Precision ag
in the
developing world

by Madeline Fisher

With its emphasis on applying inputs in the right amounts and at the right times and places, precision farming seems like a natural fix to the problems facing the developing world's farmers. While developing nations consume 60 to 70% of the world's fertilizers, farmers in these countries often don't know the exact nutrient status of their lands. Global nitrogen use efficiency hovers around 40%, and water use desperately needs optimization, as well, especially in places like India where drought is threatening to expand. Most importantly, many countries struggle with low, stagnating, or declining crop yields, something that precision farming techniques promise to boost.

Yet, what seems clear-cut in theory can be remarkably tricky in reality, as Colorado State University professor and ASA and SSSA Fellow Raj Khosla began realizing about five years ago. Tapped to chair the International Conference on Precision Agriculture in 2006, Khosla suddenly found himself on the radar of people the world over, all asking the same question: How do I make these practices work in my country? At first, "that really puzzled me, that really made me think," Khosla admits, and for good reason. Precision farming in the United States, Europe, and Australia is conducted in fields that are tens to hundreds of acres in size, whereas farms in China, India, and Africa are often 5 acres or less. Moreover, conventional precision practices involve mechanization, big equipment, and sophisticated technology—tools that are way beyond the reach of smallholder farmers.

Nevertheless, precision agriculture research is expanding in the developing world today, thanks to pioneering work at places such as the International Rice Research Institute (IRRI), as well as scientists like Khosla, who have joined the international effort more recently. The first symposium of the new ASA Precision Agriculture Systems Community, held at last year's ASA, CSSA, and SSSA Annual Meetings in San Antonio, included several talks with a global focus. A few years earlier, Khosla helped launch the International Society of Precision Agriculture to advance the emerging science. And his own research collaborations in Colorado, China, and India have convinced him not only that "precision agriculture can be practiced on most fields, most farms, and most places on this planet," he says, but that it can also deliver on its promise to improve profitability, increase yields, and foster food security worldwide.

"I'm not proposing that precision ag is the *only* solution," Khosla said in a talk at the Annual Meetings last fall. "But I'm a strong believer that it's part of the solution."

Other scientists are less sure. But even those who agree know that bringing these techniques to the world's poorest, least developed regions means taking an uncertain path. "You have to completely reset your thinking about what precision agriculture is on a farm," says Bruce Erickson, a Purdue University precision farming expert and ASA's agronomic education manager.

Relatively New Concept

With the concept now finding its way around the globe, it's easy to forget that precision agriculture is still relatively new even in the United States. Its modern practice in fact began only in the 1990s, when global positioning systems (GPS) first became available for civilian use. Once this happened, GPS technologies for farm equipment quickly emerged, allowing farmers to map their fields in great detail and apply inputs in precise amounts and locations using variable-rate technology (VRT). Soon afterward, yield monitors linked to GPS began revealing the vast variability within farm fields while light bars and autoguidance helped farmers steer their equipment more precisely—and thereby minimize overlapping applications of expensive seed, fertilizers, and pesticides. Most recently, sensors have been developed to quickly assess the nutrient levels in soils and plants.

Thanks to all these high-tech advances, precision agriculture has become synonymous with modern technology and large operations in many people's minds, but the basic principles are actually independent of both technology and scale, and they go back decades, Khosla says. What precision agriculture is truly about

Image, left: Precision planting of potato seedlings in Punjab India. *Photo courtesy of Dr. Manjit S. Kang.*

is simply site-specific farming—the idea that natural variability in soils, microclimates, plants, and other factors will respond better to customized, location-specific management practices than to approaches that treat every part of a field the same. And by tailoring inputs of fertilizers, chemicals, and water to the specific conditions within their fields, producers can cut costs, improve profitability, and boost yields.

Researchers working in developing countries have focused on this broader concept of precision farming for an important reason: When farmers are illiterate, lack capital, and cultivate fields of just 1 to 2 acres by hand, the wholesale transfer of North American precision technologies won't succeed, says Purdue University agricultural economist Jess Lowenberg-DeBoer. In Niger, West Africa, for example, where Lowenberg-DeBoer has worked extensively, the most advanced farmers "were the ones who were using bullocks or donkeys rather than doing everything by hand," he says. "And how do you put a GPS on your bullock?"

Adapting Technologies to Local Conditions

At the same time, technology is a crucial part of the solution; after all, advances like GPS are what made precision farming practical for farmers in the first place, says ASA and SSSA Fellow Newell Kitchen, a USDA-ARS soil scientist in Columbia, MO and past president of ASA. The point therefore is not to dismiss existing technologies completely, but to adapt them to the agricultural practices, economic conditions, and culture of each country. "With the technology at hand, we tend to ask, 'Well, what can we do with this?'" Kitchen says. "So, it becomes very exploratory."

