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Precision agriculture: Disruption and transformation of the agriculture and food industry

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Abstract
Precision agriculture is a new science-based paradigm reflected the digital, science, and protein disruptions in agriculture and food production. It reforms and reframes the traditional value chain, and incorporates novel ecosystems, data management, and new digital tools at each stage. The precision agriculture paradigm incorporates traditional tools like crop rotation, new livestock, seed cultivation, soil management and mechanization that alone and in combination increased crop yields and optimum use of land. But the new paradigm allows farmers and other players across the value chain to apply and use new tools of data management, superior understanding of food and health, and the impact of climate change on traditional agricultural methods and better mitigation tools for risk management.

Keywords: climate change, food security, soil fertility, value chain, protein revolution, startups

Introduction

Across the millennia, mankind has placed agriculture and food production as a priority for human survival. Today the global pandemic, climate change, and Russian's invasion of Ukraine threaten this vital sector where food insecurity is now a geopolitical priority. There is also a new paradox, food abundance amidst a sector of food scarcity. Climate change alone impacts food shortages, via drought, water scarcity, soil depletion, abnormally high temperatures, for instance. In the US alone, the cost of weather-related disasters now cost billions, just when agriculture and food production is undergoing massive disruptions. Three transformative change agents – the digital revolution, the protein revolution, and biotechnology revolution – converge to start a new paradigm for agriculture and food production, called precision agriculture.

As a transformative force, precision agriculture blurs industry boundaries, and injects a collaborative fusion of the physical, biological, chemical, and digital spheres of knowledge. The new paradigm still uses older processes, such as crop rotation, new livestock, seed cultivation, and soil management to improve crop yields and optimum use of land. In this new paradigm, precision agriculture enhances developing technologies – both analytical and digital – for farms, food processers, and food distribution, including new apps with software applications for seed distribution, optimum land use, natural ecosystem diversity, and a host of innovative solutions across the value chain.

The new paradigm is a strategic inflection point, where old assumptions and conventional thinking now give way to new startups and innovation across the value chain. This paper examines the changing landscape of agriculture and food production, where food and farming have special characteristics. In economic terms, there is relatively inelastic demand for farm output, and as a group of products, a small drop in price, say 10-15 percent, doesn't lead to an increase in consumption. Equally, the supply side of agricultural output is very immobile, and operates with time constraints. The input costs are relatively fixed, even if the output prices are low or high. Few sectors face constant uncertainty, from weather conditions to animal disease.

In this sense, farm outputs and food have the quality of an 'experience good,' with many intangible qualities, illustrated in a high-class restaurant of *haute cuisine*. President Kennedy understood in laymen's terms this dilemma: "The farmer is the only man in our economy who buys everything at retail, sells everything at wholesale, and pays the freight both ways."

The demands of agricultural and food

In advanced countries, the 21st century march of science is transforming organizational activities across the food value chain, impacting costs, processes and competencies that give sustainable competitive advantage. Precision agriculture is a new paradigm, introducing all aspects of the digital, scientific and the protein, using data and data analytics at each stage of the value chain, from the soil, animal and plant husbandry, food processing, logistics and retailing, and the human resource competences to optimize output. In most high-income countries, there is growing bifurcation of the industry value chain by organizational size, e.g., small firms vs. large corporate farms, local and regional processing plants vs. large global giants with plants in many countries, and small retailers and local markets against big-box food supermarkets. However, in the developing world, there are new threats, food insecurity, made worse by climatic factors as well as low absorption capacity to introduce tools and methods of the precision agriculture paradigm [1].

Unlike the vast land mass of countries like Canada, the United states, France, Russia and Ukraine, in most countries, farms and farming are often restricted by small plots, arid soil, and subject to controllable forces, including weather patterns (extreme cold, and storms that cause flooding, soil erosion, deforestation and more recently, severe firestorms). Historically. food shortages and food abundance became linked to military and colonial conquest, and the source of wealth for landowners. The value chain for food production was stable for centuries, consisting of three stages: 1) land and inputs for soil and animals, farmers and growers, 2) abattoirs and food processors and 3) food retailers, from fast food chains, small convenience stores, to national big-box retailers.

