT in late 2012 as a scientist with a specialization in heat and stress resilient maize, based in Harare, Zimbabwe. He has been working as an abiotic stress phenotyping specialist since late 2015, and is considered a pioneer in remote sensing work in CIMMYT maize breeding. In addition to his work as a scientist, he also writes codes for the programs used in proximal sensing.

"As part of my current job, I develop, test and validate low-cost and high-throughput field-based phenotyping tools and methods for different desired traits in crops, including drought, heat and low-nitrogen stress," he said.

"My team is working to provide opportunities toward next-generation phenotyping that is more compatible with maize breeders needs and that will significantly minimize selection cost while maximizing selection efficiency, accelerating the process to deliver maize varieties with better genetic traits to farmers."

Zaman-Allah's commitment to food security extends beyond his job. On his own time, he shares knowledge gained at CIMMYT to inform his contacts at universities and national agricultural research centers in Niger and help increase his home country's capacity to produce healthy crops.

"Maize and wheat are not usually grown in Niger due to heat, drought and low soil fertility, but due to recent advances in CIMMYT technologies and improved varieties, they are now a possibility," he said. "People were doubtful at first, but when improved varieties from CIMMYT Mexico and CIMMYT-Zimbabwe were planted side by side with locally released varieties, there was no comparison—the CIMMYT varieties performed far better."

Working at CIMMYT has given Zaman-Allah a unique opportunity to help farmers while also working with a top-notch international team.

"I really enjoy the teamwork, the innovation and the challenge to make a difference," he said. "It's immensely satisfying to be able to contribute in helping smallholder farmers through my work. Whenever I take vacation, I always go back to the village in Niger where my family is from, and I love to talk with local farmers about the latest agricultural technologies that could help them."

Dagne Wegary at a busy intersection on the maize value chain

by **Mike Listman**

Like many scientists at the International Maize and Wheat Improvement Center (CIMMYT) who grew up in smallholder farm households, Dagne Wegary draws inspiration from recollections of adversity and has found in science a way to make things better.

"I saw how my community struggled with traditional crop and livestock husbandry and, at an early age, started to wonder if there was a science or technology that might ease those hurdles," Wegary said, referring to his childhood in a village in Wollega, a western Ethiopian province bordering South Sudan.

"I chose to study and work in agriculture," Wegary explains. "Even though the farming system in my home village has not changed significantly, I am happy that the community is now among Ethiopia's top maize producers and users of improved seed and other agricultural inputs."

As a maize seed system specialist, Wegary works at the nexus between breeding science and actual delivery of improved seed to farmers. He interacts regularly with diverse experts, including CIMMYT and Ethiopia's breeders and members of the national ministries of agriculture, the Ethiopia Agricultural Transformation Agency(ATA), non-governmental organizations including Sasakawa Global-2000 and World Vision, and especially public, private or community-based seed producers.

Quality seed is farmers' principal means to improve productivity and secure food, according to Wegary, who calls it "the carrier of complementary production technologies, which in combination with improved agronomy can significantly increase crop yields."

"I am most happy with Ethiopia's increased maize productivity and self-sufficiency, which is due partly to the use of improved technologies to which we all contribute," he said, noting that maize grain yields in Ethiopia had more than doubled since the 1990s, reaching 3.7 tons per hectare in 2016, a level second only to that of South Africa, in sub-Saharan Africa.

According to Wegary, these improvements are the result of strong government support for maize research and development, along with the strong partnership between CIMMYT and the national program that has led to the release of high-yielding, stress tolerant and nutritionally-enriched maize varieties. He said that farmers' have also increased their use of improved technologies and that public, private and community-based companies now market seed.

"Supplying seed used to be highly-centralized, but farmers' main sources of seed now are cooperatives that buy from seed companies or companies that market directly to farmers" Wegary explained. "Many companies have their own stockists and dealers who directly interact with farmers."

Before joining CIMMYT, as a scientist with the Ethiopian Institute of Agricultural Research (EIAR), Wegary helped to implement a number of CIMMYT-led projects. "These allowed me to know CIMMYT very well and sparked my interest in joining the Center and working with its high-caliber and exemplary scientists."

A plant breeder by training with a doctoral degree in breeding from the University of the Free State, South Africa, soon after joining CIMMYT Wegary began to contribute to projects to develop and disseminate seed of improved maize varieties with high levels of drought tolerance and enhanced protein quality.

He has been involved since the early 2000s in promoting quality protein maize (QPM). The grain of QPM features enhanced levels of lysine and tryptophan, amino acids that are essential for humans and certain farm animals. Wegary took part in a CIMMYT project that supported the release of five new QPM varieties.

"Many companies are now producing and marketing QPM in Ethiopia," Wegary said. A 2009 study in the science journal *Food Policy* found that eating QPM instead of conventional maize resulted in 12 and 9 percent increases in growth rates for weight and height, respectively, in infants and young children with mild-to-moderate undernutrition and where maize constituted the major staple food.

