Science & Technology

From the Dust Bowl to Drones to Big Data

The Next Revolution in Agriculture

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In the face of a global population approaching 7.5 billion people, the agricultural sector faces two major challenges—producing enough food to feed every person, and protecting the environment that it, and everybody else, desperately relies on. There is an unbalanced equation in which agricultural production plus usable land should equal the needs of a growing population; unfortunately for agricultural production, the amount of usable land is inversely proportional to the growing population. The current agricultural system needs to adapt and become more efficient on less farmland, and under climate change threats, in order to feed a growing population. Farmers must consider their personal ability, financial stake, and a myriad of environmental considerations before leaping into a new practice or adopting innovative technology. This article aims to describe the critical role of technologies in the production of more food when there is less water and land available. First, we present the changes that have occurred to agriculture over the last century. Second, we illustrate how precision agriculture technologies can help farmers and policymakers address the challenges that agricultural systems face in both the United States and other parts of the world. We conclude the article with insights and future perspectives on how farmers can adopt these technologies to increase their profit and reduce the environmental footprint of agricultural systems.

The Role of Agriculture in Feeding a Hungry and Crowded Planet

Large-scale agriculture cultivates much of the world's food, even though it is often criticized for its environmental footprint. We are far removed from the age of subsistence farming, and that shift has meant an ever-changing landscape of agricultural practices. With a continuously growing population, it is no surprise that farmers are perceived to have little responsibility for driving consumption habits and economic trends. In fact, it should be quite the opposite—be-

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cause the world could not prosper without a strong agricultural base, the practices and advancement of the agricultural sector are some of the most important facets for society to consider.

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Environmental consciousness is present in the mind of most farmers. They know their livelihood depends on their continuing ability to produce healthy crops. Since the 1970s, environmentalism among the general population, particularly in the United States, has grown to become a staple of many people's consumption habits and social and political ideologies. From the perspective of most professionals in a field related to or influenced by the environment, this is a laudable stance. Especially in agriculture, one cannot understate the importance of the environment. However, "thinking green" has led to the placement of agricultural under a microscope that cannot truly capture the complexity of farming systems. Farmers are generally aware of the adverse impacts they may be making on the environment through their practices, but advancements that reduce environmental harm are not always available or even known. It is not fair to only look to the farmer in reproach: policymakers also carry weight in shaping agriculture.

From the Dust Bowl to Precision Agriculture

The United States faced seemingly insurmountable challenges in the 1930s. The Great Depression had set in, disabling the economy. One of the biggest environmental disasters on record—the Dust Bowl—took place. A phenomenon rooted in exhaustive agricultural practices in the Great Plains states, including Oklahoma, Texas, Colorado, Kansas, and New Mexico, gave rise to a national crisis. Unpredictable climate conditions brought record-breaking drought to the most heavily cultivated land in the country. At the time (and to this day), farmers in the Great Plains commonly planted grain crops, such as wheat and corn. Before the cultivated grain crops, the Great Plains were home to native grasses and forbs. Over time, these grasses and forbs had generated deep root systems adapted to the semiarid climate. To start farming the land, these native grasses had to be removed, necessitating the development of the cast-steel plow. Intense tillage practices, in conjunction with the steel plow and the introduction of gas-powered tractors, effectively removed the native prairie grasses. As a result, soil quality in the region rapidly deteriorated. Winds carried the dry soil all over the country; fertile topsoil diminished, leading to a popular demand for action among citizens and legislators. People experienced unfavorable air conditions as far away as Washington, DC, resulting in policy changes that incentivized environmentally conscious farming. In the past, research and advancements in agriculture were primarily focused on increasing crop productivity without considering the potential environmental costs of yield increases. Today, any improvement in crop yield takes into account the environmental consequences. Contemporary agricultural research emphasizes expanding resource use efficiency and technological development, while also taking into account environmental sustainability.

Today, effective and environmentally conscious farming methods are well-known and recognized by the farming community throughout the world. The next step is the continued growth of the technologies beholden to a tiny green microchip. Some technologies have already made their way into the life of the average farmer. Agriculture has been home to self-driving and leveling tractors, and GPS equipment has been implemented in other massive machinery with precision and safety since the 1990s. Those complex GPS and auto-steer systems are now considered a necessity in the massive mechanical marvels that are the newest cultivators and harvesters. Variable rate application technologies are capable of distributing different amounts of agronomic input (e.g., fertilizer, irrigation, herbicide) across the same field to match the actual need of the input. The variable rate input can be either predetermined through the creation of a so-called prescription map or varied on-the-go through active sensors (e.g., chlorophyll detection, the presence or absence of weeds), thus minimizing waste and pollution, as well as maximizing resource use efficiency. Geospatial data collection technologies, including specialized aircraft and a plethora of adorning sensors and photographic equipment, have been consistently growing in availability and necessity.

