Chapter 8
Information and Communication Technology for Small-Scale Farmers: Challenges and Opportunities

Shahriar Shams, S. H. Shah Newaz and Rama Rao Karri

Abstract With the rapid growth in the world population, food production is going to be the biggest challenge for the 21st century. Industrialisation and urbanisation are taking away the available agricultural land and hence there is immense stress on the food production to cater the enormous growth of population. The farming community are struggling to meet the increased demand for food production due to limited agricultural land. Natural calamities, extreme weather events and wider variations in rainfall and temperature, destructing crops and reducing yields, thus affecting farmers' incomes and livelihoods. Unsustainable agricultural practices further worsen the soil fertility and capacity to retain water, thus result in soil erosion. These problems can be minimised by utilising the Information and Communication Technology (ICT) to the farming community, especially small-scale farmers. The advances in the agricultural practices and up-to-date weather/climate information, immensely help the farmers to implement the best practices and contribute to sustainable agriculture. This chapter focuses on the need of ICT to provide the best sustainable practices and optimised water management, which can revolutionise farming technology. An assessment of various available technologies based on user-friendliness, affordability and pros and cons are discussed in detail for appraising their applications by the small-scale farmers.

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8.1 Introduction

Farmers often find it difficult to practice climate-smart agriculture due to lack of clear understanding and interpretations of the latest weather and climate information, which significantly influence the agricultural activities. The incomes and livelihoods of farmers depend on agricultural yield, which relies on extreme weather events or interannual variations in rainfall and temperature that can result in the destruction of crops or reduced yields. Soil reduce water retention and crop yield capacity could arise from unsustainable agricultural practices leading to an indirect effect on ecosystem degradation and habitat loss.

Small-scale farmers depending on household members for the agricultural works mostly comprise of small farms with less than two hectares of cropland with a major focus on producing staple food for household consumption [1]. According to the World Bank's Rural Development Strategy [2], small-scale farmers have been identified with limited resources including land, capital (low asset base), skills and labour. Particularly in Asia there has been significant decrease in farm size (China's 0.56 hectares in 1980 to 0.4 hectares in 1999; India 2.2 hectares in 1950 to 1.33 hectares in 2001; Philippines 3.6 hectares in 1971 to 2 hectares in 1991; and Pakistan it 5.3 hectares in 1973 to 3.1 hectares in 2000) due to urbanisation and rapid industrialisation [3–5]. It is estimated that there are altogether 500 million small-scale farmers out of which 87% are in Asia/Pacific region. The majority of these small-scale farmers are from China (193 million), followed by India (93 million). Three other Asian countries with a large number of small-scale farmers are from Bangladesh (17 million), Indonesia (17 million), and Vietnam (10 million). Small-scale farming has contributed to the "Green Revolution" in many Asian countries. The total value of agricultural output is significant as for example farm output exceeds 50% in India though the amount of land used by small-scale farmers is only 44% due to higher use of labour, and a generally higher index of cropping intensity and diversification. One of the major challenges the farming community is like to face is the impact of climate change resulting in an increase in temperature [6, 7], fluctuations in rainfall patterns [8], increased intensity and frequency of flash floods and droughts [9, 10]. They pose a threat to food security and the livelihood of millions of people [11]. With the climate changes, the farmers face difficult challenges which can be mitigated by interpreting the variations in the seasonal climate conditions and adjust their agricultural management practices accordingly in terms of plantation, irrigation and harvesting. Generally, either the land is over irrigated to overcome dry weather or under irrigated expecting wet conditions. The decision in applying the right amount of water at the right time depends on the soil moisture, plant growth, and availability of sunlight. This holistic application of irrigation can be further aided by automatic irrigation, guided by advancements in ICT. This approach will assist farmers to know "when to plant" and specifically "which crops or crop varieties to plant", and "when and what amount of water" to apply for various types of plants. This chapter focuses on the need and mitigation measured for water management with the application of the expert systems, automatic fertigation (use of appropriate sensors) and smart, optimized water irrigation. This framework provides a sustainable eco-system.

8.2 Challenges Faced by Small-Scale Farmers

Small-scale farmers are facing a number of challenges while producing food in a sustainable manner. They are more vulnerable to climate change as compared to large-scale farmers, due to lack of awareness and limited financial capital [1].

8.2.1 Poor Water Management and Water Shortage

Poor water management such as flood irrigation results in excessive use of water in many countries of Asia while during the dry period, the absence of water deteriorates agriculture productivity. The rising demand for non-agricultural uses of water is leading to water scarcity and severely limits the expansion of irrigation. Unsustainable extraction of surface water and overexploitation of groundwater can result in falling of groundwater table. As a result, small-scale farmers have to rely on more costly pumps due to the high suction head. Besides, improper application of fertilizers and pesticides lead to water pollution and damage the productivity of crops.