Wegary believes sub-Saharan Africa's biggest challenges include climate change-induced heat and drought, natural resource depletion, and pest and disease outbreaks, coupled with increasing populations. In combination these factors are significantly reducing food security and the availability of resources.

"I want to be a key player in the battle towards the realization of food and nutritional security, as well as the economic well-being of poor farmers, through sustainable and more productive maize farming systems."

Clare Stirling sees no silver bullets to control agriculture's emissions

by **Mike Listman**

There are no easy fixes nor can business as usual continue, if humankind is to reduce the climate footprint of global agriculture while intensifying farming to meet rising food demands, according to an international scientist who has studied agriculture and climate interactions for nearly three decades.

"Climate change is a threat multiplier, intensifying the challenges of population growth, food insecurity, poverty, and malnutrition," said Clare Stirling, a scientist in the sustainable intensification program of the International Maize and Wheat Improvement Center (CIMMYT). "With almost 60% of global food production coming from rainfed agriculture and more than 650 million people dependent on rainfed farming in Africa alone, our food system is already highly vulnerable to changing climates."

Stirling, who is CIMMYT's liaison with the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), believes that agriculture—including smallholder agriculture—can play a key role in meeting greenhouse gas emission targets, but only with combined and coordinated efforts that cross institutional and disciplinary boundaries.

CIMMYT contributes through a systems approach to developing and promoting climate smart technologies—including drought tolerant maize and wheat varieties, conservation agriculture, and precision nutrient and water management—as well as research on climate services, index-based insurance for farmers whose crops are damaged by bad weather, and data and models for greenhouse gas emissions in India and Mexico.

"Take the case of India, the world's second-largest food producer," Stirling explained. "Mitigation options for crops, of which rice-wheat systems are a major component, include improved water management in rice, more precise use of nitrogen fertilizer, preventing the burning of crop residues and promoting zero or reduced tillage, depending on local conditions and practices. With the right policies and training for farmers, these options could spread quickly to reduce emissions by as much as 130 Megatons of CO2e per year from the crop sector alone. The big challenge is achieving large-scale adoption for significant mitigation to occur."

Science needed for local mitigation targets

Born in Malawi and having spent her early childhood in Zimbabwe, young Stirling also lived a year with her parents and siblings in a house trailer on a farm in Devon, United Kingdom. "Most of my childhood and teen years were spent living in villages, riding horses, and working on farms during school holidays. Out of this came a desire to work in agriculture and overseas."

Stirling obtained a bachelor's degree in plant science and a doctor's degree in environmental crop physiology at Sutton Bonnington, University of Nottingham, U.K., performing fieldwork for the latter at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderbad, India.

As a Ph.D. student at Nottingham, she also joined a research group under the late Professor John Monteith that was quantifying relationships among crop growth, radiation, and water use. The resulting equations underpin many of today's crop simulation models. "My research since has focused on environmental interactions and crop growth, so climate change became an important part of this, starting with an M.Sc. course on the topic that I set up in Essex University in the 1990s."

Among the intractable challenges Stirling sees is soil degradation. "Unless this is addressed, it will be impossible to sustainably intensify or build climate resilience into food systems," she explained. "We must manage limited organic matter and fertilisers better and more efficiently, to achieve healthier soils."

She is also concerned that the climate science to support national and local climate change adaptation planning is much less certain than that which informs long-term global scale targets. "CIMMYT has an invaluable role with its global and strategic research mandate to develop technologies that will raise productivity and resource use efficiency in future, warmer climates," Stirling asserted.

"Local climate predictions are likely to remain uncertain and adapting to current climate variability may not be enough for long-term adaptation in many places, with the surprises that may be in store," Stirling added.

"International organizations such as CIMMYT need to offer stress-tolerant, high-yielding germplasm and sustainable management systems, as well as harnessing big data and digitization, to transform adaptation to deal with future, more extreme climates. Finally, future farmers will need to get the most out of good conditions and good years because, the way things are headed, there may be little hope for coping in bad years."

Read about research by Stirling and colleagues:

"Tek B. Sapkota, Jeetendra P. Aryal, Arun Khatri-Chhetri, Paresh B. Shirsath, Ponraj Arumugam, and Clare M. Stirling. 2017. **Identifying high-yield low-emission pathways for the cereal production in South Asia**. *Mitig Adapt Strateg Glob Change* DOI 10.1007/s11027-017-9752-1.

Francelino Rodrigues on high-tech farming

by **Katie Lutz**

When Francelino Rodrigues started at the International Maize and Wheat Improvement Center (CIMMYT) in 2013, the majority of the maize and wheat trials were still being carried out by walking through the field and taking measurements manually.

Through a collaborative work initiative with colleagues from maize and wheat breeding programs, and with support from senior scientists, Rodrigues brought a whole new world of digital mapping and proximal high-resolution soil sensing to the center's trials thanks to his background in precision agriculture.

