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# Cloud Computing in Agriculture

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***Abstract:*** *According to the United Nations, in order to feed the world's expected population of 9.7 billion people in 2050, agricultural production must rise by 69% between 2010 and 2050. Using cloud computing for agriculture to monitor crop inputs and output can help meet the food demand. Cloud computing in agriculture has been a breakthrough and a game-changer for the industry. Often cloud computing is used to gather, analyze, and store data about agriculture. This paper provides a primer on the use of cloud computing in agriculture.*

***Keywords:*** *cloud computing, edge computing, agriculture, technology.*

## INTRODUCTION

Agriculture is one of the earliest of occupations on the planet. It has seen a tremendous transformation over the last five decades due to advances in technology. Seed, irrigation, and fertilizers have also greatly improved, assisting farmers in increasing yields. Artificial intelligence, big data analytics, cloud computing, Internet of things, and other emerging technologies could boost yields, enhance water efficiencies, and promote resilience in crop production and other areas of agriculture. They can help farmers use resources more efficiently and sustainably [1].

With about 7.8 billion people inhabiting this earth, it is inevitable to consider ways to meet the rising demand for food. Agriculture industry needs to be smarter about finding innovative ways to get more out of each piece of land. Agriculture businesses are modernizing through smart agriculture based on cloud computing and IoT technologies. These technologies create solutions for the effective usage of finite resources like arable land and water.

Cloud computing is the pay-as-you-go service for IT resources over the Internet. Rather than building, owning, and maintaining their own IT infrastructure, businesses can use cloud to access technology resources such as computing capacity, storage, and databases on a pay-as-you-go basis. Without cloud solutions, it's hard to build a good IT infrastructure. Many sectors have greatly benefited by cloud computing, and agriculture is one of them. A typical agriculture cloud system is shown in Figure 1 [2]. When farmers outsource their computer infrastructure and handling to the cloud, it allows them to focus on their core business, instead of having to invest in computer infrastructure.

## CLOUD COMPUTING BASICS

Cloud computing is the on-demand availability of computing resources (such as storage and infrastructure), as services over the Internet. It represents the underlying platform technology enabling cloud manufacturing. It is a newly emerging service-oriented computing technology. It is the provision of scalable computing resources as a service over the Internet. It allows manufacturers to use many forms of new production systems such as 3D printing, high-performance computing (HPC), industrial Internet of things (IIoT), and industrial robots [3].

The key characteristic of cloud computing is the virtualization of computing resources and services. Cloud computing is implemented in one of three major formats: software as a service (SAAS), platform as a service (PAAS), or infrastructure as a service (IAAS). These services are illustrated in Figure 2 [4] and explained as follows.

SaaS: This is a software delivery model in which software and associated data are hosted on the cloud. In this model, cloud service providers offer on-demand access to computing resources such as virtual machines and cloud storage.

PaaS allows the end-user to create a software solution using tools or libraries from the platform service provider. In this model, cloud service providers deliver computing platforms such as programming and execution.

In the HaaS model, cloud service providers can rent manufacturing equipment such as 3D printers.

Just like cloud computing, CM services can be categorized into four major deployment models (public, private, community, and hybrid clouds) [5]:

- Private cloud refers to a centralized management effort in which manufacturing services are shared within one company or its subsidiaries. A private cloud is often used exclusively by one organization, possibly with multiple business units.
- Community cloud is a collaborative effort in which manufacturing services are shared between several organizations. Services are provided to multiple organizations from a certain community with similar business goals.
- Public cloud realizes the key concept of sharing services with the general public. Public clouds are commonly implemented through data centers operated by providers such as Amazon, Google, IBM, and Microsoft.
- Hybrid cloud that spans multiple configurations. and is a composed of two or more clouds (private, community or public), offering the benefits of multiple deployment modes.