8.2.2 High-Value Agricultural Products

Small-scale farmers face a number of problems producing high-value agricultural products due to labour-intensive, stringent food safety and quality standards as well as high volatility in prices, thus resulting in high market risk. Small-scale farmers in the semi-arid region are more vulnerable to crop shocks, particularly when it comes to natural calamities and disasters (e.g. El Nino in the Philippines, Tsunami in South East Asia and flash floods in Bangladesh). Use of ICT to forecast natural disasters and taking proper remedial techniques are the biggest challenges for small-scale farmers.

8.2.3 Impact of Climate Change

Small-scale farmers in poor developing countries are more vulnerable to the impact of climate change. Even moderate change in weather conditions ($\cong$1 °C for wheat and maize, ≅2 °C for rice) can reduce yields significantly, due to less resistant to their heat tolerance [2]. How to accommodate plants or crops from moderate warming using the greenhouse environment is a major challenge for small-scale farmers due to limited resources and the availability of funding.

8.2.4 Institutional Innovations for Productivity

Small-scale farmers can enhance productivity through new agriculture dominated by value chains. However, the most important challenge is promoting contract farming. These supply chains have high-value exports, which is done both through private and public sector initiatives.

8.2.5 Affordability

Farmers' preferences and willingness to pay for smart agriculture technologies vary significantly based on potential benefits and costs of procuring the technology. Farmers' priorities may differ from technology to technology based on their age, gender, landholding size, income level, farming system and location, the financial subsidy provided by Government or semi-governmental agencies.

8.3 Information and Communication Technology (ICT)

ICT can play an important role in disseminating information to small-scale farmers on the forecasting of weather, selection of production technologies and potential agricultural input and output prices. Many successful examples of ICT usage benefiting small-scale farmers are growing. As a case study, an "agribusiness division of Indian Tobacco Company (ITC) sets up 6400 Internet kiosks called e-Choupals in nine Indian states, reaching about 38,000 villages and 4 million farmers. This program was started in the year 2000 and proposed for five years. Later, it was extended for another two years due to its success. During this program, the farmers are trained and given free information on local and global market prices besides the weather, and best farming practices. They have been able to purchase goods such as wheat, soybeans, coffee, shrimp, and pulses through the e-Choupal network valued at $400 million [2]. With the introduction of smart agricultural technology, traditional agriculture has been transformed using advanced ICTs, eventually contributing to significant improvements in agricultural productivity and sustainability. Smart farming aided by ICT reduces the ecological footprint". With advances in ICT, it is possible to create an update and remote sensor network, thus allowing continuous monitoring of the farm.

8.3.1 Remote Monitoring and Control

In order to actualize smart farming, the role of sensors and actuators is significantly important. With the rise of technological advancement in semiconductor technology, the cost of sensors is declining rapidly.

8.3.1.1 Sensors and Actuators

A sensor is generally referred to a device, module or subsystem that can sense any particular event or any change of its surroundings and can notify to this information to other nodes (e.g. local gateway) in a sensor network. Broadly speaking, in a Wireless Sensor Network (WSN), "a sensor node is comprised of four basic modules: sensor/actuator module, a communication module, a processing module and power source module". The role of the sensing subsystem is to sense any particular event, whereas the connectivity subsystem is in charge of forwarding the sensed information to another node in a WSN. The processing module of a sensor node transforms the sensed data into a specific format for notification while the power source module supplies power to the sensor node. A wide variety of sensors are used in the agricultural field for detecting temperature, moisture, water level, conductivity, salinity etc. as shown in Table 8.1.

An actuator is a module or subsystem of a machine, and it is responsible for actualizing an action (e.g. moving or controlling any subsystem) when it receives a control message. For example, an actuator module may be responsible for opening the valve of an irrigation facility or opening a window for ventilation. Similar to the sensor module, an actuator requires communication module in order to get instruction remotely and provide its current status whenever required.

Wireless communication technologies can play a significantly important role in collecting data from sensors and controlling the actuators installed at a farming facility remotely. With the rapid technological advancement, most of today's sensors are equipped with tiny communication module allowing transferring sensed data to a remote place. To date, there are several communication technologies available that a sensor communication module can use in order to communicate

Table 8.1 Sensors for different types of data collection [12–14]

Sensors applied for agriculture	Sensor available for the relevant data
Soil	Moisture content, temperature, conductivity, salinity, water level, dielectric permittivity, rain/water flow and water stress estimation
Plant	Moisture content, wetness, temperature, CO_2 concentration, hydrogen, photosynthesis
Weather	Temperature, light intensity, wind speed, wind direction, humidity, atmospheric pressure

Table 8.2 Comparison of communication technologies [14, 16–19]

