The Precision Agriculture Revolution

Making the Modern Farmer

By Jess Lowenberg-DeBoer

Thousands of years ago, agriculture began as a highly site-specific activity. The first farmers were gardeners who nurtured individual plants, and they sought out the microclimates and patches of soil that favored those plants. But as farmers acquired scientific knowledge and mechanical expertise, they enlarged their plots, using standardized approaches—plowing the soil, spreading animal manure as fertilizer, rotating the crops from year to year—to boost crop yields. Over the years, they developed better methods of preparing the soil and protecting plants from insects and, eventually, machines to reduce the labor required. Starting in the nineteenth century, scientists invented chemical pesticides and used newly discovered genetic principles to select for more productive plants. Even though these methods maximized overall productivity, they led some areas within fields to underperform. Nonetheless, yields rose to once-unimaginable levels: for some crops, they increased tenfold from the nineteenth century to the present.

Today, however, the trend toward ever more uniform practices is starting to reverse, thanks to what is known as "precision agriculture." Taking advantage of information technology, farmers can now collect precise data about their fields and use that knowledge to customize how they cultivate each square foot.
One effect is on yields: precision agriculture allows farmers to extract as much value as possible from every seed. That should help feed a global population that the UN projects will reach 9.6 billion by 2050. Precision agriculture also holds the promise of minimizing the environmental impact of farming, since it reduces waste and uses less energy. And its effects extend well beyond the production of annual crops such as wheat and corn, with the potential to revolutionize the way humans monitor and manage vineyards, orchards, livestock, and forests. Someday, it could even allow farmers to depend on robots to evaluate, fertilize, and water each individual plant—thus eliminating the drudgery that has characterized agriculture since its invention.

ACRE BY ACRE

The U.S. government laid the original foundations for precision agriculture in 1983, when it announced the opening up of the Global Positioning System (GPS), a satellite-based navigation program developed by the U.S. military, for civilian use. Soon after, companies began developing what is known as "variable rate technology," which allows farmers to apply fertilizers at different rates throughout a field. After measuring and mapping such characteristics as acidity level and phosphorous and potassium content, farmers match the quantity of fertilizer to the need. For the most part, even today, fields are tested manually, with individual farmers or employees collecting samples at predetermined points, packing the samples into bags, and sending them to a lab for analysis. Then, an agronomist creates a corresponding map of recommended fertilizers for each area designed to optimize production. After that, a GPS-linked fertilizer spreader applies the selected amount of nutrients in each location.

Over 60 percent of U.S. agricultural-input dealers offer some kind of variable-rate-technology services, but data from the U.S. Department of Agriculture indicate that in spite of years of subsidies and educational efforts, less than 20 percent of corn acreage is managed using the technology. At the moment, a key constraint is economic. Because manual soil testing is expensive, the farmers and agribusinesses that do use variable rate technology tend to employ sparse sampling strategies. Most farmers in the United States, for example, collect one sample for every two and a half acres; in Brazil, the figure is often just one sample for every 12 and a half acres. The problem, however, is that soil can often vary greatly within a single acre, and agricultural scientists agree that several tests per acre are often required to capture the differences. In other words, because of the high cost of gathering soil information, farmers are leaving productivity gains on the table in some areas of the field and overapplying fertilizer and other inputs in others.

Researchers are beginning to tackle the problem, developing cheap sensors that could allow farmers to increase their sampling density. For example, one new acidity sensor plunges an electrode into the soil every few feet to take a reading and records the GPS coordinates; manually sampling on that scale would be far too costly. Such sensors have not yet arrived at most farms, however. Some haven't proved reliable enough, breaking after a few acres of use, whereas others aren't accurate enough. But several research groups around the world are working on developing sturdier ones.