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Additionally, satellites generally recognized for GPS coordinates and cellular communication can also image cropland across the globe for analysis by researchers—and they have for decades. However, all of this only represents a growth in the technologies and resources available to farmers, not the growth of understanding needed to take full advantage of these high-tech systems. Herein lies one of the major problems that society must solve: how do we link the massive amounts of data—big data—and the highly technological resources available to farmers, so they can farm more efficiently?

Precision Agriculture and Big Data

While precision agriculture (PA) and big data are related, they are not the same. PA describes recently developed technologies and principles used to assess and manage spatial (within a field) and temporal (within a season and across years) variability associated with all aspects of agricultural production (Figure 1). Big data refers to the collection, analysis, and synthesis of large data sets that may (or may not) originate from PA equipment. Big data techniques offer the capability of collecting and analyzing data at a magnitude that was previously impossible.[1]

PA equipment available on the market is the result of the recent evolution of associated electronic and information sectors being rapidly adopted by producers.[2] Examples of PA technologies include georeferenced guidance for steering, seeding, and spraying. Approximately 70 percent of tractors in the United States have GPS with auto-steering technologies and 40 percent of all corn farms can potentially use yield monitors.[3] Such monitors demonstrate that large yield differences commonly exist within a field[4]—these variability patterns can also differ from year to year within a field.[5] Additionally, farmers have access to remote sensing through aerial imagery, unmanned aerial vehicles (UAVs), soil-sensing technologies, other on-the-go vehicle-mounted sensors that they can link to handheld devices or computers and cloud-based data storage.

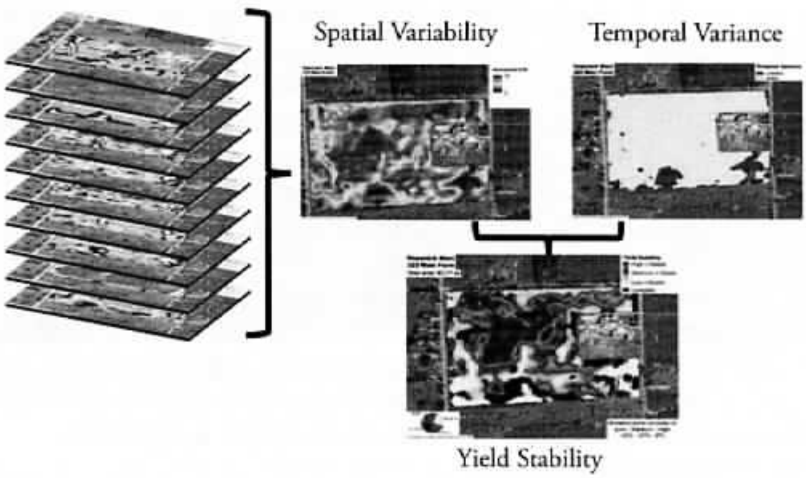

Figure 1: Advanced analytics, spatial variability, and temporal variance mapping can be used to synthesize yield stability maps to better inform management planning.

The Challenge of Bridging the Technology Gap

We must remember that soil is not dead—billions of organisms live in agricultural fields with intricate topographies, variable resource conditions, and volatility associated with the changing global climate. As the people engaged in agriculture, farmers manage to identify and encapsulate these factors into a manageable system that produces more food for human consumption than has ever been done before.

Where farmers do not use PA technologies, we can clearly see the negative impact on the environment: hypoxia in water systems from algal blooms caused by excess nitrogen and phosphorous runoff, soil erosion, aquifer depletion, degraded soils, and other negative impacts. These and many other issues will likely plague the agricultural systems in regions struggling to address increasing food demands for years to come. Realizing the potential of high-tech resources in agriculture will bring farmers' capabilities on par with the current demand for sustainably produced food. Despite the advancements, a disconnect persists between the rapidly evolving high-tech world and its application to the vital agricultural systems.