Parameter	ZigBee (IEEE 802.15.4)	Bluetooth Low Energy (BLE)	Wibree (baby bluetooth)	WiFi (IEEE 802.11)	LoRaWAN	WiMAX (IEEE 802.16)
Frequency band range	868/915/ 2400 MHz	2400 MHz	2.4 GHz	2.4 GHz	EU: 868 MHz and 433 MHz USA: 915 MHz and 433 MHz MHz (USA)	2–66 GHz
Data rate	20/40/ 250 Kbps	1024 Kbps	1 Mbps	11–54 Mbps	250 bps–5.5 kbps	75 Mbps
Cover age range	1–100 m	30–300 ft	5–10 m	40 m (indoor) 140 m (outdoor)	Urban (3–6 km) Rural (15 km)	3 miles
Cost	Low	Low	Low	High	Very low	High

with other nodes in a WSN, including ZigBee, Bluetooth, Wibree and WiFi. These communication technologies vary greatly in terms of capacity and coverage. Depending on the geographical area covered by a wireless network, they are classified them into different types: Wide Area Network (WAN), Local Area Network (LAN) and Personal Area Network (PAN). A comparison of different wireless communication technologies is given in Table 8.2. Among all the communication network technologies, ZigBee is considered to be a cheap and power-efficient solution [14].

8.3.1.2 Wireless Communication Technologies

ZigBee communication technology offers low power, low data rate and long battery lifespan, making it a good choice for smart farming, industrial automation and smart home applications [15]. Aside from this, the protocol stack of ZigBee is relatively less complex compared to the other protocols (e.g. Bluetooth or Wi-Fi). A Zigbee based network can accommodate 65,000 nodes. In order to expand battery lifespan, ZigBee node supports low to the very-low duty cycle (the active duration for transmission is very small). It supports multi-hop routing and ad hoc network topology (not a fixed topology), thereby making ZigBee as an ideal choice for deploying in a dynamic environment [15].

Unlike ZigBee, Bluetooth Low Energy (BLE) is designed to provide high data rate within a short-range [15]. This is a low-cost solution developed for portable devices that have limited power storage capability. It supports both point-to-point and point-to-multipoint connection wireless technology, allowing fast data sharing within the neighbouring Bluetooth devices. Basically, ZigBee and BLE are the communication technologies designed for short-range communication using unlicensed Industrial, Scientific, and Medical (ISM) spectrum. There are many other communication technologies for short-range communication with low data rate support, such as the Infrared Data Association (IrDA), HomeRF, and Z-Wave. ZigBee, BLE, IrDA, HomeRF, and Z-Wave are popularly used for wireless PAN communication.

Wifi is a wireless communication technology for facilitating LAN communication based on the IEEE 802.11 standards. There are different variants of IEEE 802.11 standards (e.g. 802.11a, 802.11n, 802.11ah) with different coverage and data rate capacity. The IEEE 802.11 standard supports both Ad hoc (there is no device for coordination. Each device in the network needs to relay others packets) and infrastructure mode (an access point coordinates communication among the devices with Wifi interface) for communication among the devices in a LAN. A single access point (base station) can serve hundreds of devices. Wifi supports eight Quality of Service (QoS) classes, allowing service requirement of the verity of applications running at end-user devices. Further, the power consumption footprint of a Wifi access point is relatively low (10–13 Watts) and devices power consumption for communication is low as well, thereby allowing long battery lifespan.

WiMAX (World Wide Interoperability for Microwave Access) facilitates point-to-multipoint connection within the coverage of a WiMAX Base Station (BS). The signal from a BS can reach up to 3 miles with a data rate of 75 Mbps when transmission frequency 2–66 GHz band. WiMAX wireless spectrum can be operated over both licensed and unlicensed band (ISM)—unlicensed spectrums are more widely adopted. The BS can set the data rate for each station residing in its coverage depending on received signal strength [19]. Additionally, WiMAX supports five QoS classes, allowing the network to serve different applications (media content, web browsing, streaming media) with different QoS requirement [20]. WiMAX falls under the Wireless MAN (WMAN) category due to its wide geographical area coverage.

For long-range communication Long Range Wide Area Network (LoRaWAN) wireless communication technology was introduced by LoRa Alliance. LoRaWAN is a single frequency network with long coverage allowing a large number of devices to be connected through a single LoRa base station. In Europe, the frequency used is 868 MHz whilst the USA and Asia are 915 and 433 MHz, respectively. In terms of coverage, LoRaWAN gateway could receive a signal from end-device as far as 15 km in the rural area and 2–5 km in an urban area. The data rates vary according to distance and message duration. According to Lora Alliance, LoRaWAN data rates range from 0.3 kbps to 50 kbps. In Europe, the data rates range from 0.3 kbps to 22 kbps, and US data rate is 0.9 kbps [16, 21]. Similar to LoRaWAN, IEEE 1902.1 standard introduced RuBee, which uses very low frequency (131 kHz) carrier for long-range communication, allowing 128-byte data packet transmission. RuBee equipped devices require ultra-low power consumption for communication (a sensor with a RuBee interface can have a battery life of several years).