Precision agriculture makes use of technologies and farmers' knowledge to determine the quantity, location and time resources need to be applied to grow crops. The information gained allows farmers to farm more sustainably; using less while maintaining and improving yields.

"I first discovered precision agriculture during an agricultural engineering undergraduate in Brazil," explained Rodrigues. "I was fascinated by the idea of joining technology and agriculture, so I ended up going on to complete a master's and a doctorate in precision agriculture applying it to coffee, sugarcane, and cereals crops."

After completing his doctorate with an internship at the Commonwealth Scientific and Industrial Research Organization (CSIRO), an Australian government agency for scientific research, Rodrigues realized the importance of agricultural research for development and took on his post-doctoral position at CIMMYT within the biometrics team in remote sensing and precision agriculture.

"Remote sensing can provide information at different scales and for a range of applications, from crop management to high-throughput phenotyping and landscape assessment," said Rodrigues, whose research focuses on the analysis and interpretation of spatial and temporal agricultural data sets built up by the use of proximal and remote sensing technologies, then seeing how it can be applied across CIMMYT's work.

Remote sensing devices make it possible to observe the dynamics from single plants up to entire landscapes and continents as they change over time by capturing radiation from across the electromagnetic spectrum.

Preparing for radiometric calibration for a multispectral flight over maize Tar Spot Complex disease screening; CIMMYT's station, Agua Fria, Mexico. Photo: CIMMYT archives.

"Precision agriculture and remote sensing technologies are used by CIMMYT to develop tools and practices to help farmers manage their crops more efficiently, to speed up the breeding process by rapidly assessing plant traits and to better characterize agricultural landscapes as a whole," he said.

According to Rodrigues, one of the greatest challenges is making precision agriculture accessible to smallholder farmers who don't have the means to access new and expensive technology. He is currently working on a public-private project using remote sensing data assimilation and crop modeling to build an online platform that farmers can use freely in their fields to make crop management decisions.

"Since I arrived at CIMMYT I have been exposed to a global network of world-class scientists," said Rodrigues. "It encourages me to pursue my passions and allowed me to do what I love; good science that improves lives."

Rodrigues is excited about the long-term impact of CIMMYT's research and positive about the future. "I love to work with a team of scientists from different disciplines and see that knowledge and results we generate contribute to a wider agenda," he said.

Leonard Rusinamhodzi on innovating farming systems for climate change

by **Matthew O'Leary**

Food security is at the heart of Africa's development agenda. However, climate change is threatening the Malabo Commitment to end hunger in the region by 2025, said Leonard Rusinamhodzi, a systems agronomist at the International Maize and Wheat Improvement Center.

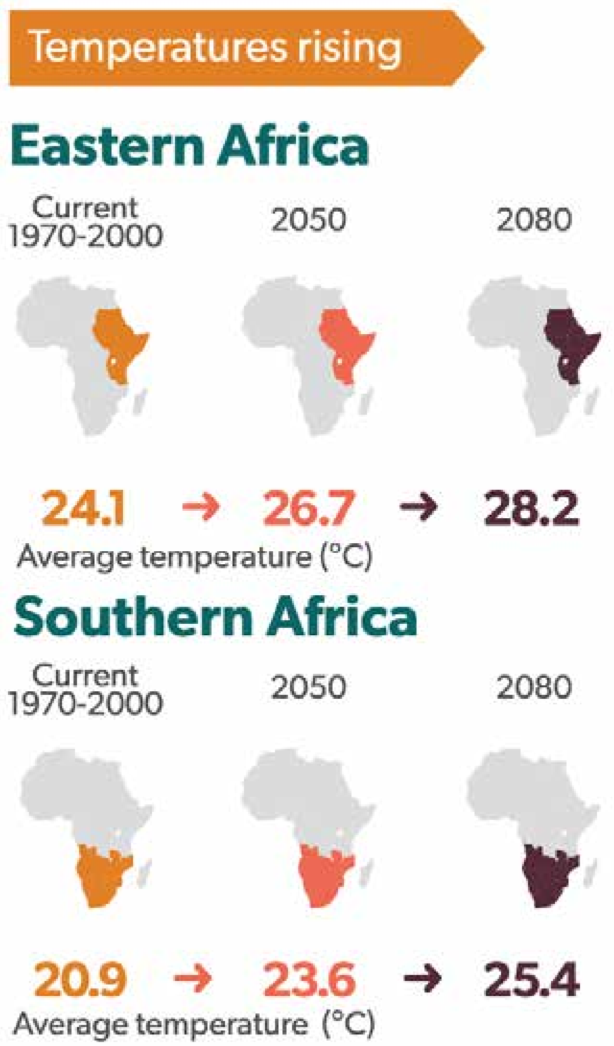
Erratic rainfall and increasing temperatures are already causing crops to fail, threatening African farmers' ability to ensure household food security, he said. Africa is the region most vulnerable to climate variability and change, according to the UN Intergovernmental Panel on Climate Change.