Capital investment is one barrier. Farmers do not always have the financial ability to purchase expensive technology systems. Investment funding is not readily available for technology companies to develop new sensors or unmanned aerial systems (UAS) for geospatial data collection. Institutions and researchers compete for limited funding dedicated to developing analytic systems and applications of agricultural technology. Companies cannot afford to exist solely for the purpose of collecting and visualizing data for farmers. However, a small number of individuals and corporations are looking for breakthrough solutions to help interpret and convert big data into solutions that could change the future of agriculture.

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Even though farmers are knowledgeable when it comes to their land and crops, it is less common for them to possess the knowledge needed to assess acquired imagery and geospatial data and to then translate that information into applicable management practices. The average farmer in the United States is nearing sixty years old and the technology that could bring one's farmland into a new era is just beginning to be developed and explored. UAS, with their humming drones and small, powerful data collection equipment, are some of the most complicated systems to ever grace a field. Data gathered from sensors attached to a drone—which can cover a square-mile field in mere hours—are transmitted to and amassed in huge data sets only recently deciphered for practical use by researchers.[6] Now that researchers can translate the raw data into helpful insights, farmers are increasingly reaping the benefits of increased efficiency from new technological systems.

In the past, agricultural improvements were far more direct. The Industrial Revolution brought John Deere's cast-steel plow and engine-powered machinery to fields, a simple case of reducing labor and increasing production potential. Other great advances came with the expansion of plant and animal genetics and breeding, bringing about the Green Revolution in countries like India, which acquired cultivars able to more effectively absorb nitrogen. At about the same time, agriculture began to irrigate more expansively and efficiently. From that point onward, the advancements came quickly, including rapid soil testing, a better understanding of pest management practices, progressively advanced mechanization, further advancement in genetic modification, and the beginning of the technology boom that brought GPS and other computerization to farm equipment. All of these advancements required relatively less technological knowhow, employing a more straightforward approach for adoption than the current technologies in question. Beginning with the computerization of machinery and the collection of massive amounts of data, agricultural advancement slowed due to the lack of technical expertise or basic financial constraints among farmers. Furthermore, with rapid advancements in high-tech farming, leaders in the field are developing new information and practices faster than farmers are able to digest and use them. This leads to misconceptions and unfamiliarity, contributing to a gap that needs to be filled before the next revolution in agriculture.

Turning UAV Images into Useful Insights for Farmers

Farmers and researchers are inundated with crop yield and imagery data, but such data are of little value until they are translated into actionable information that improves economic and environmental efficiency.[7] Useful assessments of yield variability would integrate several years of data because a given limiting factor can exert different spatial and temporal influences on yields of different crops.[8] The optical and thermal data collected from UAS is viewed against indices and other parameters from previous agricultural research, such as the normalized difference vegetation index (NDVI), the soil adjusted vegetation index (SAVI), the leaf area index (LAI), or canopy temperature. Canopy temperature data collected with thermal sensors mounted on UAVs or other airborne vehicles provide information on the water status of the plant. Progress made in variable rate irrigation systems, such as center pivot systems capable of distributing different amounts of water in different parts of the field, have led to increased irrigation efficiency. In rain-fed systems, where irrigation is not available, identification of water use by plants can still be used to optimize a system. Nutrient uptake in crops requires

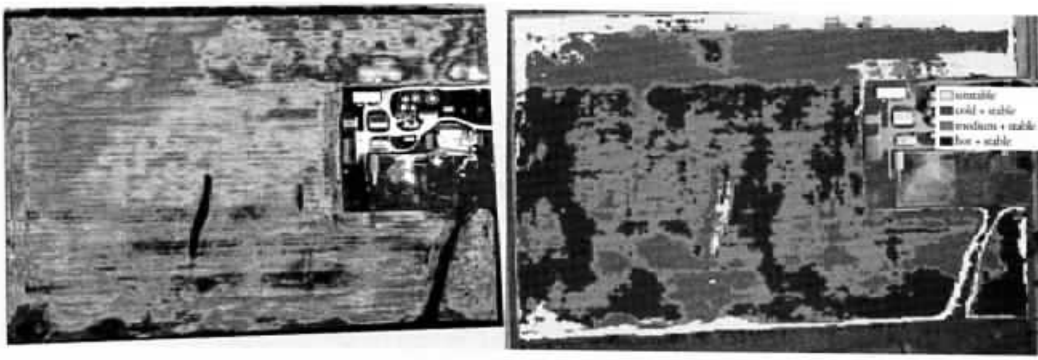

Figure 2: Integrated thermal images of corn field to show spatial and temporal variability of canopy temperatures.

water, so in areas of water stress within a field, less fertilizer is advisable. Coupling optimized water and fertilizer use results in overall higher yields per area of crop, and ultimately higher resource use efficiency—a win-win situation for the farmer and the environment.

