# Agricultural Automation and Food Processing

Dan Slomski
June 2020

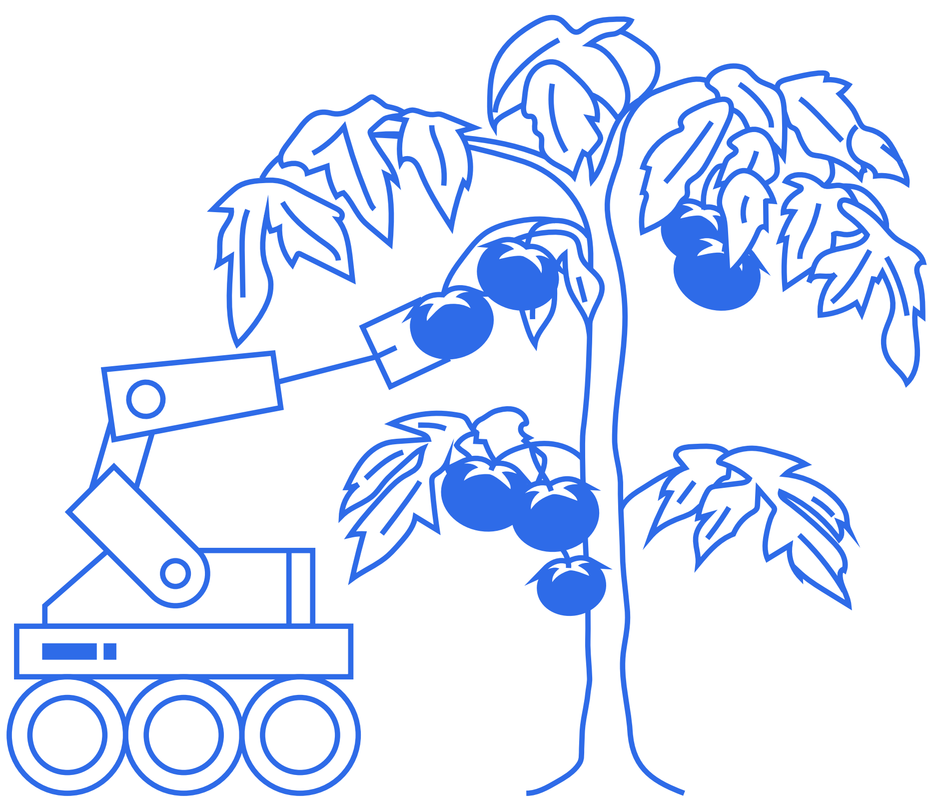
Prime Movers Lab

The advent of agriculture in ancient times may have been the fundamental enabler for all known civilizations to flourish. And ready access to food remains a cornerstone to society even today. We all need to eat, and there are more of us every day. Advances in farming technology have been enabling increased crop yields since time immemorial; and nowhere is this more visible than in the last hundred years with the widespread adoption and expansion of agricultural automation. Even before the emergence of COVID-19, the adoption of new farming techniques and the use of technology to automate the processes of growing, harvesting and transporting crops, has been critical to address an increasing shortage of farm labor and the need to increase food production. It is estimated that we will need to expand food production by an additional 70% from today's output to feed the World's population in 2050, according to the Food and Agricultural Organization of The United Nations. In a post-COVID world, there is an even more paramount need to leverage technology and science to ensure a robust food supply chain in which animal and plant produce reaches consumers reliably, sustainably and safely.

While the field of agricultural technology (Ag Tech) continues to expand to bring us more food at less cost, there are certain avenues of technological expansion that can be seen to improve not only the quantity of food produced, but perhaps more importantly the robustness of the supply. In the face of major labor disruptions such as we continue to see with COVID, we need to have systems of production in place that can operate with minimal human intervention.