Small-scale family farmers, who provide the majority of food production in Africa, are set to be among the worst affected. Rusinamhodzi's work includes educating African farmers about the impacts of climate change and working with them to tailor sustainable agriculture solutions to increase their food production in the face of increasingly variable weather.

The world's population is projected to reach 9.8 billion by 2050, with 2.1 billion people set to live in sub-Saharan Africa alone. The UN Food and Agriculture Organization estimates farmers will need to increase production by at least 70 percent to meet demand. However, climate change is bringing numerous risks to traditional farming systems challenging the ability to increase production, said Rusinamhodzi.

Rusinamhodzi believes increasing farmers' awareness of climate risks and working with them to implement sustainable solutions is key to ensuring they can buffer climate shocks, such as drought and erratic rainfall.

"The onset of rainfall is starting late and the seasonal dry spells or outright droughts are becoming commonplace," said Rusinamhodzi. "Farmers need more knowledge and resources on altering planting dates and densities, crop varieties and species, fertilizer regimes and crop rotations to sustainably intensify food production."



Data sourced from the UN Intergovernmental Panel on Climate Change. Graphic created by Gerardo Mejia.

Growing up in Zimbabwe – a country that is now experiencing the impacts of climate change first hand – Rusinamhodzi understands the importance of small-scale agriculture and the damage erratic weather can have on household food security.

He studied soil science and agronomy and began his career as a research associate at the International Center for Tropical Agriculture in Zimbabwe learning how to use conservation agriculture as a sustainable entry point to increase food production.

Conservation agriculture is based on the principles of minimal soil disturbance, permanent soil cover and the use of crop rotation to simultaneously maintain and boost yields, increase profits and protect the environment. It improves soil function and quality, which can improve resilience to climate variability.

It is a sustainable intensification practice, which is aimed at enhancing the productivity of labor, land and capital. Sustainable intensification practices offer the potential to simultaneously address a number of pressing development objectives, unlocking agriculture's potential to adapt farming systems to climate change and sustainable manage land, soil, nutrient and water resources, while improving food and nutrition.

Tailoring sustainable agriculture to farmers

Smallholder farming systems in Africa are diverse in character and content, although maize is usually the major crop. Within each system, farmers are also diverse in terms of resources and production processes. Biophysically, conditions – such as soil and rainfall – change significantly within short distances.

Given the varying circumstances, conservation agriculture cannot be promoted as rigid or one-size fits all solution as defined by the three principles, said Rusinamhodzi.

The systems agronomist studied for his doctoral at Wageningen University with a special focus on targeting appropriate crop intensification options to selected farming systems in southern Africa. Now, with CIMMYT he works with African farming communities to adapt conservation agriculture to farmers' specific circumstances to boost their food production.

Rusinamhodzi's focus in the region is to design cropping systems around maize-legume intercropping and conservation agriculture. Intercropping has the added advantage of producing two crops from the same piece of land in a single season; different species such as maize and legumes can increase facilitation and help overcome the negative effects of prolonged dry spells and poor soil quality.

"The key is to understand the farmers, their resources including the biophysical circumstances and their production systems, and assist in adapting conservation agriculture to local needs," he said.

Working with CIMMYT's Sustainable Intensification Program, Rusinamhodzi seeks to understand production constraints and opportunities for increased productivity starting with locally available resources.

Farmer Elphas Chinyanga inspecting his conservation agriculture plots in Zimbabwe. Photo: Peter Lowe/ CIMMYT.

Using crop simulation modeling and experimentation, he estimates how the farming system will perform under different conditions and works to formulate a set of options to help farmers. The options can include agroforestry, intercropping, improved varieties resistant to heat and drought, fertilizers and manures along with the principles of conservation agriculture to obtain the best results.

The models are an innovative way assess the success or trade-off farmers could have when adding new processes to their farming system. However, the application of these tools are still limited due to the large amounts of data needed for calibration and the complexity, he added.

Information gathered is shared with farmers in order to offer researched options on how to sustainably boost their food production under their conditions, Rusinamhodzi said.

"My ultimate goal is to increase farmers' decision space so that they make choices from an informed position," he said.

Rusinamhodzi also trains farmers, national governments, non-profit organizations, seed companies and graduate students on the concepts and application of sustainable intensification including advanced analysis to understand system productivity, soil quality, water and nutrient use efficiency and crop pest and disease dynamics.

Good data management key in fight against food insecurity, says Carolina Rivera

by **Katelyn Roett**

Over the next 50 years, the world's population is set to be more than 9 billion. To feed this amount of people food production will need to more than double.

Doing this will require us to grow food faster than ever before, a global task which will be even more challenging if we don't first improve the way we collect and share information, according to Carolina Rivera, a wheat physiologist at the International Maize and Wheat Improvement Center(CIMMYT) and data coordinator with the International Wheat Yield Partnership(IWYP).