More practical are sensors that look at the color of plants to determine their nutritional needs. Plants with too little nitrogen, for example, tend to turn pale green or yellow, whereas those with enough appear dark green. Several U.S. and European companies have developed sensors that detect greenness, generating measurements that can be used to generate a map recommending various amounts of nitrogen to be applied later. Alternatively, the measurements can be linked directly to the nitrogen applicator to change the application rate on the go. A tractor may have a sensor mounted on the front and an applicator on the back; by the time the applicator reaches a point that the sensor has just passed, an algorithm has converted the readings into settings for how much fertilizer to apply. Because research in this area has focused mainly on small grains, such as wheat, barley, rye, and oats, the technology is mostly limited to the parts of the United States and

Europe that grow those crops. According to a 2013 survey by Purdue University, only seven percent of agricultural-input dealers offer plant-color sensors. Given the number of start-ups in this area, however, it is clear that many investors see the technology as a potential gold mine.

FIELDS AND YIELDS

The government's GPS decision also enabled another revolutionary technology to emerge: yield monitoring. Most harvesters in the United States and Europe are outfitted with special sensors that measure the flow rate of grain coming in. An algorithm specific to the crop then converts the resulting data into a commonly used volume or weight, such as bushels per acre or kilograms per hectare. That information is then turned into colorful maps that show the variation within fields.

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These maps have become a staple of farming magazines and trade shows, and for good reason: they have given farmers unprecedented insight into the effects of various production techniques, weather conditions, and soil types. Such a map can help a farmer arrive at yield numbers for the purpose of insurance or government programs, measure the results of experiments that test the qualities of genetically modified crops or the effectiveness of various cultivation practices, and reveal which parts of a field aren't living up to their potential. In the eastern United States, it was only through yield monitoring that farmers were able to convince landlords that flood-related crop losses were not limited to completely submerged parts of the field; they also extended to a ring around those spots. In response, farmers installed more subsurface drainage systems. In Argentina, the technology has taken off because most managers of large farms there, unlike their U.S. counterparts, rarely operate vehicles themselves (a consequence of the peculiar history of landownership there). For them, yield maps offered on-the-ground insight into productivity they couldn't otherwise get.

When it comes to the quality of the data, however, yield-monitoring technology still has a long way to go. In most cases, the algorithms that convert data about flow into volume or weight measurements must be calibrated annually for each crop and farm, and many farmers don't bother to do so. The data can also be affected by how fast a harvester is driven and other idiosyncrasies. And although research studies can rigorously analyze data from yield monitoring, farms and agribusinesses typically lack the necessary statistical skills and software. The next step in yield monitoring is for agribusinesses to adopt the statistical techniques now used mainly by researchers; since their findings would be spread across millions of acres, they should be able to justify the cost.

PLOW BY WIRE

The most common use of precision-agriculture technology is for guiding tractors with GPS. Manually steering farm equipment requires skilled operators and is a tiring endeavor. And even the best drivers often overlap their passes by as much as ten percent to avoid skipping parts of the ground. The late 1990s saw the introduction of LED light bars, each a series of LED lights in a foot-long plastic case that is mounted in front of the operator of a tractor, harvester, or other vehicle. If the lights in the center are lit up, then the equipment is on track. If those on the left or the right are illuminated, then the driver needs to correct the steering.

Someday, farms might be filled with hundreds of small autonomous robots.

Increasingly, farmers are taking this technology to its next logical step, replacing the light bars with automatic guidance systems that link GPS data directly to a vehicle's steering mechanism. Although an operator still needs to sit on the equipment, for the most part, it can be driven hands-free. The technology first gained widespread use in the 1990s in Australia, where clay-rich soils—plus a lack of freezing and thawing—make fields particularly vulnerable to compaction from wheeled vehicles. Australian farms used GPS automated guidance to concentrate equipment traffic on narrow paths, preventing the rest of the soil from getting compacted. Today, about 40 percent of fertilizer and other agricultural chemicals are applied with automated guidance in the United States.

Such systems have led to numerous spinoffs. One category is mechanisms that track the path of a tractor and automatically shut off its seed-planting and chemical-spraying functions when it passes over parts of the field that have already been covered or are environmentally sensitive. The technology is especially useful for irregularly shaped fields, which are vulnerable to overplanting and overspraying.