In *The Wealth of Nations* (1776), Adam Smith noted that agriculture "is much more durable, and cannot be destroyed by [the] violent convulsions" of war and political instability (p. 427), drawing attention to the role of public policy impacting farm output. His friend and colleague, David Ricardo (1817), whose work *Principles of Political Economy and Taxes*, lays out the theory of comparative advantage, focused on the returns to land as a fixed factor "for the use of the original and indestructible powers of soil". Smith, Ricardo, and other like Von Thünen, Arthur Young and Thomas Malthus dealt with the scientific and production difficulties of agricultural specialization, the issues of space and distance to markets, and the stagnation of farm wages and rising land rents.

Farms and food production are resource-intensive, requiring cultivated land, clean water, and inputs like grass and animal feed that yield a high input/output ratio for end products. At current levels, agriculture requires about half the world's total vegetated ice-free land. It is also the most water-intensive of any sector, and releases about 25 percent of all greenhouse gases, according to the Rome-based Food and Agriculture Organization of the UN. In countries measured by disposable wealth, the geographic shift from rural areas to urban living places new cost demands, such as a shortage of farm labour, and the logistics of transporting output to processors and retailers. Infrastructure investments include the farm ecosystem - electricity, high speed internet, and storage capacity. Globally, farms and farming are often separated from the natural ecosystems where uncultivated land, small forestry, grasses and shrubs provide a habitat for pollinators like bees and diverse wildlife, as well as a means to control pests, lessens soil erosion, and buffer water runoffs from croplands.

The vast majority of farms produce cereal crops like soya, wheat, and rice, as well as dairy and meat (primarily pork, beef, and lamb). Environmental activists and lawsuits now jeopardize small farmers and inadvertently promote consolidation among smaller and less profitable units. In urban areas, farm output also faces environmental activism, political pressure for rezoning, hence rising land costs. Furthermore, the farm sector faces logistical challenges, not only as packaged goods for the retail sector, but fresh and frozen products that require storage, refrigerating, and timely delivery. These stylized facts help explain the growing consolidation of the food sector [2]. and corporate strategies to bundle and unbundle future outcomes via takeovers, vertical integration, and new market niches like plant-based to gain competitive advantage.

Table 1: Bundling and concentration in the US food sector

Beef	Corn	Soybean	Flour	Pork	Broilers
Packers	Exports	Crushing	Milling	Processing	
(81%)	(81%)	(80%)	(61%)	(59%)	(50%)
Tyson	Cargill-	ADM	ADM	Smithfield	Tyson
ConAgra	Continental	Cargill	ConAgra	Tyson	Gold Kist
Cargill	ADM	Bunge	Cargill	ConAgra	Pilgrim
Farmland	Zen Noh	AGP	General Mills	Cargill	ConAgra

***Source*:** Adapted from MacDonald (2017), footnote 2.

More significantly, scientific and medical studies, such as the reports written in the British medical journal, *The Lancet*, address the linkages between food systems, nutrition, and health, and the impacts of the trend towards monopolistic competition in agriculture. In one study, the authors address policy prescriptions to reduce the use of petrochemical fertilizers and pesticides, as well as the need to protect pollinators, i.e., the natural ecosystems that sustain and regenerate healthy soils. The EAT–Lancet Commission [3] addresses the trend to monopolistic control, often depicted as 'big industrial agriculture' that pose challenges for human health: "The triple challenges of obesity, undernutrition, and climate change, which interact and affect human and planetary health, need solutions that disrupt their common underlying societal and political drivers."

The conventional stable, well-defined boundaries of the value chain, where industry dynamics often displayed concentrated and oligopolistic practices, also shaped a form of complacency with a focus on scale efficiency and high advertising budgets. Today, a transition occurs with the confluence of food abundance and food scarcity, even among advanced nations like Britain and the US. But not all stages of the value chain face the same risks. Players in the middle stages become more concentrated and buffered by the risks facing farmers as price takers or the low switching costs of consumers at food retailing. Big box retailers and supermarket chains shift certain costs to food processors, who then put price squeezes on the farm belt, thus providing superior margins in densely populated urban areas. A related issue is food delivery service via on-line shopping, or an accelerating trend to meal delivery, now a projected $28 billion by 2023 and growing 6.5 percent a year in America.