Demand for wheat by 2050 is predicted to increase by 70 percent from today's levels due to population growth and dietary changes, but the challenges to wheat production are stark and growing. The crop is at risk from new and more aggressive pests and diseases, diminishing water resources, limited available land and unstable weather conditions related to climate change.

"The data tells us that we won't meet future demand unless we're able to significantly increase genetic gains," says Rivera. Current annual genetic yield gains of cereals range from 0.5 to 1 percent, meaning that genetic improvements made to crops by scientists are at best resulting in 1 percent higher yields than the previous year, notwithstanding the possibility of improvements due to crop management which are known to be much harder for resource-poor farmers to implement.

Since Rivera started as an IWYP data coordinator, she's helped release a new instance of the public database called "Germinate," which hosts phenotypic, genotypic and other data on wheat collected by CIMMYT staff, IWYP project members, and partners around the world. She seeks to deploy new technologies to capture data and develop better systems to standardize, collect, compile and curate field data gathered by members of her CIMMYT research team and their partners.

"Three years ago, around 80 percent of CIMMYT's wheat physiology field data in Mexico were collected manually," said Rivera. "But now, the use of tablets for data collection, improved protocols for data processing, among other tools allow us to have real-time quality control. By standardizing our results and facilitating data curation and analysis, we help scientists make faster, more informed decisions."

Rivera has a unique perspective in crop data management because she applies her on-the-ground knowledge of wheat research to adopt and adapt new technologies and systems that meet the needs of scientists. As a wheat physiologist, she has identified new traits associated with the optimization of plant morphology aiming to boost grain number and yield.

"Data management can seem like an afterthought to the research, but having more controlled and optimized workflows will become crucial for breeding programs as data volumes increase," says Rivera. "Achieving high-quality data management is a challenge – like with any change in technology, it requires a huge shift in the way people do their job and tools they use."

Despite this, more than 2 billion genotypic data from CIMMYT have been made available in the Germinate and Dataverse platforms, and Rivera believes that data sharing will eventually become part and parcel to the work wheat researchers conduct.

Before starting her current position at CIMMYT, Rivera received her doctorate in crop science from the University of Nottingham. Ultimately, she believes that the adoption of better data management practices across research institutions will soon become a cornerstone in the ability to create "ideal" wheat plants that produce more grains, feeding more people.

Mike Olsen uses new technology to improve farmer's yields

by **Jennifer Johnson**

Global challenges to agriculture such as climate change, crop diseases and pests mean that the International Maize and Wheat Improvement Center (CIMMYT) is constantly working to develop new, improved, resistant varieties for farmers.

However, crop breeding is expensive, time-consuming work, meaning that it takes several years for farmers to get seed solutions to the challenges they are facing today.

Mike Olsen, upstream research coordinator for CIMMYT maize program, works with scientists to use new technologies to increase breeding program efficiency and genetic gain — developing improved maize varieties with the traits smallholder farmers' need, such as disease resistance or drought tolerance, using less time and resources than ever before.

"Our whole team is trying to improve genetic gain for various traits, and to deliver more genetic gain with fewer resources, through the application of phenotyping innovation, genomics and molecular markers for crop improvement," Olsen said. "Our work at CIMMYT assists our breeding teams to be more effective in developing improved products for farmers."

Originally from the United States, Olsen grew up on a small farm in Wisconsin and would go on to study plant breeding and genetics at the University of Minnesota. "During my undergrad years I had the chance to visit South Africa and saw rural poverty for the first time. At the time, I was taking classes in plant biology and genetics and I was inspired by the idea of using agricultural improvement as a method for poverty eradication—it's a big part of why I went into plant breeding," he said. "As a graduate student, I became very interested in the mission of CIMMYT. I was studying at Norman Borlaug's alma mater — working in Borlaug Hall, in fact — which inspired me to pursue a career at a CGIAR center. CIMMYT was a perfect fit that allowed me to do something I've wanted to do since I was 19 years old."

The farmers he has met around the world inspire Olsen to come into work every day. "Knowing that the outcome of our work is providing income and food security to millions of vulnerable people is what's so exciting about what we do. Being able to serve as a conduit for bringing advanced technology for crop improvement for resource poor farmers and consumers is incredible," he said.

Beyond the day-to-day activities of conference calls, travel and airports, the big picture work of what Olsen does is to lead a global team of talented scientists, help with grant writing and project oversight, with a focus on breeding program optimization. "I have been very involved with the Genomics and Open Source Breeding informatics initiative (GOBii), which helps breeding programs efficiently use genetic information, and I'm currently working on a collaboration with DuPont Pioneer on seed production in Africa to deliver higher quality seed to smallholder farmers," Olsen said. "What I most enjoy about my work is the people. I have to be honest, coming to CIMMYT I was moving out of a hands-on science role into working with people, and the collaborative nature of this job has been really energizing for me. I've had the opportunity to mentor some of our talented young scientists into greater leadership roles, and it has been really exciting seeing their professional growth. It's the CIMMYT mission that gets us all out of bed in the morning, but I really enjoy the people I work and collaborate with."