A Forbes article on AgTech highlights a couple of the key areas of food production that I believe are fruitful ground for investing in supply chain reliability:

- Water Management: Systems designed to maximize plant yield through efficient watering
- Plant / Soil Analytics: Services to analyze soil quality and plant health
- Sensors: IoT devices to measure the health and growth of plants
- Advanced Machinery: Drones to monitor crops, and robots to pick them
- Grocery Supply Chain Management: Food quality / safety tracking
- Vertical farming: which uses LED lighting, advanced sensors, and automation to effectively stack farming plots on top of one another indoors.
- Cultured meats and plant-based proteins: Although these approaches are fairly labor intensive in the lab today, when they reach industrial scale they will need to leverage increasing automation to bring down costs.



# History

Machine technologies are not the only way we have increased food production in the past, but machinery will always be a large part of the equation. Advances in hybrid-seed (seeds produced by cross-pollinating different strains of crops, like corn, to improve characteristics such as yield and disease resistance) led to a dramatic increase in corn grain yield starting in the 1930s. The US Department of Agriculture estimates that "we produce at least 20 percent more corn on 25 percent fewer acres than in 1930 when seed of hybrid corn became available in quantity to American farmers." Primary source material from farmers who lived through this transition indicate a 3.75x increase in per acre yield of corn in the decades after hybrid seeds were introduced.

The increased yield brought about by hybrid seed led to the proliferation of innovations like the gas powered tractor, needed to efficiently harvest the higher-yielding crops. The impact that hybrid seed and new technology had on crop yield is apparent when looking at bushel per acre (bu/ac) yield of corn grain in the US.

This innovation was desperately needed at the time since:

1. The Dust Bowl of the 1930s showed the negative impact on crop production of inefficient farming practices used to meet rising demand
2. The resulting crop failures coincided with the Great Depression, which had left millions poor and starving; driving a need to produce more food at lower prices

There is a similar dynamic playing out now in which farmers are being negatively impacted by labor shortages, even while greater production is needed to address demand from population growth, and a financial crisis akin to the Great Depression is being driven by COVID-19 shutdowns. Now, like in the 1930s, it will take a combination of more efficient farming and advances in automation to address these challenges.

# State-of-the-Field Today

Farmers are experiencing mass labor shortages that are impacting how and what they grow. A 2019 survey of 1,071 California farmers by the California Farm Bureau Federation in collaboration with the University of California-Davis showed that:

- 55% of farmers had labor shortages
- 37% of farmers said they had adjusted cultivation practices to ease labor shortages
- 31% said they are switching acreage to less labor-intensive crops

In many parts of the world there is heavy reliance on seasonal migrant workers for farm work, and a global pandemic in which people are not able to move freely makes this dynamic risky for farmers. In the US, 10% of farm workers are participants in the H-2A visa program. These workers have jobs lasting less than one year and are often housed by their employer and transported to job sites — this creates an additional burden for farmers because of the need to maintain social distancing at the job site, and in the housing and transport of workers. Reducing reliance on these workers through automation would be a panacea for farmers facing labor shortages, and could reduce the spread of disease to consumers and between workers.

Historically, the combination of automation and new farming techniques have increased crop production significantly. One example of this, grain yields has already been covered, and another prominent example, fruits and tomatoes, will be covered in more detail later. Increasing food production 70% by 2050, as the UN says we need to do to meet demand, is unlikely to happen without blending more automation into our farming techniques, and this presents an opportunity for investors and technology founders to help bring powerful new innovations into this continuously growing market.

In addition to making our food supply safer, automation would have the added benefit to the consumer of empowering farmers to grow/harvest what there is demand for, not what there is enough labor to grow/harvest. This is good for consumers and farmers because the crops that are actually in demand can be made available at a lower cost with increased safety.

The term “Smart Farming” encompasses technologies that increase farming efficiency and automate the production lifecycle for crops. The agricultural technologies that will become the bedrock of Smart Farming are:

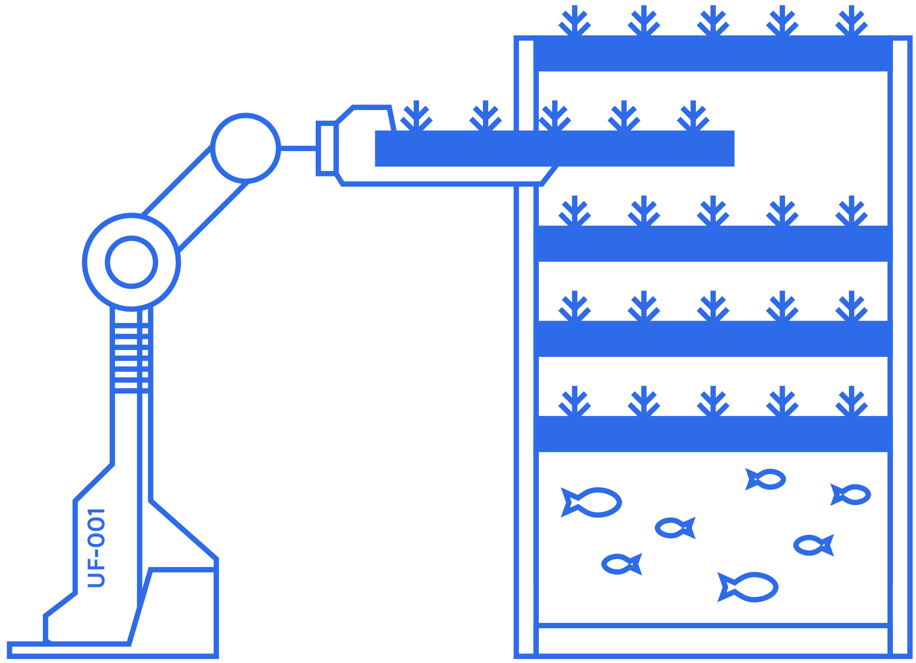
- autonomous robots, which can be used to plant seedlings, harvest, sort, irrigate, and measure crops
- aerial drones, which can be used to seed, spray, and inspect crops
- sensors/IoT, which can be used to optimize the cultivation process and provide valuable data to inform the new fleet of robotic workers.

As part of the move towards smart farming, we can expect to see a wave of driverless tractors hitting the market. As autonomous driving technologies mature, tractors and agricultural equipment will likely be the first to convert over, given that they are operating in largely open, empty spaces.

Smart Farming also includes new farming techniques that can be more efficient and lend themselves better to automation, such as Indoor Farming. Indoor Farming uses enclosures like greenhouses, hoop houses and warehouses to protect crops from the uncontrolled environments we collectively refer to as the “outdoors”. The controlled environment can make automated harvesting vastly easier by increasing the predictability of crop readiness, and eliminating the need to work around the weather to complete a harvest. And because the enclosed environment naturally reduces the number of plant diseases that must be accounted for it is easier for growers to achieve organic standards by skipping the need for pesticides and herbicides. According to USDA data aggregated by The Greenhouse blog, there are 40,000 US farms growing traditional crops indoors, producing a market value of $14.8bn annually. However, the US only accounts for 0.2% of the global greenhouse vegetable market. Increasing its share of this market will allow the US to fully harness the power of automation technologies in crop cultivation.

An important subset of indoor farming is vertical farming. Plug and Play defines vertical farming as “the practice of growing produce stacked one above another in a closed and controlled environment.” Vertical farms often utilize hydroponics, in which plants are grown in a medium such as pebbles or gravel with water and mineral nutrient solutions; aeroponics, where no growing medium is used and plant roots are sprayed with water and nutrients; or aquaponics, where aquatic animals such as fish or shrimp are cultivated alongside the plant crop, forming an circular biological ecosystem. Vertical farms reduce the need for labor by using robots to seed, harvest, monitor, and handle logistics. Further, they can use up to 70% less water than traditional farms because evaporation and soil runoff are almost completely eliminated. Another important benefit is that these vertical farms are more space efficient — Iron Ox, a vertical farming startup, claims it grows 30 times more produce per acre than a regular farm. However, vertical farming is still an evolving field and not all approaches are created equal. Iron Ox and the well known Plenty still rely on very labor-intensive processes to grow and package their produce. Our portfolio company Upward Farms has found ways to automate the majority of their process from end to end, from seeding the grow trays all the way to harvest and packaging, while simultaneously reducing 90% of all moving parts through their clever floating-raft conveyance system. Indoor Vertical Farming also provides the ability to locate the grow operations such as Edenworks closer to end customers. The indoor growing facility can be co-located near the distribution centers of major produce retailers, allowing them to provide fresh greens reliably year round, even in climates with harsh winters; thus requiring less importation and transportation infrastructure and resulting in fresher produce for the end consumer. In these ways automation can aid local sourcing efforts and agricultural sustainability initiatives to transform our food production practices for the better.