Farmers in Africa and most of Asia, for example, usually lack even the most basic information about the fertility of their fields. But pulling soil cores and sending them to a laboratory for analysis isn't an option because lab facilities don't exist. One solution to the problem, says Lowenberg-DeBoer, would be to outfit local agro-dealers or extension offices with battery-operated, table-top soil testers, to which farmers could bring a composite soil sample and get a sheet of simple nutrient recommendations in return. Another would be to make use of field sensors, such as those that measure plant chlorophyll (or a related parameter) to estimate nitrogen status.

Work by Kitchen and others has shown that when tractor-mounted chlorophyll sensors are used to guide applications of nitrogen during the growing season, nitrogen use efficiency can increase by up to 60%. The drawback is the sensors' price: At $10,000 or more, they may not return enough to make the investment worth it, even for some U.S. producers. So a few years ago, researchers at Oklahoma State University set out to make a more affordable version. The handheld device they came up with, called the Pocket Sensor, has only an operating button, a display window for the readings, and two leveling tools—a length of string and a bubble level—for keeping the sensor at the right height and angle above the crop. Its use is equally simple. Operators

hold the sensor over a row of plants and take readings as they walk along.

The design may be minimal, but the Pocket Sensor seems to perform as well as more expensive technology. Working in Mexico with CIMMYT researchers in 2010 and 2011, Oklahoma State University plant and soil science graduate student Jared Crain found high correlations between measurements taken with the Pocket Sensor and a commercial sensor, the GreenSeeker, in both wheat and corn. The findings bode well for the group's ultimate goal, which is getting the technology into the hands of people worldwide to improve nitrogen use efficiency. After identifying field locations where the soil or vegetation simply looked different, for instance, a smallholder farmer could take sensor readings in each zone and then make a map showing where to add nitrogen in low, medium, and high amounts. If this doesn't sound terribly precise, it's definitely a step up from what many farmers do now, Kitchen says, which is to fling fertilizer indiscriminately across their fields.

Precision Leveling: Boosting Yields, Saving Water

Khosla, meanwhile, has been working with researchers in India on both water and nutrient use efficiency. Many farm fields across the country are flood-irrigated, he explains; when irrigation water becomes available in canals, farmers simply open the flood gates and let water course across the land. The fields are so undulating and uneven, however, that certain areas become waterlogged while others drain too quickly, leading in both cases to wasted water and nutrients and reduced grain yields. Hypothesizing that precision farming techniques might improve the situation, Khosla and scientists from CIMMYT and IRRI carried out a study at an experimental farm on the Indo-Gangetic Plains of India, where irrigation and other demands are currently depleting groundwater by 13 to 17 km^3 a year.

The method they turned to was precision laser leveling. In the approach, a laser beam is shot across a field, giving farmers a stable reference point to go by as they level out bumps and valleys in the ground. In their study, published in the *American Journal of Plant Sciences* last October, laser leveling combined with another technique for boosting water use efficiency, raised-bed planting, produced an average of 17% more grain than traditional farming practices. What's more, the new practices led to a 50% savings in irrigation water, with laser leveling alone cutting water use by one third. That's because by distributing water more evenly, the practice brings about good seedling germination and crop development, even with less irrigation overall.

So pleased was Khosla with the results that he subsequently persuaded his collaborators at the Delhi-based company Tata Chemicals to carry out an on-farm study with two goals: to repeat the findings and demonstrate

Top left image: Courtesy of the International Rice Research Institute. **Center image:** Originally submitted with the *Agronomy Journal* article, "Calibrating the Leaf Color Chart for Nitrogen Management in Different Genotypes of Rice and Wheat in a Systems Perspective," by Shuklaa et al. (Agron. J. 96:1606–1621). **Top right image:** Data collection with the Pocket Sensor in corn and wheat in Mexico. *Photo courtesy of Jared Crain, Oklahoma State University.*

Leveraging Cell Phone Technology

Most of the developing world's farmers may not own yield monitors or GPS systems, but what they do often have in spades are cell phones. In Africa, for example, "it's surprising," says Jess Lowenberg-DeBoer, a Purdue University agricultural economist with ties to Niger, West Africa. "People who you think don't have enough to eat have cell phones."

As a result, agricultural scientists and public health officials alike have been brainstorming ways to leverage the technology; for instance, to warn farmers about swarming locusts or approaching storms or to collect health information from people in remote areas. But in one region, at least, ideas like these are now becoming tangible solutions, thanks to work by the Philippines-based International Rice Research Institute (IRRI).

For more than a decade, a team led by IRRI deputy director general for research and ASA and SSSA Fellow Achim Dobermann has been studying ways to bring precision agriculture techniques to small rice farms in Asia, where 90% of the world's rice crop is grown. The solution they devised and tested widely is called site-specific nutrient management (SSNM), a simple form of precision farming that matches nitrogen applications to local field conditions and balances them with inputs of phosphorus and potassium. In several studies, Dobermann and his colleagues demonstrated SSNM's capacity to boost yields, nutrient use efficiency, and profits. Then the next hurdle arose: Bringing SSNM to Asian smallholder farmers.