The precision agricultural paradigm transformation

In many respects, the agriculture and food sector is facing a Kodak moment, a dramatic shift in core skills and culture, a metaphor for a knowledge transition from analogue film technology to a digital platform. For farmers and other stakeholders across the value chain, data-informed decision-making widens the lens to assess how annual harvests directly impact price changes, land use and water availability, weather forecasts soil and land conditions, logistics improvements, and superior understanding of cost structures for labour, equipment, seeds, operations, including inventory management and pesticide prevention. The transition to a data-based systems [4], in short, allows smart farming to apply data analytics to improve overall performance, including yields per acre.

On-line ordering and delivery of meals imitates ideas of logistics and transportation of pizza franchises in urban areas, or the centuries old practice in Japan of b*ento* meals for travelers, but now updated for order and delivery of restaurant quality meals delivered at predetermined times. New startups and those with franchise operations and subscription services for repeat orders allow delivery of set meals using recyclable containers and utensils. New startups are applying similar order and delivery services that focus on food preparation and delivery for vertical markets like military bases, hospitals and schools, university campuses, and corporate offices. Precision agriculture and food awareness are transformed as much or more about smart customers as smart farming or smart processing.

Estimates by international institutions like the UN and FAO forecast a world population in 2050 of 9.5 billion or more show the need for a 70 percent improvement in agricultural output. The existing supply-demand disequilibrium also creates enormous waste, a sign of inefficiencies and silo thinking. As a trillion-dollar industry, stakeholders now face the associated risks and costs of life-threatening diseases like obesity, heart failure, and diabetes. Over 800 million people, mainly women and children, subsist on poor diets of starchy foods, with less consumption of fruits and nutrient-rich food. While weather issues have some impact, the evidence also points to managerial and technical inefficiencies actions leading to high food loss, with the greatest in small- and medium-scale production and processing firms.

The growing awareness of food loss and waste in Europe and North America, estimated to be 60 million tons a year in the USA, or almost a third in the total food supply chain, and an estimated 100 million tons in the European Union, stems from inadequate organizational systems, such as time-based logistics and just-in-time supply chain practices. At any stage of the value chain, some organizations display the symptoms of rigidity as a form of managerial lock-in and competency traps [5] that prevent or postpone new knowledge creation and experimental activities. The paradigm shift reframes the traditional value chain model and the rhythm of activity cycles, the patterns of interactions and coordination, the skill sets, and knowledge sharing.

The accelerating transition towards precision agriculture is attracting venture capital, and new business models from startups but also corporate incubators from incumbants like the large food processers, equipment manufacturers, and retailers. *Agtech*, a term describing the entrepreneurial transition, as new startup funding [12] now reaches over $500 million in the US alone. Agtech is a reponse to catastrophic outcomes of climate change on food production, and illustrates a wide range of technologies and IT applications, including all aspects of farm management; satellite and drone sensors to monitor weather patterns, and cameras and sensors to provide mapping for air quality, humidity and temperatures.

Table 2: Structural dimensions of agriculture and food production traditional model precision agriculture