As a systems engineer, this is exactly the type of efficient, mutually-beneficial scenario that I was seeking to create in my hardware design work. And now my work in venture capital is providing a much broader perspective, enabling me to locate and share these breakthrough technologies that are working for the good of us all.




# Hybridized Plants and Harvesting

When designing and running automation equipment, uniformity is king. If the material being handled is all the same size, shape, weight, texture, firmness, it's much easier to pick, move, separate, inspect, etc. This remains true in agriculture; and dealing with living, growing biological shapes presents interesting challenges. With increasing automation taking place in agriculture, it makes sense that farmers might again look to selective breeding and GMO crops to solve some of these challenges in the modern age. But now, instead of just optimizing for raw yield, a farmer might choose a variety of crop that is known to grow more uniformly with fruit of a certain size; or stalks of a particular height that can more easily be harvested by a tractor with a mechanical picker; or maybe a variety that all comes ripe at the same time so a whole field can be harvested at one time. So in this modern age, many more parameters need to be optimized for than just yield or taste. A blueberry that tastes amazing, but is very delicate and must be hand-picked, will not be as desirable to a farmer as a blueberry with a tougher skin that can be machine-harvested and survive through the conveyor belts of the washing and packaging process. And in fact the price the end customer pays will directly reflect the ease of harvesting, packing, transport logistics, and spoilage. Of course, the intent is to maximize all of these parameters simultaneously, including taste and quality; but food engineering, as will all engineering, is truly the art of managing tradeoffs. For this reason, oddly-shaped heirloom tomatoes that must be hand-picked and hand-packed will always be more expensive.

If aspects of the plant can be made more homogenous, then the machine to handle that crop can be simpler, which often means less expensive and more reliable. But even if the plant cannot be made more homogenous, there are still ways to automate its handling; it’s just that the system complexity may have to scale up to handle the irregularities. More sensors can be added, or more degrees of motion can be built into the actuators. Machines can be built to handle even the most odd-ball of shapes. But this doesn’t come free, the complexity of such a machine often goes up by orders of magnitude, and with it the cost to purchase and maintain. In agriculture, where volume is high and prices are low, it’s very important to keep equipment costs down and robustness/reliability up. The equipment has to work or it won’t get used. In farming and food production there is often a narrow window of time to harvest, process, and deliver the product before it goes bad. So a large-scale farmer is unlikely to have time to futz around with a finicky piece of equipment. For this reason, the more reliable tool will generally win out in the field and in the packing house. Human hands and eyes are very easy to train, and then very reliable for short timespans of a couple of hours. Cameras and end effectors (technical name for grippers) are much harder to train to do the job right. So ideally the crop itself would not require complex end effectors to be developed to handle it. Better if the crop is known to be uniform enough that simple, robust metal rails, sieves, combs, or some other simple mechanism can be used to perform a function over and over and over again with no babysitting and no maintenance. For this reason, crop science, genetics, informatics, and machine automation all go hand-in-glove to streamline this process. So I believe that the advances in food production that we will see over the coming decade will be due in equal part from advances in machine automation as well as from efforts made in the life-sciences to engineer better plant hybrids.

The benefits of using hybridized plants coupled with customized machinery have already been brought to bear on certain crops such as blueberries, grapes, strawberries and tomatoes.

In one example of this, BBC Technologies, which was acquired by TOMRA foods for $67m in 2018, has built a blueberry sorter and packager whose artificial intelligence and image processing can "discern a stem hole from a bird peck and will reject punctured fruit that is likely to rot" and "is learning to detect dozens of different varieties and subtle seasonal differences, so fruit grown at the beginning of a season will be sorted and packed differently than fruit that comes at the end of it".