It is possible to create valuable maps and data sets by applying analysis tools to the imagery collected by aerial systems and data from sensors. Mapping can be done for multiyear rotation farmland and show a lack of prolonged production stability and potentially give insights on how to adjust for optimized yields. Mapping can also be done for areas of consistently hotter or colder canopy temperatures depending on water available in the soil (Figure 2).

Temporal stability maps, which show areas of consistently higher yields, lower yields, or fluctuations, can provide information that allows farmers to optimize their inputs and increase overall production.[9] Unfortunately not all farmers have capitalized on stability maps and variable rate application of input is currently still anecdotal owing to the complexity in transforming data into action and value. The farmers that implement variable rate application do not use a systems approach (crop models) that accounts for the interaction of soil, crop, management, and weather,[10] but instead their decisions are largely intuitive and often based on incorrect assumptions.

The recent successes of, and gains from, the integration of various remote sensing platforms, yield monitor data, on-the-go sensors, and crop models are becoming more apparent both in the academic world and in new companies operating in this space (e.g., Climate Corp and CiBO Technologies).[11] Crop models are critical tools in precision agriculture because they can simulate responses at high resolution by providing them with spatially varying inputs (e.g., spatially variable soil properties, daily weather data, and management). For example, a crop model may be used to simulate multiple homogeneous zones within a field and across a farm, each with its own set of input conditions. Powerful computer systems allow field scale models to be extrapolated to regional or even national levels, especially now as more public domain input data is available.[12]

How Can Policy, Farmers, and Businesses Usher in Big Data Agriculture?

Policymakers can and should do more to support agricultural advancement programs. For example, they could fund the programs to educate farmers or promote incentives to farmers for adopting PA technologies aimed at reducing nutrient loss (leaching and greenhouse gas emissions) in the groundwater and into the atmosphere. They could also leverage the land-grant universities' agricultural extension programs—authorized under the Morrill Land-Grant Acts—which were designed to transfer the results of research to people to improve their lives. These widely trusted institutions can disseminate information about interpretation of yield maps and offer guidance for those that wish to adopt precision agriculture technologies. These approaches would truly ensure long-term sustainability of cropping systems by enhancing resource use efficiency, reducing greenhouse gas emissions, and increasing profits for farmers.

However, incentivizing the adoption of PA doesn't solve the whole issue. As previously mentioned, the average age of the US farmer is nearing sixty, contributing to a gap in abilities regarding technology that is quickly evolving. This issue is generating an interesting conversation about the future farmers of our planet. By creating buzz around PA and big data as the future of farming, it is more likely that a younger generation will become interested, bringing a new, highly technologically skilled force to the fields. Beyond the technical know-how, data collection on behalf of farmers is a key challenge that needs to be addressed to ensure farming advancements. Yield monitors are not as used as researchers would hope, and in places where PA and data collection are becoming staples of the everyday farmer, the value of analysis depends on the quality of data collected. Considering the cash value estimated in nutrient loss, or inefficient use of other agrochemicals, generating actionable management plans and accurate prescription mapping should be regarded as a critical measure in bringing PA and big data into the fold, both in the actual agricultural systems and in the economic sector.

Concluding Remarks and Future Perspectives

The current unsustainable water and nutrient management strategies seen in many agricultural areas of the world can be significantly enhanced by adopting precision agriculture technologies coupled with crop modeling.[13] Agriculture has been a picture of innovation over the past century, and it has the opportunity to continue to push the curve today. Precision agriculture and big data have the potential to redefine how people see where food comes from. To boost the underwhelming adoption of such promising practices, we must support researchers, institutions, business, and advanced farmers, on whom we depend.

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To feed a growing global population, agriculture is on the road to combining hundreds of years of practice and traditional knowledge with technology that once belonged to science fiction. Our image of a farmer is destined to change into an image of a person with technologically advanced skills. Researchers and institutions should push the boundary of data analytics by integrating modeling, expert knowledge, and detailed field data necessary for an appropriate prescription of spatially variable inputs. Businesses will need to fill the void in services that transitioning agriculture will require by utilizing the work of the researchers and institutions to develop actionable management plans and assist in spreading affordable data collection and analysis. Of course, filling in the gaps with big data to create the next agricultural revolution will benefit not only the economics of agriculture, but the environment as well. We are only leasing the Earth's land, so we must leave it in better condition than that in which it was given to us.

Notes

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