Economic Issues		
Industry Structure	High Entry Barriers, Economies of Scale in Middle Segments of the value chain	Reduced Entry Barriers – high collaboration across value chain
Agriculture Value Chain	Five distinct stages, segmented organizational boundaries, domestic orientation at upstream stage	Increasing coordination and integration, new digital tools for information sharing, data analytics and knowledge transfer
Technological change	Confined to upstream application of science to animals, crops, seeds, and soil	Injection at in each stage of the value chain of intangible capital with software and science applications, IT systems, and plant-based technologies
Organizational Issues		
Changing Demographics	Aging of the Workforce, farmers apply limited digital tools	New entrants based on STEM education, application of digital tools ad the Internet
Corporate Ecosystem	Bifurcated boundaries between small scale, family farms and corporate entities with scale	Highly focused on end customers, new mechanisms to integrate the value chain
IT and Software	Primarily weather-related, small spending on IT and software	Growing use of IT, Data Analytics, high spending at each stage of the value chain
Transformative Drivers		
Climate Change	Primary Emphasis on Seasonal Variations, Storm mitigation, and Soil Conditions	Dominant issue for all aspects of the value chain, starting with soil erosion, water abundance or scarcity, and storms
Automation	Mechanism of farms, food production, and logistics and distribution; limited use of IT tools	Radical shift away from labour-intensity at all stages of the value chain, new uses of data analytics to integrate forecasting inputs, production, yields and final outcomes
Knowledge Transfer	Limited to science applications, mostly from government outlets, veterinary medicine, and the pharmaceutical sector	Growing emphasis on intellectual property, science applications, increasing R&D % of sales at each stage of the agricultural value chain

***Source*:** Author's Calculations

The galvanizing scale up of plant-based start-ups, often aided by collaboration with fast-food chains and incumbent food processors, provides new mechanisms for fast-growth through novel channels. To cite an example, in the meat alternative sector, there is huge variation in B2B, such as grocery stores, big box food retailers, universities, hotel chains, and sports stadiums, and in B2C selling through on-line delivery, quick-service restaurants, convenience stores, and fast-food franchises. Strategies for plant-based burgers allow new branding, such as Burger King (Impossible Whopper) and White Castle menus, or Beyond Meat associating with TGI Friday's, Carl's Jr. and Red Robin, or Canada's Tim Hortons. Beyond Meat's marketing success leads to increased direct competition from companies like Impossible Foods, which has a marketing tie-up with Burger King for plant-based burgers in America, and like Canada's Tim Hortons, is owned by Restaurant Brands International. The meat alter nativities sector [7], while now small relative to the quarter trillion-dollar American meat industry, is sometimes referred to as meat analogue, or imitation meat. The core ingredient is a gluten based, or soy-based mycoprotein from peas, wheat or other sources (including insects) that recreate or simulate a similar taste, appearance, and texture of food made from meat, poultry, fish, and shellfish, which manufacturers claim has similar nutritional value.