Mechanical grape harvesting has become the norm in California, where 80% of wine grapes are harvested by machine. One machine can harvest 15 to 20 tons of grapes per hour, work that would normally take 30 or more human pickers, at less than half the cost of picking by hand.

Labor costs in the domestic strawberry industry are roughly $1b per year and it is becoming harder to find people to perform the backbreaking task of picking the berries from the knee-height bushes. Reducing the number of hands that touch strawberries on their way to the end consumer has cost and safety benefits also, while alleviating the problem of finding people to do the work. Strawberry picking robots can pick 8 acres of strawberry plants in one day and can replace the work of 30 human pickers. Harvest Croo Robotics and Agrobot are two startups competing to serve this expanding market.

Other than corn and grain, tomato harvesting is perhaps the longest standing, most impactful example of harvesting automation that we have. Automated harvesting of processing tomatoes (those found in canned tomatoes and sauces, soups, juices, salsa and Ketchup) was introduced in the early 1960s, and within 5 years 99.9% of the industry was using mechanical harvesters. In this case, adoption of automation was also catalyzed by two things: 1) a labor crisis caused by the end of the Bracero Program in 1964, which brought seasonal farm workers to the US, largely from Mexico and 2) the introduction of the VF-145 tomato in 1961, a hybrid with tougher skin and an easy ability to be destemmed, both of which allowed for it to be handled by automatic harvesters. California's production of tomatoes saw a more than five fold increase from 1.3 million tons to over 7 million tons from 1954 to 1975 a result of combining automation technologies with new farming techniques. In 2015, 14.3 million tons of processing tomatoes were harvested, almost entirely by machine.

# Dealing with non-homogeneity

While many of the crops grown in the world today are bound for a processing facility to be crushed, shredded, milled, or otherwise processed, the plant produce we are most familiar with in our daily lives are the whole fruits and vegetables we hand-select at the grocery store or farmers market. Because of the need to maintain visual appeal, these crops are often carefully picked, and then sent to a packing house to be cleaned, sorted, and packed for shipment. These products pass through several different supply chains on their way to you, and many different hands. While these facilities do uphold the highest hygiene standards to protect the consumer, the workers often need to work shoulder to shoulder on the processing floor for long hours; which in this time of COVID-related restrictions has proven to be problematic for both workers and food processing companies.

Nowhere is this more on display today than in the meat processing industry, which has had a number of high profile closures due to corona-virus outbreaks among the workers. Robots may not be suited for every task needed in meat processing, and certainly not for every type of animal carcass, but there are companies such as Scott Technologies Unlimited that are attempting the effort. They use X-ray analysis on every single carcass, which is then conveyed into a process flow of intelligent robotic saw blades which use the X-ray data to make customized cuts on whole lamb carcasses, often more accurately and consistently than a human worker could provide. The future of automated meat processing is underway and may be ripe for investment and innovation; at least until the cultured-meat industry matures and begins to address more of the demand.

# Data in the fields

Using data to optimize crop inputs/outputs and track their progress throughout the growth lifecycle is known as **precision agriculture**. According to MIT, “Precision agriculture augments a farmer’s decision-making ability by integrating advances in our understanding of crop growth, sensor technology and wireless connectivity”. Drones are a key component of precision agriculture since they provide farmers with valuable data that allows for greater efficiency with inputs like water and fertilizer, resulting in greater quality and yield. Drones also allow for constant monitoring of crops so that problems, such as improper irrigation or disease, can be quickly identified and their impact minimized.

In order to derive maximum benefits from precision agriculture, a suite of IoT devices is needed for monitoring soil, crops, water, and climate conditions, among other things. Agrilinks, a knowledge sharing platform provided by the US Agency for International Development sums up the necessity of IoT sensors and the value they provide:

“An essential component of precision agriculture is low-cost, connected sensors that can measure important parameters related to farming. Data from these sensors are transmitted via wireless networks, aggregated in web-based data storage, analyzed, packaged into a recommendation, and fed back to help farmers make decisions."