Terry Molnar uses native maize varieties to find novel traits for breeding

by **Laura Strugnell**

Increasingly erratic weather, poor soil health, and resource shortages brought on by climate change are challenging the ability of farmers in developing countries to harvest a surplus to sell or even to grow enough to feed their households. A healthy crop can mean the difference between poverty and prosperity, between hunger and food security.

Terry Molnar, a scientist at the International Maize and Wheat Improvement Center (CIMMYT), is helping farmers face these challenges by using the natural diversity of plants to unlock desirable genetic traits inside food crops.

Working at CIMMYT as a Maize Phenotyping and Breeding Specialist, Molnar studies the traits found in different maize varieties found in the CIMMYT seed collections that can be used to strengthen crops and produce healthy food and better livelihoods.

Growing up in New Mexico, in the United States of America, he had a unique opportunity to work with a conservation group preserving seed from Native American and Hispanic communities of northern New Mexico and southern Colorado.

"Seeing all the diversity there was in the maize, beans, chilies really inspired me to go into genetics and breeding as a career," Molnar said. Following that inspiration, he earned his bachelor degree at Colorado State University and continued his Masters and doctoral studies at North Carolina State University with a focus on plant breeding.

At CIMMYT, he studies native maize varieties called landraces to identify useful traits such as resistance to heat and drought, which can be used to breed new varieties that help farmers produce more food despite mounting challenges.

The high level of native maize diversity is due to its varied geography and culture in Latin America where it originated. As farmers selected the best maize for their specific environments and uses, it diverged into distinct races. At present, there are over 300 recorded unique races of maize in Latin America alone.

Molnar evaluates the landraces varieties in the field for a large set of characteristics, called the phenotype. Additionally, the landraces have been characterized genetically, called the genotype. Using the phenotype and genotype, Molnar can start to unravel the complexity of important traits such as drought and identify sources of resistance.

"Our projects are trait-targeted, so the first step is to make educated guesses as to which of the landraces might be good for that trait. There are over 25,000 maize landraces varieties in the CIMMYT Maize Germplasm Bank and we don't have the infrastructure or money to test them all."

"We try to cast a wide net and evaluate as many landraces as we are able in the field under the conditions of interest. After this initial evaluation, I keep the best ones and start the breeding process," Molnar said.

This involves crossing the landrace to elite maize lines that already have desirable traits like high yield, to develop new lines. The final step is to create hybrids from these new lines and evaluate them in yield trials. After several years of testing, anything that is better than the original lines for the trait of interest will be released to breeders and research scientists.

Climate change predictions suggest that in the coming decades, heat and drought will greatly increase in many important maize growing areas of the world. Molnar works to find tolerance traits for drought and heat within landrace maize plants. As well as becoming a growing problem in the future, drought and heat already affect farmers in any given year, he said.

As part of this work, Molnar also looks for landrace varieties with natural resistance to two prevalent maize diseases, tar spot complex (TSC) and maize lethal necrosis (MLN). TSC is an important disease in the southern half of Mexico, Central America and northern South America, and can decrease yields by 50 percent when it gets into fields early in a growing cycle. Most of the farmers in the affected areas are too poor to afford fungicides, so resistance built into varieties is very important. MLN is a large problem in eastern Africa.

"Like TSC, when MLN gets into fields early in the cycle the results can be devastating, with up to 100 percent potential yield loss," said Molnar. "MLN is spread by insect vectors, and similar to the situation in Latin America, many farmers in east Africa are too poor or don't have access to insecticides."

The last trait Molnar looks for is pigmentation, specifically blue and red kernel color. This is part of an effort to develop new end-use markets in Mexico. Pigments in maize are due to increased concentrations of anthocyanin, an antioxidant, which has been connected to decreased cancer risk. Blue and red maize can be used for specialty food products or for industrial use such as the extraction of natural colors for use in other food products. In both cases, the pigmented maize commands a higher price for the farmer and gives them access to new markets.

Molnar finds great satisfaction in his work, both from the difference he makes in farmers' lives, and from the process of finding the traits in the first place.

"I enjoy being out in the field, looking at maize, meeting and talking to farmers and working with my collaborators," Molnar said. "I'm fascinated by the incredible variety that exists in maize and its ability to grow almost everywhere under most environmental conditions. Before the Europeans came, maize was already growing from Canada to Chile and from sea level to over 3000 meters in altitude and from the humid tropics to bone-dry desert. It's an incredibly adaptable species."

He is motivated by the passion to promote the rich variety of traits found in native maize varieties.

"I'm driven by the doubt of others. A lot of maize breeders working at the private seed companies don't believe it is possible to derive anything commercially useful out of a landrace since modern hybrid maize has been bred for so long and is now so elite. I would like to prove them wrong," he said.

Lorena Gonzalez fast-forwards action on hunger using technology

by **Matthew O'Leary**

Intrigued by the unique relationship our food crops have to their geographical environment, Lorena Gonzalez dedicated her passion for geomatic technology to collect site-specific farm data that is revolutionizing the way researchers and farmers tackle hunger.