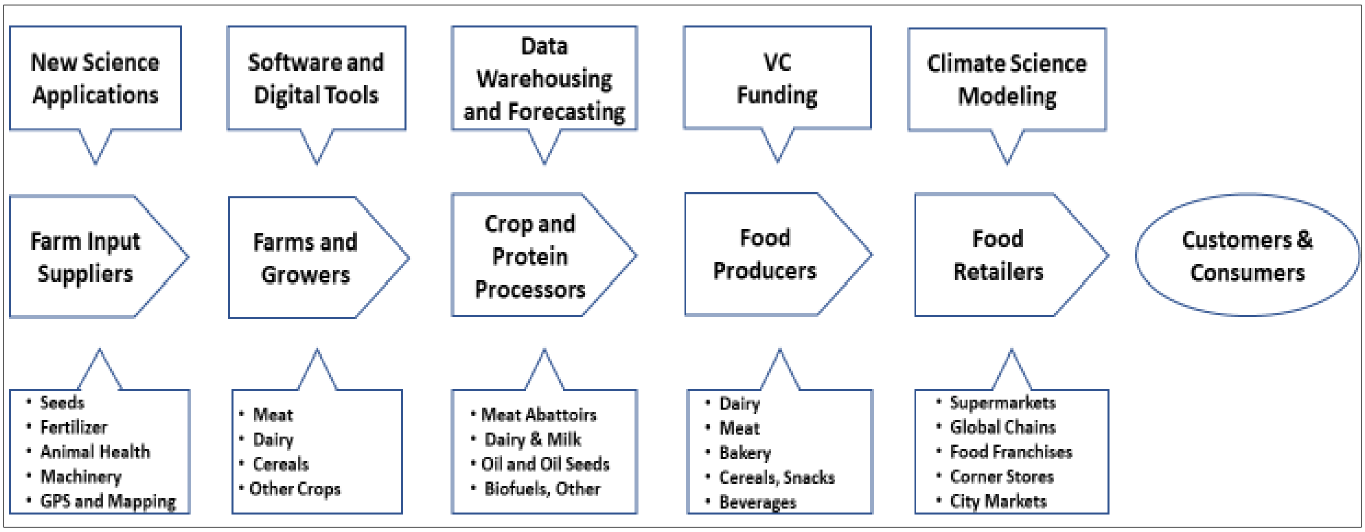

Fig 1: The precision agriculture and food value chain

Innovation and new technologies provide GPS and other devices for tractors, wagons, harvesters and seeders to gather real-time data and archive it for future use to monitor past performance, future forecasting, and assess current production and yields based on farm inputs. These tools allow new modes of data analysis at each stage of the value chain and transform the sector where data analytics and new forms of intellectual capital improve yields and outputs. However, the food sector, lank many others, is home to many firms with flawed business models, like Delivery Hero or Oatley Dairy, with shareholders expecting huge gains, only to face the reality of the rivalry trap [8] of incumbents' aggressive response.

A symptom of the new challenges facing farming and agriculture globally is the availability of clean water in a sector that is water-intensive, and many geographic areas face water shortages. In most advanced countries, water is a free good, and abundantly available, despite evidence that water is not an infinite resource. Moreover, there is growing understanding to treat water as a critical financial asset class, impacting food production, military security, and a potential for diplomatic fault lines between countries. In California, by contrast, where the agriculture sector exceeds $50 billion per year, with only two percent of American cropland, farmers often pay three times the price of water of residential consumers. In fact, better technology now exists to monitor gross water consumption, given the need to provide water for farming and food production. Water management, for firms and government, is now a distinctive corporate competence.

Globally, there is a new phase of entrepreneurial zeal among actors – startups university labs, corporate incubators – addressing novelty and innovation at each stage of the value chain, often combining both incremental innovation and radical transformation, such as plant-based foods, well-funded vegan dairy production, and a host of software applications that strengthen the new industry paradigm. Precision agriculture combines new forms of digitization, state-of-the-art supply chain innovations, and organizational forms of collaboration within the value chain. Each stage is designing novel ecosystem formations, often with governments and scientific personnel. New start-up formations attract the flow of venture capital to Agtech and accelerate knowledge diffusion and new corporate alliances.

Organizational Barriers to Precision Agriculture

Around the world, food abundance and food scarcity and the growing worries of food security have raised the policy stakes beyond the farm gate and food retailers. It is now clear that the world's food supply, like raw materials such as oil and gas, is not evenly distributed among the regions of the world, so the burdens of geography must be overcome. The challenges go beyond the availability of arable land to plant crops, raise animals, and provide the combination of weather conditions, water, fertile soil, and the natural ecosystems that sustain productive growth and high yields. Some fertile countries are geographically enormous – Australia, Canada, Ukraine, France, and Argentina, for instance, with relatively small populations. The US ranks at the top with the amount of arable land, while some countries, notably India, China, Brazil, Indonesia, and Nigeria have a limited land mass but large populations. For example, India has 53 percent of total land that is arable, but 360.8 people per square kilometer, while Brazil has 22.8 people per square kilometer but only 7 percent of the total land is arable, compared to 15 in China with 139.7 people per square mile.

Such differences affect the global food supply where some countries produce and export food and those that must import food. Obviously, economic growth and population dynamics impact discretionary spending and food consumption. But so too do domestic policies like tax subsidies, tariff policies, regulatory relief to protect jobs, and other distortions that limit competition and create high entry barriers. Today, even an agriculture and food-abundant nation like America faces food shortages and long lineups at food banks.

