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The Digital Harvest: Growing Agriculture with Time

Ansh Gupta

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I. Introduction

The world has a food problem, and it is not just about growing food. It is about growing good-quality food on a consistent basis and in a cost-effective manner that yields to the demand created in the market. Agriculture is both a contributor to and a consequence of climate change, and it can also be a solution to it. It is one of the most powerful tools to end poverty in second- and third-world countries. It boosts the economies of countries by up to 25%, especially in developing ones.

By 2050, the food industry is expected to reach a 70–100% increase, and just increasing agricultural land is no longer the right solution. It is time for us to implement better farming techniques and increase the yield of crops per acre. Having a sustainable farm that can produce on a consistent basis is all about understanding the factors that influence production.

The aspects that this research paper covers are precision agriculture, data analytics, artificial intelligence, machine learning and its correlation with precision agriculture, the use of drones, and analysing how these things sway the market and its supply and demand chain.

Diving into the specific terms used in agriculture and understanding the key differences between these terms, which are precision and accuracy, is important. Precision refers to the exact number of nutrients required in the soil for optimal growth. Accuracy is the closest number of nutrients required in the soil for optimal growth.

Given the fact that agriculture is heavily dependent on weather and climate change, it is very important to understand the dynamics of how it is changing every year due to climate change. The old methods of farming and the traditional ways of farming used on farms will no longer be effective.

II. Evolution of agriculture

Agriculture has evolved in the past few years and undergone some major technological and methodical changes, which are:

2.1 Changes in agricultural productivity:

Agricultural productivity refers to the quantity of output produced with a given quantity of inputs. It is a metric that reflects improvements in farmers' production efficiency and technological progress. The TFP (total factor productivity) for the US from 1948 to 2019 has increased by almost 165%. But this has not always been consistent. It is highly dependent on factors like weather patterns and the inputs of the farmers, which are again dependent on the budget assigned by the government. These variable factors do not ensure constant growth and often force an average farmer to utilise more resources than is actually required.

2.2 Health challenges for agricultural workers and livestock

Climate-related health risks such as heat stroke, pesticide exposure due to severe pest presence, degraded air quality, and vector-borne diseases are the most common factors that limit the farmers' ability to work up to their full potential. This significantly affects the quality of work and the ability of the cattle to provide it.

III. Economics

Agriculture contributed almost $1.1 trillion to the US GDP and accounted for almost 11% of employment. This number ranges widely from on-farm jobs to workers in the food industry and food processing industry.

3.1 The Bullwhip Effect

The bullwhip effect refers to a scenario in which small changes in demand at the retail end of the supply chain become amplified while moving up the supply chain from the retail end to the manufacturing end. Due to the inconsistency, this effect significantly decreases profits and escalates the problem in the supply chain, leading to either an excess or deficit of a certain product. The domino effect here starts with consumers. When the market sees more demand, retailers place large orders with wholesalers, who then place large orders with manufacturers, who in turn place larger orders with suppliers. The deeper the supply chain goes; the more demand exponentially increases.

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Market studies show that by the time items are delivered back to retailers, the demand is over, and there remains a bulk of unnecessary stuff.

A rise in inflation has been the dagger behind such an effect. It almost kills even the smallest possible profit margin, forcing retailers to empty their stock at massive discounts. Now, when the demand increases again, the retailer orders in bulk again, and this loop begins once again.

3.1.1 **Bullwhip Effect on Agriculture:**

Around 52% of all fruits and vegetables in the US, Canada, Australia, and New Zealand are lost in the supply chain before even reaching consumers. The primary reason is inefficiencies in the agri-food supply chain.

Increased customer requests for fresh products only compound the bullwhip effect. In the food sector, the bullwhip effect is intensified by "poorly aligned incentives across the supply chain and the lack of system design in these supply chains". (Prof. Kara, UNSW).