Geospatial data aren't just for plowing straight lines, however. For decades, NASA and some of its foreign counterparts have encouraged farmers to use their satellite imagery. Along with aerial photography, these images form the basis for "geographic information systems," which enable farmers to store and analyze spatial data. The technology has proved particularly useful in areas where multiyear data are available, since it allows growers to divide large fields into zones that receive different seeds, fertilizers, and herbicides.

Some managers of farms are even using GPS to keep an eye on their employees in the field, especially in the former Soviet Union and particularly in Ukraine. Since the biggest farms there—many of which cover over 100,000 acres—tend to rely on hired staff and not owner-operators, farm managers like to track all field operations in real time. If a tractor stops for more than a few minutes, for example, the head office will notice and can call the driver to inquire about the problem. The tracking technology also allows managers to crack down on employees who use company machines on their own farms.

YIELD OF DREAMS

Precision agriculture has already turned one of the oldest sectors into one of the most high-tech, but the best is yet to come. The next step likely involves "big data." Farmers and agribusinesses are increasingly considering how to best take advantage of their treasure troves of data to boost profits and make agriculture more sustainable. In 2013, for example, the agriculture giant Monsanto acquired the Climate Corporation, a start-up founded by two Google alumni to use weather and soil data to create insurance plans for farmers and generate recommendations for which crop varietals are best suited to a particular plot of land. Another low-hanging fruit for big data is research on how to use equipment. For example, it's not clear how fast a tractor should be driven when planting corn: too slow makes for an inefficient process, but too fast results in uneven planting, which hurts yields. After collecting data on the tractor's speed, the eventual yield of the crop, and other factors, however, one could determine the optimal speed for planting.

In order to harness big data's power, companies will probably have to pool information across farms. In the United States and Europe, individual farms are too small to generate a meaningful quantity of data, and even the very large farms in Latin America and the former Soviet Union would benefit from combining data with their neighbors. The problem, at the moment, is that farmers have little incentive to collect quality data. In the United States, some start-ups have tried to pay farmers for data, without much success. So far, it is the agricultural-input suppliers and agricultural cooperatives that have been able to collect the most data. But even their data sets are relatively small.

Some of that big data may come from drones. With the United States largely out of Afghanistan and Iraq, some suppliers of military hardware have turned their attention to the agricultural market. The move might be smart: small, unmanned aircraft can capture regular images of crops to guide irrigation, pesticide application, and harvesting. And unlike satellites, drones are largely unaffected by cloud cover. Given the operating expense and expertise required, drones will most likely be used commercially at first only for high-value crops, such as wine grapes. And in the United States, the Federal Aviation Administration will first have to open up the skies to commercial drones.

The technology that would truly transform agriculture as we know it is robotics. The rapid adoption of GPS guidance has opened the door to more autonomous farm equipment, and most major manufacturers have already tested driverless versions of their tractors. Once the driver is removed from the picture, the design criteria for a piece of equipment change radically: it can become far smaller. It's possible to imagine farms someday filled with hundreds of small autonomous robots, doing everything from planting to harvesting. Robots could scout fields continuously and identify pest and disease problems at the earliest possible stages. They could apply pesticides in tiny doses, targeting individual insects or diseased plants. They could efficiently manage small and oddly shaped fields, such as those common in the eastern United States, which are hard to farm profitably with conventional equipment driven by humans. In the United States, by reducing the need for Mexican laborers, robots might even affect immigration policy.

When it comes to emerging technologies, it is a fool's errand to pick winners. But the history of farming in the twentieth century offers some clues to its future. Almost all the agricultural technologies that were widely adopted in the twentieth century were characterized by what economists call "embodied knowledge," meaning that the scientific advancements were contained within them. Farmers didn't have to know how pesticides killed insects or how a gasoline tractor worked; they just needed to know how to spray the chemical or drive the vehicle.

Likewise, the tools of precision agriculture will gain widespread use only once they are sold in easy-to-use forms. That's why GPS guidance has become so widespread: farmers don't need to understand it to use it. And so variable rate technology for fertilizer, to take one example, will take off the day a farmer can trigger it with the mere push of a button. Eventually, precision agriculture could take humans out of the loop entirely. Once that happens, the world won't just see huge gains in productivity. It will see a fundamental shift in the history of agriculture: farming without farmers.