## APPLICATIONS OF CLOUD COMPUTING IN AGRICULTURE

Cloud computing applications in agriculture have revolutionized the field in recent years. It is applied to the agriculture sector in many ways to help it grow. Some common applications of cloud computing in agriculture include the following [6]:

- *Crop-related information:* The cloud can capture information related to all crops grown in the recent past, thereby helping farmers make decisions on what to grow next.
- *Weather information:* The cloud can store region-specific weather information, helping farmers make crop-related decisions. With the help of cloud computing, weather can be forecast for a specific duration, which can help the farmer in the selection of crops.
- *Soil Information:* Besides soil profile, the cloud can also provide a trend of soil in the past, which will help in predicting the trend in future.

- *Monitoring Growth*: The growth of various crops can be monitored in different regions and at regular intervals.
- *Farmers' Data:* The use of data is rising exponentially in the agriculture industry. Smart agriculture creates a vast amount of data on the farm on daily basis. The use of advanced technologies in agriculture generates a large amount of data, known as big data, which can be analyzed to make better farm-level decisions. Enhancing decision support for farmers is contingent on integrating data from various sources.
- *E-commerce:* Traditional e-commerce agricultural product sales have not been able to meet the increasingly fierce market competition needs of the agricultural product market. Through the agricultural management information system of cloud computing, farmers from rural areas can sell their produce directly to the end users/retailers and avoid middlemen who tend to exploit farmers.
- *Precision Agriculture:* This uses technology to keep track of and get the most out of everything. Cloud computing helps farmers achieve precision agriculture. Cloud-connected wireless sensors collect data from the field, which is then analyzed by machine learning algorithms in real-time to give farmers a better idea of how their crops are doing. High-resolution satellite photography enables precision agriculture even in cloudy locations. Figure 3 shows how precision farming works [7].
- *Growth Tracking*: The growth of various crops can be controlled, allowing for the comparison of current growth trends to previous growth patterns. Cloud analytics can be applied to the stored data to provide growth tracking insights.

**BENEFTIS**

Cloud computing offers a wide range of benefits to companies in the agriculture industry. The integration of cloud computing principles with traditional farming opens up a world of possibilities. The convergence of big data, artificial intelligence, cloud computing and the Internet of things can help farmers minimize greenhouse gas emissions while maximizing crop yield. Cloud computing can help farmers with real-time computation, data access, and storage to users without them knowing about the physical location. The ultimate goal is to provide farmers with cloud-service based monitoring, modeling and decision-making tools for their farm health and production management. Other benefits of cloud computing in agriculture include the following [8,9]:

- *Cost:* Moving to the cloud helps companies optimize IT costs. Cloud lets you offload some or most of the costs of purchasing, installing, configuring, and managing your own on-premises infrastructure. The cloud solutions offered by the biggest industry players are too expensive for average-sized farms. Cloud computing farming expenses depend on the amount of data generated by the IoT system. The cost of cloud computing is going to increase. Edge computing in agriculture frees businesses from storing mammoth volumes of irrelevant and useless data.
- *Global Scale:* Cloud computing enables global outreach. Farmers and businesses around the globe are using cloud computing to accelerate innovations in agriculture. The benefits of cloud computing services include the ability to scale elastically. Although the uptake of cloud computing took a while to spread, the leader is the technology giant Japan, followed by China, and the USA. These and other nations have realized the importance of ICT quickly and are adopting it in all sectors, including agriculture.
- *Agility:* With cloud, your organization can start using enterprise applications in minutes, instead of waiting weeks or months for IT to respond to a request, purchase and configure supporting hardware, and install software.

- *Flexibility:* Due to the architecture of cloud computing, users can access cloud services from anywhere with an Internet connection, making services flexible.
- *Collaboration:* Collaboration is made easy with cloud computing. Team members can collaborate on the same data and system in the cloud, regardless of their physical location. Scientists involved in agricultural research can use the cloud to directly share their information.
- *Green Technology:* Cloud computing may be regarded as a green technology since it enables resource sharing among customers that minimize the number of data centers which save power and reduce pollution.