Photo courtesy of the International Rice Research Institute.

Speaking at the ASA, CSSA, and SSSA Annual Meetings in San Antonio last fall, IRRI senior scientist and ASA and SSSA Fellow Roland Buresh described how the group first tried to disseminate SSNM recommendations in print form. But the materials quickly grew too complex, due to the vast diversity in farm practices and conditions that needed to be accounted for. So, three years ago, the team began developing a software program that asks farmers roughly a dozen questions, makes some calculations, and then delivers tailored nutrient management advice. After distributing it on CD for a time, they began offering the program via the web, smart phone, and regular cell phone.

Filipino farmers can access it with a simple cell phone, for example, by calling a toll free number that connects them to an interactive voice response system provided by a Philippines telecomm company. After they push the appropriate keypad buttons to answer questions about their farm practices—the rice variety they plant, how they manage crop residues—the information travels to a cloud-based server. The SSNM calculations are then performed, and the recommendations travel back as a text message within minutes.

The system is now operating across the Philippines and should be running soon in Indonesia, Bangladesh, parts of India and China, and even West Africa. In the meantime, the team is already taking the next step—building a broader "crop manager" system that will not only give nutrient recommendations, but also advice on land preparation, weed control, and other management topics, as well as access to credit, insurance, and other financial services.

"We started with fertilizers because fertilizers represent about 20% of the input costs for rice farmers," Buresh said. "But rice farmers need more than just fertilizer advice."

a model for offering ag services to Indian farmers. In 2011, the company worked with a wheat grower in northwestern Uttar Pradesh to laser-level his fields, perform balanced fertilization based on a few soil tests, and schedule irrigation at the right times. Before these interventions, the farmer averaged 0.8 tons per acre, reports Khosla; afterward, his yield jumped by nearly 200% to 2.25 tons per acre. “The farmer got so excited that he applied for a micro-loan, bought his own precision-leveler, and he started offering precision leveling as a service,” Khosla says.

Large-Farm Technologies Will Still Play an Important Role

It’s an encouraging outcome, and even more encouraging is how other precision farming techniques are now reaching significant numbers of smallholder farmers across Asia (see sidebar opposite page). Still, if these practices are truly going to help feed the world, the large, mechanized farms that also exist in some developing nations can’t be ignored, cautions Erickson. In Brazil and Argentina, for example, farms can far exceed North American size, creating economies of scale that make purchasing big equipment and sophisticated technology both feasible and profitable. Yield mapping, for example—which requires installing both GPS systems and yield monitors on combines—is quite popular with some farmers in these countries, Erickson says. Because labor is so cheap, he explains, the land-owning “farmer” is often not the one who works the land, and thus relies heavily on data to track farm conditions and output.

“So, precision farming applications will come a lot quicker on these bigger, more mechanized farms,” Erickson says. “There’s just a more natural fit, and there’s still quite a bit of room to grow, even now.”

Wherever precision farming takes root, it will need all the usual supports to flourish: networks of ag retailers and service providers, education and training opportunities, industry backing, and money. But the more immediate need, say scientists like Khosla, is more people who are willing to engage in what can admittedly be a challenging research effort. And even when a technology proves valuable, an often forgotten piece is integrating it into the existing farming methods and ways of doing business of various countries. “It takes people to implement new farming practices,” Erickson says.

Recognizing Variability on Smallholder Farms

On a more basic level, many scientists remain skeptical that enough variability exists in small fields to try precision agriculture in the first place, Khosla says. Data is quickly mounting, though, that show otherwise. In a study in China that Khosla took part in, for example, winter wheat yields ranged from less than 0.8 tons per acre to more than 2, even though farm fields were just 3.5 to 17 acres in size. Kitchen has witnessed the same thing in Korea. “Some of the results I’ve seen suggest that the range of variability in rice yields in their small fields is not too unlike the range we have in our grain crop yields here in the U.S.,” he says, “even though our fields are on the order of 50 to 100 times larger.”

Getting smallholder farmers to recognize this variability is key not only to helping them achieve better yields and profitability, he adds, but to become better stewards of the environment, as well. As things stand now, the world’s two biggest users of fertilizers—farmers in India and China—have little way of knowing where and when they’ve met a crop’s needs or where and when excess fertilizers are spilling into the environment.

“So, that’s the name of the game here,” Kitchen says. “It’s recognizing that the variability that exists on the surface of the globe is oftentimes just as great within one field as it is between fields that are hundreds of miles apart. And that knowledge of how this variability lays in the landscape is extremely valuable for best managing the landscape.”

M. Fisher, lead writer for CSA News *magazine*

Above image: courtesy of the USDA-NRCS.