8.3.2 Data Aggregation

With the rising importance of ICT in precision agriculture, we have been witnessing significant progress in developing sensor platform that can collect data from different sensors, filter out invalid data (preprocessing of data), make decision based on the obtained data from sensors, control the actuators, and pass the data to the end-users' applications (e.g. it may forward data to a web server which can be readily accessed by farmers to get update). Initially, to collect data from the sensors in a farming facility and control the actuators, the sensor platform requires a gateway which is generally installed close to the farming facility [22]. Furthermore, this local gateway may communicate with the associated applications running in cloud servers in order to store the time series sensor data and get insightful meaning from the data. Figure 8.1 illustrates two different scenarios. In the first scenario (see Fig. 8.1a) all the sensors and actuators are communicating using PAN network interface (e.g. Zigee) with the gateway, and the gateway uses WMAN communication interface (e.g. WiMAX interface) to communicate with BS. The PAN coverage area data is forwarded using Ad hoc mode. Once data is received at the BS, it is responsible for forwarding the data to the remote cloud server. The second scenario is almost the same except the sensor and actuator data communication approach. Here, they use the WMAN communication interface to send data to the BS directly (an infrastructure mode communication approach). Instead of a gateway (a separate standalone network component in a farm), farming data collection gateway functionality can be implemented in a BS of wireless communication technology (e.g. WiMAX, LoRaWAN, WiFi) in order to collect data [19].

Data from sensors can be regularly polled from the gateways. The inter polling interval for data collection from different sensors may depend on several factors, including accuracy of the rate of change, network bandwidth, data storage and processing capacity at the gateway, and residual battery power of the sensors (more frequent polling of data would reduce sensors' battery life). Instead of polling each sensor periodically, as an alternative approach, the sensors may send any data to the gateway only when a certain condition becomes true. Such an approach is generally referred to as the trap mechanism. The processing capacity of a local gateway may not be sufficient in the case when a farm has many sensors and actuators. In such a case, a local gateway may need to rely on remote cloud servers for data processing.

The growing number of IoT devices has led to realize the importance of enriching computing and storage capacity at the network edge and access segment. Considering this Cisco coined the concept of Fog computing, which is a relatively small computing facility embedded in the network equipment of edge and access segments (e.g. base stations, switches, routers) [23]. Therefore, another alternative

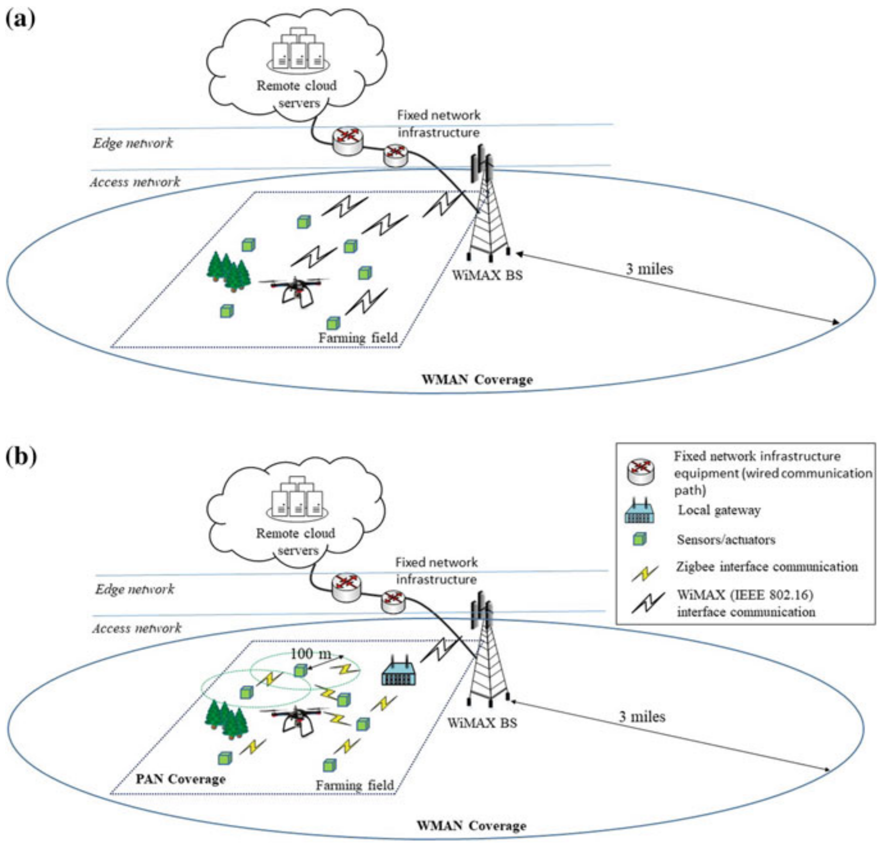

Fig. 8.1 Wireless communication technology in smart farming: **a** sensors/actuators are communicating with the gateway using wireless PAN, **b** sensors/actuators are communicating using a WMAN communication interface

option for aggregation and preprocessing of the data from the remote sensors and actuators would be at the routers and switches in edge and access network segments in the case when the local gateway has limited computational capacity.