## CHALLENGES

The agriculture industry is facing many challenges, including constraints in land and farming inputs, rising costs of inputs, and the need to improve sustainability and resilience. Due to the fact that the agriculture industry is practically free of political borders, the differential cyber laws in various nations could pose a problem. With so many complicated devices collecting so much information about agriculture, agribusinesses need a way to store and process the big data. Other challenges of cloud computing in agriculture include the following [2]:

- *Security:* A major challenge lies with regard to the security of data and services. This requires opting for the most reputed service provider for the service required. Since services are maintained by third parties, there is the problem of data security. Where there is data, there are always threats. As IoT systems transmit data to the cloud, many devices are involved. Every time data travels back and forth, the chance of its being violated, stolen, and misused grows exponentially. Edge computing is the ultimate recipe for minimizing the risk of data theft or violation, as it lets your data stay within the device that collects it. It revolutionizes data analysis by performing it locally.
- *Connectivity*: Cloud computing requires a high-speed Internet connection. It does not perform well on low Internet connections because it has to process the data in the cloud and then deliver that data to the end-user. The limitation of cloud computing, the lack of real-time connectivity, has led to the introduction of edge computing.
- *Speed:* Slow Internet connection is one of the most widespread issues in today's digital agriculture. The major limitation for the adoption of cloud computing services in rural areas is Internet speed. Collecting, transferring, and analyzing data is a time-consuming. Edge computing is the best solution for remote locations where there is no centralized Internet connection.
- *Trust:* Cloud computing has almost zero physical contact with the users (the farmers) and that creates some sort of resistance to the adoption of this technology.

## CONCLUSION

At the moment, the cloud has almost become a metaphor for the Internet. Cloud computing enables customers to use infrastructure and applications via the Internet, without installing and maintaining them on-premises. To accomplish the next productivity jump, significantly more advanced digital technologies are required. Cloud computing in agriculture offers many opportunities for the sector to prosper and grow.

The agricultural sector is undergoing a technological revolution, and the adoption of cloud computing is central to this. Through the harnessing of IaaS, PaaS, and SaaS platforms, the sector is leveraging cloud computing to enhance efficiency, precision, and scalability. Cloud computing helps farming to achieve precision agriculture. It may play a significant role in agricultural

informatization by bringing some new prospects to information management and service. More information about cloud computing in agriculture can be found in [10-12].

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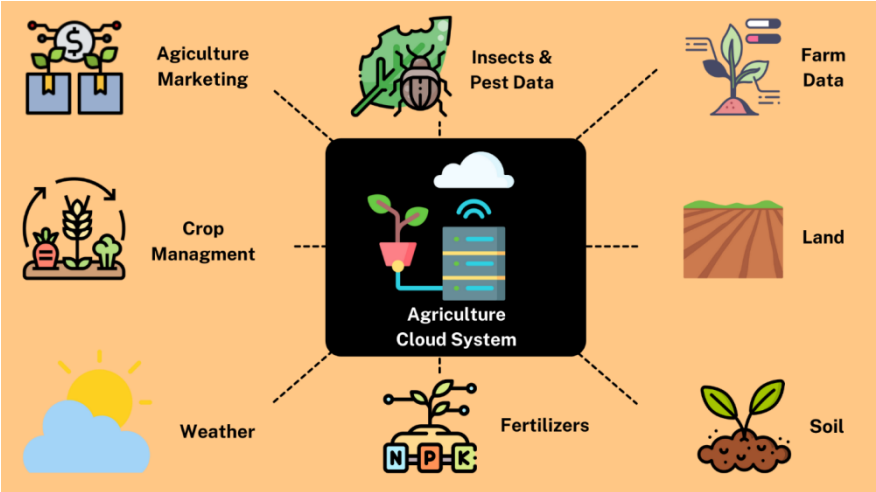