Despite the enormous societal advances with the steady march of science and knowledge diffusion, agriculture and food production remain a contested space. Poor countries not only have very low incomes to grow and consume food, they lack high grade infrastructure investments in roads, safe water, sewars and harbors. In fact, more than one billion people live more than two km from an all-season road, and even more, 1.2 billion, lack access to electricity [9], hence easy access to the Internet and computers. Poor countries are especially vulnerable in cases of war, famine, pestilence, and pandemics like COVID-19, or the ravages of swarms of locusts destroying crops.

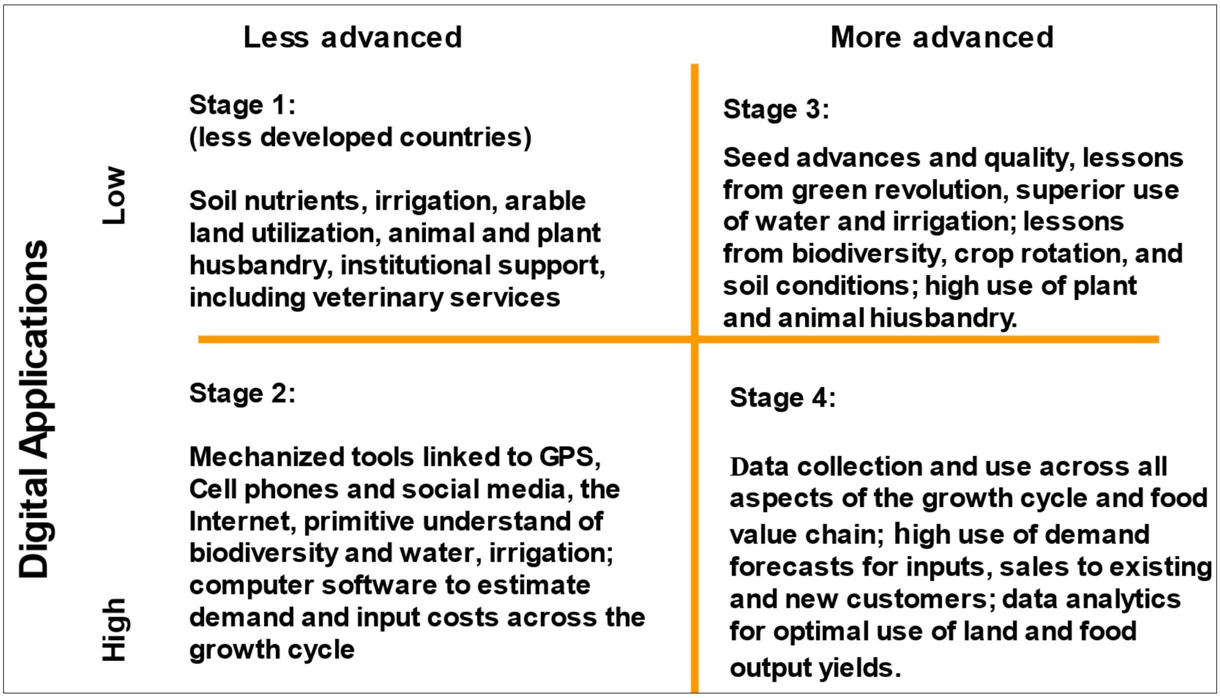

Fig 2: Precision agriculture transformation stages scientific applications

In the advanced countries of North America, Europe, Japan, and parts of Asia, scientific progress in all aspects of plant and animal husbandry are well advanced, widely shared, and enhanced by institutional mechanisms in governments, universities, the private sector. The life science revolution [10] now underway influences all aspects of food production, such as fertilizer companies, food processors, food retailers, and the global food commodity trading firms. Alone and in combination, these institutional players [11] have connections to individual farmers, as do government departments of agriculture, local veterinarians, and colleges and universities via degree courses, conferences, and scientific journals.