Working with the International Maize and Wheat Improvement Center (CIMMYT) as a research assistant, Gonzalez is part of a seismic shift in agriculture, replacing time-consuming manual data collection with technology.

Instead of walking the fields taking measurements by hand, data is collected from a distance through remote sensing. Using cameras on board manned and unmanned aerial vehicles, as well as on ground sensors, Gonzalez gathers information such as plant height, canopy temperature and relative biomass, and evaluates plant health and soil spatial variability in minutes rather than weeks.

Collaborating with farmers and colleagues from maize and wheat breeding programs Gonzalez uses Geographical Information Systems (GIS) to organize and analyze data and patterns related to specific farm locations, making it easier to relate information to growers' specific needs.

"It is important to make sure that data is properly geo-referenced, this way we know exactly how each crop is impacted by the matrix of factors in its environment," said Gonzalez. "Collecting crop management and field data such as fertilization rates, irrigations schemes or soil properties provides us with information to understand and improve plant growth."

The tailored information is used to improve farmers' decision-making, allowing for more precise agriculture to create sustainable farming systems that produce more food with fewer resources, she said.

Gonzalez' love for all things data saw her delve into the world of geospatial science studying her bachelor in Geomatics Engineering in the Mexican state of San Luis Potosi. Her passion for helping farmers achieve food security led her to apply for a job at CIMMYT. Since working with the Sustainable Intensification Program she has developed skills to collect and visualize agricultural data in meaningful ways to inform different stakeholders.

"Farmers, researchers and politicians can make better decisions when we streamline field data using available technology. The path of data from field to farm decision-makers can be streamlined using the available technology creatively and collaboratively, if we dare to build the appropriate systems."

With climate change already affecting crop production, GIS becomes an increasingly important tool farmers can use to adapt and maintain crop yields, Gonzalez said. According to PNAS, each degree Celsius increase in global mean temperature is estimated to reduce the average global yields of wheat and maize by up to seven percent. These crops are key to the survival of humanity, providing a major portion of our caloric intake.

Remote sensing and precision agriculture plays a fundamental role in the ongoing challenge to reduce and cope with the effects of climate change and maximize land efficiency. Using quality data presented in useful ways helps farmers improve decision making, she added.

Gonzalez believes providing open access to geospatial decision support tools will allow smallholder famers to gain the information needed to make site-specific decisions on the exact quantity, location and timely application of resources needed to optimize food production.

If the world is to eliminate world hunger and malnutrition by 2030 as set out in the UN Sustainable Development Goals, smallholder farmers – who produce 80 percent of the world's food – must benefit from access to remote sensing and precision agriculture, she said. Nine out of ten of the world's 570 million farms are managed by families, making the family farm the predominant form of agriculture, and consequently a potentially crucial agent of change in achieving sustainable food security and in eradicating hunger in the future, according to UN reports.

Currently, Gonzalez is collecting data for an innovative private-public partnership, Mexico COMPASS, to help Mexican smallholder farmers increase wheat and sugar cane production by identifying factors that cause the yield gap between crop potential and actual performance.

The project aims to improve crop productivity and smallholder farmer incomes while facilitating rural community economic development. The data collected by Gonzalez in Mexico's Yaqui Valley and in the state of Tabasco contributes to a system that combines earth observation satellite data with captured farm data to create a site-specific decision support tool for farmers. The project will help farmers to make better use of natural resources while monitoring crop health.

Improving smallholder farmer capacity and ability to make informed farming decisions is key to ending hunger and improving livelihoods, said Gonzalez.

A UAV is launched to collect data from a field in CIMMYT's experiment station in Ciudad Obregón, Mexico. Photo: CIMMYT/ Peter Lowe.

Wei Xiong helps farmers and policymakers make better decisions

by **Rachel Cramer**

Farmers and agricultural policymakers frequently encounter tough decisions with complex trade-offs. Selecting which crop to plant next season, for example, would be much easier with a crystal ball. Wei Xiong, a senior scientist at the International Maize and Wheat Improvement Center(CIMMYT), cannot look into the future, but he can remove a lot of the guesswork.

Xiong uses modeling tools to simulate how agricultural systems would respond to different policies, technological innovations and climate change.

"With these simulations, we can show farmers and policymakers different hypothetical outcomes," said Xiong. "We can help them make better, more informed decisions."

Xiong and his multi-disciplinary team are interested in looking at new angles of agricultural issues. For one project, Xiong is investigating how climate change could affect global beer prices. He and his team are studying the effects of increasingly frequent extreme weather events, such as drought, on global barley yields and how this could affect beer production and prices.

"We call the project drinking security," added Xiong.

Xiong is also interested in the impacts of air pollution on agricultural production and livelihoods in India and China.

"We want to know if air pollution affects yields and whether policies to curb air pollution will have any impact on farmer incomes, food prices and international trade," he said.