Inevitable growth in semiconductor research domain has a leveraged capacity of the networking equipment significantly. Therefore, the data aggregation gateway in the network may conduct a preprocessing operation before further processing (e.g. storing or analyzing). The preprocessing operation may include filter the data on the fly (e.g. removing duplicated data, erroneous or incomplete data). By doing so, the gateway would be able to reduce the amount of data for processing and storage load [24]. Further, the gateway could be the decision centre for controlling any actuators in a smart farming facility [25]. For example, it may control remotely an irrigation system or the windows of an indoor farming facility for ventilation whenever required.

Table 8.3 Gateway functional capabilities

Major functionalities	Description
Monitor	Monitor sensors' reading
Control	Control the actuators installed in a farm-based on predefined logic
Data processing	Removing erroneous and redundant data, analyze data (support data visualization), data format change, etc.
Data security	Integrity and verifying source of data collected from sensors. Encryption and decryption of exchanged data in order to maintain confidentiality
Communicate with Cloud and clients' devices (e.g. phone, tab)	Send the preprocessed or raw data to the cloud and receive instructions. Get instruction from farmers
Data and instruction storage	Store data and instruction for short or long term
Instant decision making	Based on collected data make an instant decision (e.g. opening a window for ventilation)

Drones and agricultural vehicles (e.g. weed detection and terrain levelling) can also be used for data aggregation point if they are equipped with data aggregation gateway functionalities [26]. If the sensor data is not very delayed sensitive (i.e. delay tolerant), drone or any agricultural vehicle assisted data gathering would be a feasible solution in smart farming.

There are several sensor platforms available with different functional capabilities. Among them, some of the well-known sensor platforms are SmartFarmNet [22], SensorCloud [27], and IBM Bluemix [28]. An overall summary of the functional capabilities of a gateway of the existing sensor platform is presented in Table 8.3.

8.3.3 Cloud Computing in Agriculture

Cloud computing provides on-demand service to its clients from anywhere, anytime and anyplace. This would empower farmers with new applications that will use the data collected from different sensors to infer various farming condition/context and assist farmers in making a better farming decision. We have been witnessing tremendous contribution that Cloud is making to leverage other sectors, including industries, infotainment and health services. Likewise, Cloud will contribute to increasing agricultural yields while reducing cost, save time, minimize risk, and environmental impacts. Broadly speaking Cloud can leverage the following areas significantly.

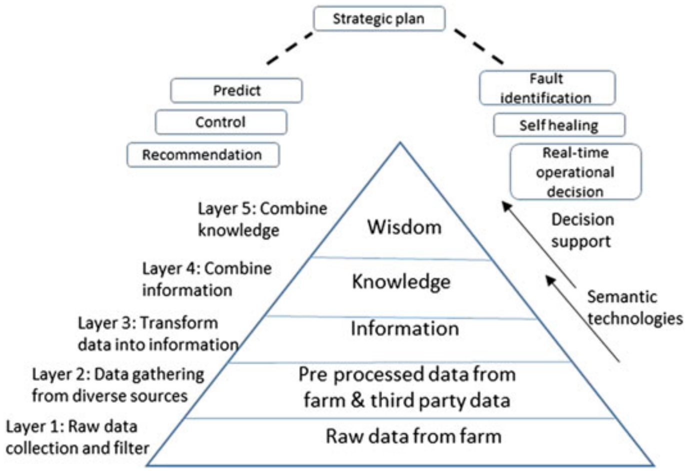

Fig. 8.2 Gaining wisdom in smart farming from data [29]

8.3.3.1 Farming Automation

Cloud service can transform data into context and piece different information together collected from various sources to come into a conclusion (see Fig. 8.2). Such ability of Cloud has been propelling the growth of other automation technologies (e.g. home and building automation, industrial automation). In the near future, our farming would become mostly data-driven and data-enabled decision making [30] due to rapid cost reduction of sensors and the necessity of increasing quantity and quality of yields in firming production. Data from different sensors installed in a farming facility will be fed into cloud-based applications to make a critical farming decision. Cloud can host different applications that will make a decision depending on context derived from input data. Besides controlling different actuators in a farming facility (e.g. automatic sprayers in row crops), Cloud can control flying drones and autonomous tractors (a tractor make its own way to the farming area) [2].

8.3.3.2 Experience Sharing

Cloud would be the repository to store all the farming data from different sensors. This can also record all relevant experience from the farmers. Depending on the requirement, the information can be disseminated to a particular farmer or a group of farmers. There would be several possible approaches to information dissemination, including voice-based service, text message and interactive video conference service [31].

8.3.3.3 Computational and Storage Support

Over the last several years, research on simulating the impact of the factors like pests, plant diseases, and climate pattern on agricultural yield loss has been widely studied [32]. The findings of these research impart that simulation can significantly contribute to making a better decision for the farmers, thereby increasing agricultural yield and offering sustainable agriculture to our society. Further, to understand biological systems and their relationships, a large volume of the dataset is required (the dataset is increasing stupendously over the past few years). The requirement of data-intensive computation (e.g. biological systems analysis and agricultural simulation) has propelled increasing demand for large computation and storage facility. Cloud computing can come into play to help the agricultural sector by offering a utility model of computing (computational power as a service) and storage (storage as a service) [33]. Cloud can offer highly scalable and available services to its customers, depending on requirements. Therefore, it can pave the way for rapid growth in the agricultural sector. For a smart farming facility, an application (a process) run in a Cloud server that collects various data from the farm and other third-party sources (e.g. weather forecast, pollution pattern, pest and diseases related information) in order to gain knowledge and capability. Such a process we can visualize from Fig. 8.3. Semantic web and machine learning technology will allow the application for smart farming intelligent (understand the meaning of data, develop knowledge and take action accordingly).