**Figure 1. A typical agriculture cloud system [2].**

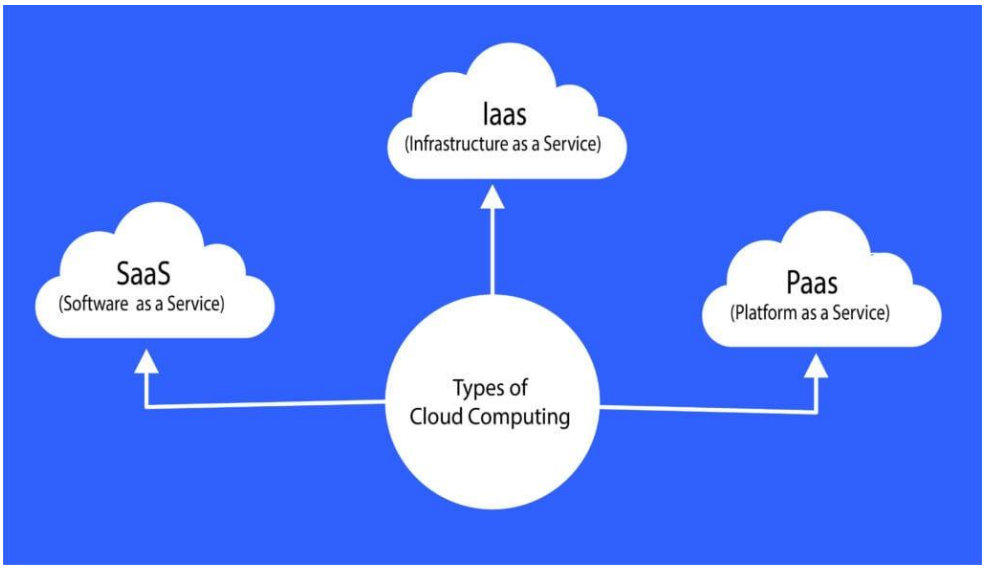


**Figure 2. Three types of cloud computing [4].**

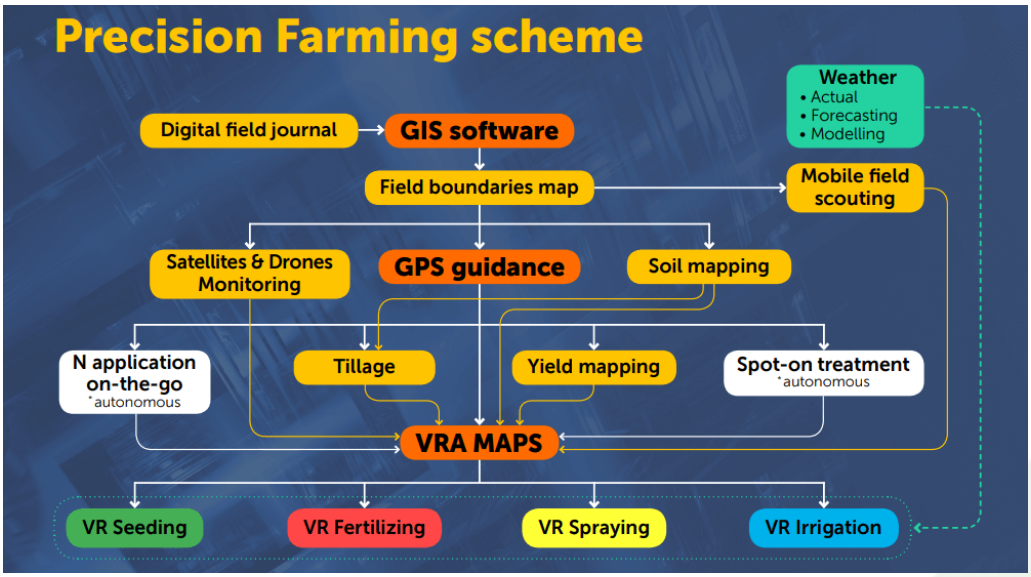


**Figure 3. How precision farming works [7].**