Xiong collaborates with a team of Chinese agricultural scientists and local extension officers on a program called Size & Technology Backyard. The program aims to increase farmers' yields while decreasing agricultural pollution in the water, air and soil. During each growing season, agricultural students stay in villages to conduct surveys and field research with farmers.

"Based on that data, we can create an agricultural modeling system that incorporates everything from the crop physiology side, to the socioeconomic side and human dimension side," said Xiong. "We can project which farmers are most likely to adopt which specific kinds of technology based on everything from their location to their family structure."

But in China, Xiong explained, agriculture still falls under government control.

"The government has always decided which crop you should plant, which area you should use and how to use the areas," said Xiong. "Most of the policies are based on suggestions by experts."

The team will use their simulation models to recommend policies that benefit farmers and the environment.

Xiong effectively links many silos through his work at CIMMYT, in large part due to his diverse educational background. After receiving a bachelor's degree in geography at Hubei University, he continued with a master's degree in meteorology from the Chinese Academy of Agricultural Sciences (CAAS) in Beijing. He later went on to earn a doctorate in agronomy from China Agricultural University.

After ten years as a professor at CAAS, Xiong worked at the International Institute for Applied Systems Analysiswhere he designed large-scale simulations of crop production and the effects of global policy. In 2014, he collaborated with other researchers on a global agriculture systems modeling project through a position at the University of Florida. Last fall, Xiong joined CIMMYT at its headquarters in El Batán, Mexico, working on sustainable intensification.

Xiong will return to China later this year to help establish a new CIMMYT office in Henan and strengthen CIMMYT's partnership with Henan Agricultural University. The new location will focus on research and training, and will host two international senior scientists with expertise in remoting sensing, informatics, physiology and crop management.

Bhoja Basnet sets sights on increasing wheat yield potential through hybrid seeds

by **Katie Lutz**

Bhoja Raj Basnet joined CIMMYT as a postdoctoral fellow working in the bread wheat improvement program in 2012. Photo: A. Cortes/CIMMYT.

Scientist Bhoja Raj Basnet knows first hand what it is like to be a smallholder farmer.

Basnet's earliest memories were formed on a one-acre subsistence farm in Jhapa, in southeastern Nepal, a fertile area in a country where the livelihoods of nearly 65 percent of people depend on agriculture.

The tiny farm provided the foundation for a journey that led ultimately to a doctoral degree in the United States and a career as a wheat breeder in Mexico at the International Maize and Wheat Improvement Center (CIMMYT).

Wheat plays a major role in Nepal's agricultural landscape. It is the country's third largest crop, cultivated on about 750,000 hectares of arable land each year with an average yield of 2.5 tons per hectare. Above wheat, farmers favor only rice and maize.

"I grew up playing with the plants and soil on my family's farm and before I entered high school I knew I wanted to pursue a career in agricultural science." Basnet explained. "As I got older I started to realize the importance of agriculture and how agriculture can really shape a child's health and future. This is what really pushed me to pursue my career."

Basnet went on to earn his master and doctoral degrees in plant breeding. After graduation in 2012 from Texas A&M University, Basnet joined CIMMYT as a postdoctoral fellow working in the bread wheat improvement program.

In 2014, Basnet began leading a project conducting research into hybrid wheat in collaboration with Syngenta, which involves researching and developing tools and technology for developing commercially viable hybrid CIMMYT wheat varieties.

Hybrid wheat is created when a breeder intentionally crosses two genetically distinct and stable wheat lines to produce an offspring that combines the best traits of the parents. The process of developing a hybrid can take years, as traits are carefully chosen to achieve desired characteristics, such as increased grain yield or stress tolerance.

The principle behind hybrid varieties is exploitation of heterosis, the superiority of the hybrid offspring over its parent varieties. This is a biological phenomenon observed in almost all living organisms. However, the magnitude of "heterosis" varies significantly based on several biological and environmental factors.

"Hybrid wheat has always fascinated me," Basnet said, adding, "I really want to see the end results and to see this work succeed."

Hybrid wheat varieties have proven to be tricky. In fact, CIMMYT's first attempt to develop hybrid wheat occurred in the 1960s and despite stops and starts over the years, has been ongoing since 2010.

Increasing investment and long-term funding commitments are a key prerequisite to achieving success in crop improvement, especially in breeding, Basnet said. Unlike traditional wheat variety development, successful research into hybrid wheat varieties depends largely on the willingness and active engagement of private sectors into research and seed businesses.

Basnet is working to develop a hybrid wheat foundation at CIMMYT by using new technology and existing research on hybrids. This hybrid wheat foundation will create genetic diversity within wheat to increase genetic gains and develop tools that can produce large amounts of hybrid seed.

"Currently less than one percent of wheat crops globally are hybrid wheat," Basnet explained. "We need to continue with this research, as hybrid crops could lead to 15 to 20 percent greater yield potential and in particular higher stability, a very important trait with climate change."

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