One low hanging fruit use case for IoT is in crop irrigation. A prevalent method of watering crops is via Subsurface Drip Irrigation (SDI), which applies water to the crop root zone via underground tubes, instead of directly on the soil surface, where most weeds live. By coupling SDI with IoT sensors to monitor moisture levels, water can be autonomously applied directly to the plant roots at the optimal time.

There are myriad use cases for the IoT data that farms will generate and being able to tie data points like light levels, irrigation, air quality, soil conditions and weather together will create whole new ways for farms to optimize cultivation.

In 2014, connected farms were generating just 190,000 data points per day per farm; by 2050, Business Insider is estimating that they will generate 4.1 million data points per day from an increasing array of different sensor types. The number of installed agricultural IoT devices has more than doubled from 2015 (30 million) to 2020 (75 million). Harnessing all of this new data from farms will allow us to maximize yields efficiently and allow for crop production to keep pace with population growth.

# Agricultural Aviation

Tractors and ground-based equipment will always be indispensable for farming. But when it comes to accessing large, dense fields covered in delicate cash-crops, sometimes the airspace above is the way to go. While most companies working on autonomous aviation for precision agriculture are working on use cases around optical surveillance and data collection, there are a few companies developing hardware solutions that involve physical interaction with the ground, such as applying chemicals, pollen, or seeds.

Crop dusting, or aerial application, is the process of spraying crops with substances like pesticides and fertilizer using aircraft. In the past, there had to be a human operating the aircraft, which was both dangerous for the pilot, who was being exposed to potentially harmful chemicals, and for the environment and surrounding population because of spray drift. This all changed in 2015, when:

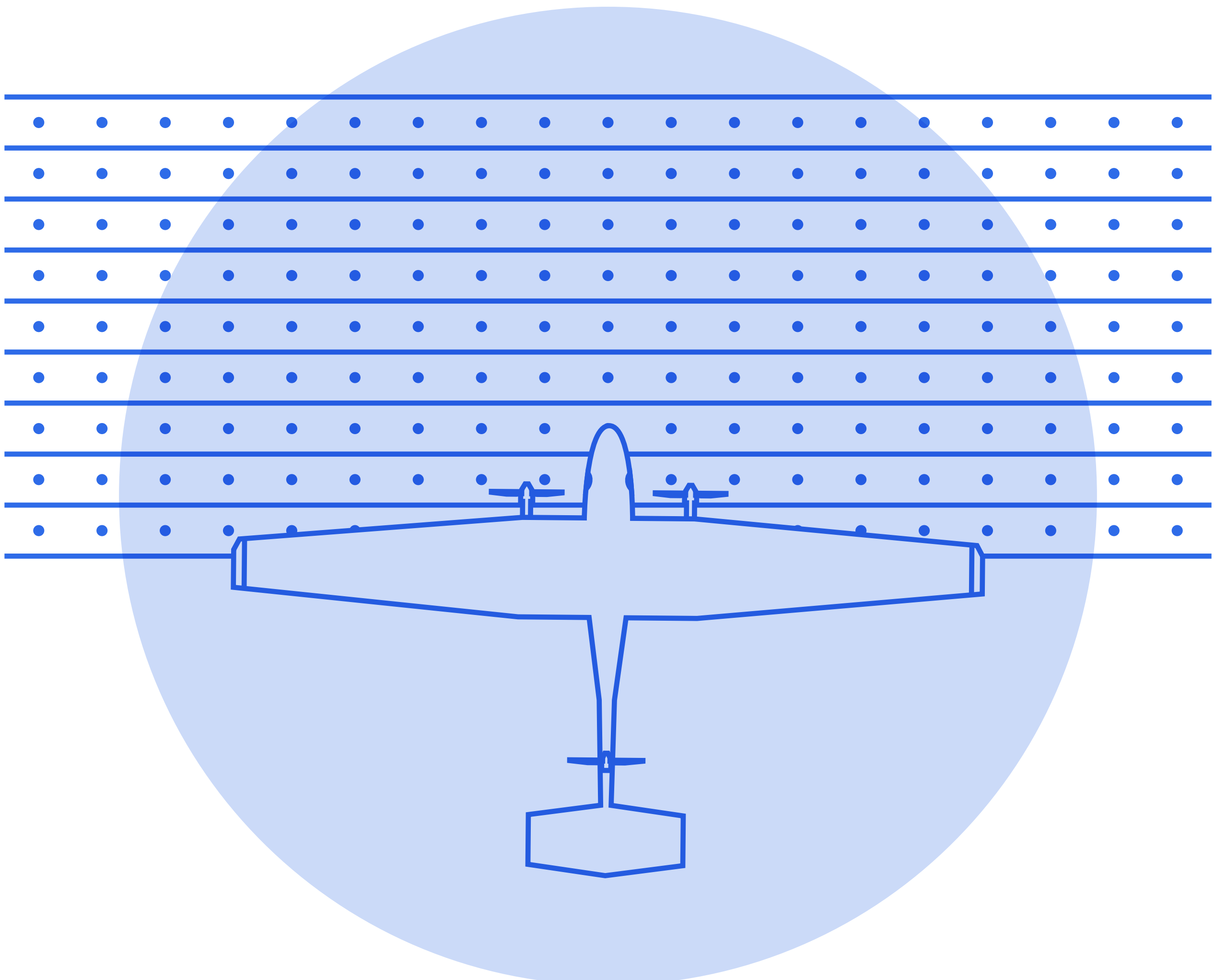
"the Federal Aviation Administration approved the Yamaha RMAX as the first drone weighing more than 55 pounds to carry tanks of fertilizers and pesticides in order to spray crops. Drones such as this are capable of spraying crops with far more precision than a traditional tractor. This helps reduce costs and potential pesticide exposure to workers who would have needed to spray those crops manually."