SmartFarmNet [22] is one of the sensor cloud platforms for smart farming applying semantic web concepts to understand the meaning from sensor data. Here, we briefly explain some major opportunities Cloud can offer to smart farming.

- Data analytics: A Large amount of data can be analyzed to get insightful meaning using predictive modeling and crop failure risk analysis models [30].
- Pest and diseases modelling: To make a strategic farming decision, understating different types of pest and diseases is increasingly important. How the factors like climate change, soil pH condition, pollutants and any invasive species may affect a particular plant should be realized in order to make a strategic farming decision. To get such insights, data from various sources (e.g. weather forecast data, air pollution patterns) need to be analyzed [32]. Cloud can provide a platform where state of the art knowledge and technology can be brought together to improve pest and diseases modeling accuracy. The farmers can be readily advised the appropriate time and amount for fertilizer and pesticides they should apply in their farming facility land in order to reduce loss if there is any pest or disease attack. The platform might predict pest and diseases attack pattern based on its input information and provide guidelines to the farmers in order to avoid such an unexpected situation.
- Fault identification: As Cloud has a large processing capacity, obviously, it can perform better data pre and post-processing. During the preprocessing phase, the Cloud should be able to better understand any faulty reading of a sensor or actuators by correlating their data. Similarly, any faulty operation in farm

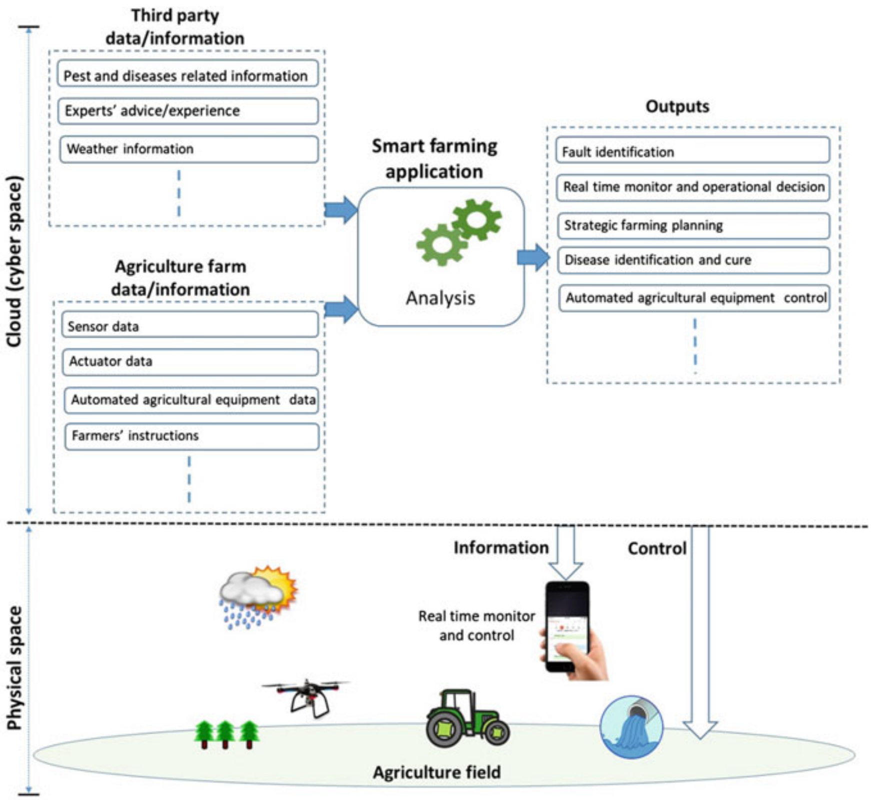

Fig. 8.3 Cloud assisted smart precision farming

management should be identified readily. Fast fault identification will offer a bigger window of opportunity to recover from any catastrophic failure of a system or change a farm operational plan that would lead to having a better outcome from a farming facility.

- Accumulating intelligence: Cloud brings information from diverse sources (see Fig. 8.3). For example, while deciding the amount of water should be irrigated within a certain amount of time in a farming land to meet certain soil moisture level, it may take into account possibility of rain which can be obtained by integrating the weather API in the farming application running in a cloud server.
- Real-time monitor and operational decision: Large computing and storage power will facilitate fast decision making, allowing a farm to be assessed almost real-time. For example, during lightening, valuable electronic equipment might be fried due to an electrical surge from a lightning strike. In such a situation, for instance, the application in Cloud for monitoring and making a decision of a farm can remotely take necessary action itself or may notify the farmers to take any necessary action.