In many advanced countries, there are also banking institutions, and now venture and equity capital firms that invest in new startups, including with food company incubators, to advance new scientific applications, often using data analytics, smart phones, and computers to track all aspects of the food chain, not only across the growth cycle but all stages of the value chain. The use and dissemination of data allows new tools for sustained innovation, illustrated by the rise of plant-based products, more effective use of water resources, and other aspects of the green revolution and new seed technology first applied in India. In some countries in Asia and Europe, simple innovations like vertical faarming, growing fresh vegetables and fruit in solar-powered greenhouses, and new, sustainable methods of irrigation pioneered in Israel enhance new forms of sustainable food production, as shown in Stage 3 and 4, Figure 1, 2.

The driving force for food producers is the growing awareness of diets, nutrition, and health, as more consumers are exposed to food content, shown vividly by a documentary on Netflix called the *Game Changer*. Clearly, demographics beyond this decade are important, not only because the decline in fertility and aging in advanced societies, led by Japan and Italy (with limited immigration) including China, but the rise in population in less developed countries, especially the Continent of Africa. In Nigeria alone, the projected population could reach over 700 million, equal to the population of North America and Europe combined, and the same as China. Most African countries lack the institutional systems of the food sciences, but smart phones, and the Internet offer many possibilities for knowledge diffusion across the food chain, as would multinational investments from Europe, North America, and Japan.

Conclusions

The agriculture and food production sector is a case study in industry transformation. The global landscape – trade agreements, digital advances, scientific breakthroughs, and new customer demands based on health and nutrition awareness - introduces a new innovative culture at each stage of the value chain. Both production costs and revenue streams change traditional business models, the bargaining power of various stakeholders, and the new dependencies for sourcing inputs. At the same time, as a result of new technologies and scientific know-how, internal issues now pervade and change established practices, bundles of operational activities, and styles of decision-making. Slowly, new startup firms and transformative change in incumbent firms are transformative the sector world-wide, by challenging conventional assumptions and setting new benchmarks for innovative solutions. These trends are pervasive, often reinforced by social media, better access to data, and collaboration with scientists and engineers, NGO activists, and entrepreneurs with a thirst for alternative consumer choices.

Agriculture and food production face a ticking time bomb, namely the demographics of an aging workforce, more farmers facing retirement and young people attracted to other careers. As the sector becomes more capital intensive, yields per acre for each crop steadily improved even as farmland steadily rises in price, made worse by urban encroachment for real estate development, thereby creating a huge entry barrier for young farmers. In most countries, agriculture is a seasonal industry, dependent for the planting, growing and harvesting months on the weather. In reality, it requires a year-long attention to pre-season forecasting of land use, crop choice, seeds, and cash flow needs.

The existing stock of farmers and farm families work longer hours, with less early retirement, thereby skewing the demographic aging to older farmers, with far fewer in the 25 or younger cohort. Traditionally, agriculture is a male-oriented profession, where farmers are often older (more than half of Canadian farmers are 55 or older, 58.3 in America, and an average of 67 in Japan, and 60 or older in Africa, even though the continent is among the youngest populations in the world. It is estimated that only ten percent or less are under 35, and half the family income comes from off-farm employment. However, in Asia, many countries experience a demographic shift to female farmers, over 50 percent overall, according to the FAO (2017), such as Cambodia, Vietnam, Laos, and Bangladesh, to less than a third in Latin America (14.2 percent in Chile, 31.3 percent in Peru, 24.8 in Columbia and Ecuador.

Around the world, the agriculture and food sector is facing a dramatic, paradigm shift in core competences, value chain dependencies, and c-suite mindset. Disruptive forces are challenging core assumptions, as shown in the protein revolution, but also the new requirements to address concerns about food nutrition and health outcomes. The food sector is also subject to the ravages and threats of climate change, impacting key inputs like soil nutrition, sustainable water supply, diverse natural ecosystems, and temperature changes. The tools and methods from digital and scientific collaboration offer new opportunities to organize and manage each stage of the value chain, starting at the farm gate. Both digital technologies and science enable farmers, processors, food retailers, and consumers to know, understand, and assess processes and patterns across the food value chain, with concrete data, including applying using easy-to-use software as tools of assessment, kaizen improvement, and innovation. Precision agriculture and food are transformed as much or more by smart customers than smart farming or smart management.

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