Drones can get closer to the actual crops they are spraying, leading to greater precision and less drift. While this could also be accomplished by spraying from a tractor, drones can do the job between 40 and 60 times faster.

Drones can also provide farmers with data that helps them determine where to plant seeds. Once a drone gathers this data, another drone can be used to plant the seeds in this location. MIT Technology Review outlines this process: "These systems shoot pods with seeds and plant nutrients into the soil, providing the plant all the nutrients necessary to sustain life." And notes that some of these systems can achieve an uptake rate of 75% and decrease planting costs by 85%.

Of the drones that are working on applications that involve interaction with the ground, 95% are employing multi-rotor copter-style drone aircraft. The advantage of these is that they require almost no runway whatsoever (only requiring a small landing pad), are very precise and can handle obstacles well. However, these copter-style drones inherently have short range, very limited payload, and slow airspeed. For these reasons, they will never be suitable for longer range beyond-line-of-sight cargo delivery, and their area coverage rate for crop spray applications will be limited by airspeed and wind conditions.

Representing the other 5% of drones in this category are fixed wing aircraft. Fixed wing aircraft provide greater payload capacity, speed, and range than their copter-style counterparts. This is the area where we are most excited and have been choosing to invest. Our portfolio company Pyka is building autonomous planes designed to make agricultural chemical application safe, fast and precise. The company's self-flying, fixed wing aircraft systems use autonomous flight controllers and onboard sensors to fly precise paths and land safely on rough service roads. The craft can update flight patterns in real time while detecting the right path and timing for spraying the target areas to compensate for changing wind conditions and reduce chemical drift into unwanted areas. This enables cultivators to spray agricultural chemicals and dust crops over hills and challenging terrain, while using less chemical per acre and decreasing accidental exposure to workers. Further still, these autonomous aircraft may one day be able to fly at night, using LIDAR and other non-imaging sensors to perform aerial application when the wind naturally dies down after sunset and when no fieldworkers are present; a task that no human pilot could safely do without illuminating the entire field.



# Conclusion

We are very excited about investing in the future of agricultural technology. We see this as a field of massive growth and guaranteed continuous need as we move to feed the 9.8 billion people projected to be alive in 2050. Further, I'm personally passionate about freeing human minds from the drudgery of repetitive task-work such as picking and sorting on a processing line. Doing the same exact action over and over for hours on end is machine work, which they are perfectly suited for; freeing the human mind to dream, create, build, and fix. This is what we are perfectly suited for.