Some of the primary factors that lead to this domino effect are seasonal demand, batching orders, price fluctuations, and inventory management challenges. In order to mitigate this effect, communication along the supply chain line needs to be improved, as does the use of data-driven forecasting and efficient inventory management practices to create a stable and sustainable supply chain.

Data-Driven Agriculture

Computer algorithms are primarily employed to identify the best possible environmental conditions for enhancing the concentration of aromatic compounds in crops, commonly referred to as volatile compounds. The primary challenge faced in using these tools is the lack of open-source data. Most of the agriculture is done on large-scale farms that are in rural areas and far away from the houses of the farmers. This makes the transmission and collection of data weak, leaving satellite data collection as one of the few forms. The latter is expensive. While machine learning and artificial intelligence algorithms have advanced with time, agricultural data and algorithms are lagging far behind. The lack of standards in data collection and sharing and the thousands of factors that influence the growth of a particular type of crop are simply too wide to collect. There are inconsistencies on each farm for each crop on almost every acre in the type of soil, the nutrient level, etc.

4.1 Case Study:

Research from Microsoft in data-driven agriculture shows that one of the biggest challenges in deploying the Internet of Things (IoT) in massive farms is the lack of connectivity—connecting all the collected data to the cloud that develops these algorithms. This problem is being resolved by using TV whitespaces, which are basically unused TV spectrums that can travel very long distances. This end-to-end IoT system uses TV spectra to enable connectivity and also send sensor data to the cloud.

Precision agriculture means working both above and below the soil. One drone flight can collect up to 15–20 GB of data, which can be combined with satellite imagery to develop algorithms to enhance the productivity of the soil and the farm. In a broad sense, this is a boon to the farmers,as they can now manage their farm acre by acre instead of the old approach of managing it field by field. This saves a lot of resources, energy, time, and cost, therefore further increasing their profit and eventually reducing the end-tunnel cause of the bullwhip effect.

4.2 Aerial Imaging for Farmers on a Low Budget

Precision agriculture can be enabled by using drones since capturing aerial imagery can lower costs and imply successful implementation of data collection. However, operating a drone may fall beyond the reach of a farmer and does come with an initial investment of capital. The way this technology would work is by using TYE (tethered eYE). It is made of a tethered helium balloon with a custom mount that can hold a camera and a backup battery. This also involves computer vision algorithms that capture data about crop growth through aerial imagery. These models then analyse this data to make predictions about the expected crop yield, allowing farmers to optimise harvesting and distribution plans throughout the supply chain.

Researching agriculture is not only related to farms and crops. It also includes livestock and the poultry industry.

The above-mentioned technology can also be used to monitor livestock. Tethered cameras or sensors can remotely monitor the behavioral patterns of animals, enabling the farmer to see which periods would give them the most produce. When used with precision, these models are also capable of alerting the farmer of any sudden changes, emergencies, or unusual behavior amongst the cattle, ensuring rapid treatment and further lowering costs.

The primary goal of using technologies, methods, and practices is to reduce costs and optimise the produce, which would significantly improve quality and the economy and reduce the wastage of excess resources.

4.3 AI for Affordability:

While aerial imaging can reduce costs and save time spent on fieldwork, artificial intelligence can be used to reduce the number of sensors on drones using multimodal AI and enhance the ROI (return on investment) of the hardware that is used on the farm by using AI to guide optimal strategies for sustainable and profitable produce.

4.3.1 **Multimodal AI on Farms:**

Imagine it is winter in Ohio, and a farmer is preparing to fertilise his field to ensure a proper yield and protection from the harsh weather and temperature. The weather analysis from the nearest weather station shows a temperature slightly above 32 F, and the farmer, being relaxed, fertilises the field, but sees the very next morning that due to certain temperature islands on the farm, about 40% of the crops are dead. This is one of the primary reasons for the sudden fluctuations in prices in agriculture.