- Crop harvesting period selection: The cloud platform (the application) may recommend the appropriate crop harvesting time taking account factors such as an increased amount of agricultural yields and profit (market value of the yields).

8.4 Role of ICT in Automated Agriculture

The robots that are used in agricultural purpose are referred to as agricultural robots. With technological advancement, we are witnessing the rapid proliferation of machinery in all spheres of life. In particular, both in the agricultural and industrial sector the growth has been astronomical. In many countries, the ageing population is increasing, and birthrate is declining. This is resulting in reducing the number of people in the labour force group in those countries. Furthermore, the global population is rapidly increasing. All these factors are contributing to moving automated agriculture-related research and development activities in breakneck pace. In a farming facility, automated equipment can be referred to as a system that does not require any manual intervention during its operation. Some commonly automated agricultural equipment are harvesting robots, driverless tractors and sprayers, and drones. Drones could be used for taking pictures of plant leaves to identify types of diseases the plant may have based on the image analysis and providing expert advice based on the expert-based decision support system. Besides, based on the weather condition built in an irrigation system can operate as per the water requirements.

8.4.1 Automatic Irrigation

Irrigation scheduling techniques depended on soil, crop and weather conditions and based on those conditions, and it is necessary to decide when to irrigate and how much water to be applied. To overcome this dependency and aid in decision making regarding irrigation scheduling, automatic irrigation has gained momentum. Automatic irrigation can be two types: fixed-rate and variable rate, as stated in Table 8.4. ICT can be used for automated farm management. All the automated equipment (sensor, actuators) are connected through communication interfaces. A smart application running on a gateway or the Cloud can be operated automatically. Bhatnagar and Poonia [34] demonstrated a prototype model for irrigation based decision support system by implementing a wireless data acquisition network to collect climate data. Soil moisture, temperature, weather conditions and sprinkler position were monitored remotely using the Bluetooth and GPS technologies. Goap et al. [35] developed an IoT based smart irrigation system by predicting soil moisture based on a machine-learning algorithm with smart irrigation scheduling

Table 8.4 Types of automatic irrigation system

Fixed-rate	Variable-rate
Cheaper with fixed control of water application. No correlation of water application with the weather condition	Cost-effective with the optimum application of water-based on weather condition
Fixed control of irrigation time and water flow	Variable control of irrigation time and water flow
Irrigation systems use ON/OFF controllers. These controllers cannot give optimal results for varying time delays and varying system parameters	Artificial Neural Network (ANN) based intelligent control system for effective irrigation scheduling
Designed based on the open-loop controller. It functions are predetermined, i.e. when to start/end watering with time delay intervals fixed. In this case, it does not determine whether the desired output or goal is achieved or not	Designed based on closed-loop feedback. In this type of controller, the necessary sensors are required to check the right amount of water needed for irrigation

Table 8.5 Application of agricultural production system models

Application area	Ref.
Farmer advice	[48, 49]
Yield gap analysis	[50–52]
Tools for farmers	[53]
Climate change and adaptation	[54–57]

using field sensors and weather forecast data. The developed smart irrigation system integrated a site-specific irrigation controller with infield data feedback and supported the decision making and real-time monitoring of irrigation operations. Issues like energy consumption for autonomous operation of sensor nodes dictate design and development issues including communication, protocols and deployment. The use of WSNs which comprises of battery-powered nodes consumes a large amount of energy [36], and therefore, solar-powered based nodes are greatly preferred [37, 38].

During the past decade, crop system models dominated by DSSAT [39], APSIM [40], CropSyst [41], EPIC [42, 43], STICS [44] and DSSAT-GREET [45], DSSAT-CSM [46] have evolved as agricultural production systems models with rapid expansion while less emphasis on model improvement [47]. The agricultural production system model has a wide range of applications, as shown in Table 8.5.

8.4.2 Automatic Fertigation

Automatic fertigation is used to overcome the intensive and laborious process (fertilization such as broadcasting, manual spreading and spraying) of applying fertilizers to increase the soil fertility through adjustable settings for nutrient concentration, water flow, time and length of delivery and other parameters that directly affect plant growth and plants productivity. The precise and optimal application of fertilizer at the root zone of plants is a complicated task which can be made simple and easy through the pinpoint application of fertilizers at the right time, at the right place using sensors. An automated fertilizer applicator consisting of input, decision support and output modules using GPS technology, real-time sensors and Bluetooth technology was built by Cugati et al. [58]. The input module is used to provide GPS and sensor data values to Decision Support System (DSS) that calculates the optimal quantity and spread pattern of fertilizer based on real-time sensor data acquisition through Bluetooth communication modules to regulate fertilizer application rate. He et al. [59] developed and integrated optimal fertilization decision support system by using sensors to acquire real-time data of soil moisture, conductivity, temperature, PH value, air temperature, humidity, CO_2 concentration, illumination etc. This system used wireless sensors LAN using the IEEE 802.11 protocol (WiFi) and GPS analysis server.