In order to combat this, a technology called DeepMC has been developed by Microsoft. DeepMC is a multiscale encoder-decoder framework that combines weather station forecasts with sensor data to predict such temperature islands on a massive farm. This technology has a success rate of almost 90%.

4.3.2 Optimal Advisories:

There are three parameters that crop yielders need to consider before making any decision.

1. *Strategic: decisions* that impact the future of the farm. These need to be more calculated thananalyzed, as they give an estimate offertilizers, resources, workforce, etc. These also include the type of crops to be grown in a specific season and which areas of the farm need more nutrients. These are more statistical. *(Note: The last point of the above can only be found if the farmer is already using data and precision agriculture on his farm to maximize output.)*
1. *Tactical:* Creating a scheduled practice that warns them of when to turn on the motors for regular water supply, fertilize the soil, collect additional aerial data, etc. It is more disciplined and schedule-based.
2. *Real-time:* Information like weather situations and soil conditions change every second, making it very difficult to predict them in advance over a long period of time. Therefore, decisions about the drone's flight path, aerial visibility, etc. are highly dependent on real-time feedback.

Many of these choices are made in situations filled with various uncertainties, whether they are related to nature, human factors, or machinery. Artificial intelligence has the ability to create a sequential decision-making framework to assist farm operations. It leverages insights gathered by the FarmBeats system (Microsoft’s Research Project) to calculate the best actions for strategic, tactical, and real-time decision-making. This system finds optimal strategies by combining farm-specific recommendations with rules influenced by factors like nature, market conditions, and policies, all while considering signal dynamics. These AI technologies play a role in making agriculture more accessible by delivering practical insights and guidance to individual users in a cost-effective and high-quality manner.

Vertical Farming

The general conception of people about agriculture is of vast green fields arranged in a special pattern and design with a bright, shining sun. These practices have long harmed our planet, making it one of the biggest reasons why agriculture is a cause of climate change, and the severity of the problem has reached such a level that we have lost a third of our arable land over the last 40 years. However, things have gradually evolved, and people have started doing vertical farming. Even though this farming technique has been around for a long time, relatively newer, high-tech vertical farming companies are emerging today. These projects use hydroponic designs to provide crop access to natural sunlight, so they are able to harvest with less waste of land, water, and energy.

It also allows the farmers to produce a perfect microclimate, enabling them to grow their crop all year round. These farms use smart sensors to monitor technical variables including temperature, carbon dioxide, oxygen, humidity, nutrient concentration, pH, pest control, irrigation, and harvesting. Vertical farming, being at the core of controlled environmental agriculture, leverages cutting-edge imaging and sensor technologies such as cameras and thermal imaging for the measurement of plant development, temperature, and various environmental factors. It uses approaches like automated dosing systems to deliver nutrients to the plants and monitor the nutrient solution, and sterilisation systems that enable the optimal growth of plants and keep them under international food safety regulations. It is done using chemical disinfection, UV-C sterilisation, and ozone sanitation. These modern-day techniques make great use of computer science and incorporate automation-based artificial intelligence systems to get the most environmentally friendly harvest possible.

IV. Conclusion

In the face of a growing global population and the challenges of climate change, agriculture is at a crossroads. Agriculture, crop cultivation, and the food processing industry all need to grow at almost double the speed of the increase in the human population. Additionally, what matters more is growing quality food over quantity at the same and/or reduced prices to cater to the demands across the globe.

In this digital era, technology has been advancing things in every facet of life, and to combat this growing challenge, technology can be implemented too. Throughout this paper, we have delved deep into the history of agriculture, its economic significance, new methods and practices, computer vision, and algorithm development. We have also covered the detrimental effects of the bullwhip effect, which is the primary cause of food wastage down the supply chain line. We have also seen that farming, or the agriculture business, has completely changed its general definition and has been transformed into vertical farms that are proving to be far more productive than traditional farms. As we shape the future with digital harvesting, it is crucial to lay the seeds to feed the growing population and produce quality food.

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