8.4.3 Precision Agriculture

Precision Agriculture (PA) is known as precision farming, information-intensive agriculture, prescription farming, target farming [60]. Taylor and Whelan [61] defined PA as integrated information and production-based farming system that is designed to increase long-term, site-specific and whole-farm production efficiency, productivity and profitability while minimizing unintended impacts on wildlife and the environment. PA has been emerging as the next great revolution in agriculture, which emphasizes agricultural developments with a particular focus on production, economic, and environment. It can pinpoint the exact location of the farm that requires specific attention to manage plant disease or to improve soil condition by optimizing the use and varying the rate of inputs, such as fertilizer, across a field based on the need identified by GPS guided grid sampling. PA technology encompasses four key information technologies, namely location determination (via GPS), GIS, computer-guided controllers for variable rate application (VRA) of crop inputs, and sensing technologies for automated data collection and mapping. Among the four, GPS and GIS have been more widely used [62] to increase yields for row crops, hay production, pasture management, and other agricultural activities. Besides, this approach can be used for mitigating leaching problems [63].

8.5 Challenges in ICT Based Precision Farming

There are several challenges that need to be addressed in order to make ICT based precision farming into its full potential. Here we discuss some of the major issues that should be addressed in future research.

- Sensor network security: Most network sensors are deployed in the farming area left open, and they are prone to have physical attacks. Due to limited computational and power supply in sensors, strong security mechanism management in sensors is hard to implement. In WSN, mostly the communication takes place in broadcast nature allowing the network to be exposed to attackers. Some of the common attacks in WSN are eavesdropping, denial of service and tampering data [64]. For example, an automated agriculture facility may take a wrong operational decision if an attacker tempers or injects false data in WSN. An automated agriculture facility needs to understand the possible security threats (some of them could be deliberate or accidental). It should set possible safeguards to combat against any security threats.
- Reliable and available network infrastructure: Real-time monitoring and control of an automated agriculture facility are increasingly important. Communication network infrastructure is key to develop a successful automated agriculture facility. The network segment connecting BS with the remote Cloud has a significantly important role. Any failure in a communication network may isolate an automated farm from remote monitoring and control system (farmers would not have any idea about the current status of their agriculture farm in such a situation). Many of the farming equipment and sensors/actuators information is mission-critical (the information should reach at the decision centre within a certain time frame). A communication network infrastructure may fail to due to many reasons, including application failure, network device failure, network interface failure and communication path failure. A highly reliable and available network needs to be designed for the agricultural farming facility. It must be noted that a highly reliable and available network we can achieve mainly by increasing capital and operational expenditure.
- Cost of sensors and actuators: Currently, the price of sensors and actuators is still not affordable for the farmers in the developing and underdeveloped countries.
- Power supply availability: Many types of equipment in an agricultural farming facility would require a continuous power supply from the grid. Due to natural disaster or accident, failure of power supply would lead to having a catastrophic effect on the entire farming facility. Therefore, redundant power sources, including battery and renewable power source, need to be installed in order to provide uninterrupted power supply to the farming facility.
- Educating farmers: Technology is progressing at a breakneck speed. However, a major portion of the farmers in the developing and underdeveloped countries are not educated. This would result in the poor adoption of new technology.

Uneducated farmers would show a less favourable attitude towards accepting ICT based farming management compared to the educated one [65]. Therefore, to allow ICT to leverage our future farming, ICT literacy, level of awareness and education of farmers need to be improved.

- User-friendly applications: Some farmers do not have ICT literacy. Hence, they may be reluctant to use ICT based farming management. The applications for controlling and monitoring farm need to be designed such that farmers can easily understand.
- Metadata, semantics, and ontology: In order to provide advanced intelligent systems based on collected data and information, we have been witnessing significant research progress in this domain. Nevertheless, more research effort is needed to realize automated smart farming.
- Fast fault identification: Identifying fault in sensors/actuators, farming equipment and communication network equipment would be another challenging issue that should be addressed in future research.
- Analysis paralysis: Huge amount of data collected from sensors/actuators and other sources without a meaningful way to understand would not bring any advantage in smart farming. Finding meaningful data would lead to providing useful information (and knowledge).

8.6 Conclusion

Small-scale farmers in developed/developing countries can be immensely benefitted by updating their farm's practices in terms of irrigation and plantation by implementing best water management through ICT and data management. The use of remote sensors, automated technologies, drones, cameras, climate-based intelligent irrigation system, professional expertise and continuous monitoring from a remote location through smart handheld devices can revolutionize the agricultural farms, both in terms of better yields and contributing to the nation's Gross Domestic Product (GDP). With the advancements of practices and technology, these contributions to the farmers in small-scale farming are gaining momentum with continuous support to various stakeholders ranging from small-scale farmers to policymakers. There are numerous opportunities for further development of ICT and bringing to every corner of the words. The challenges lie in keeping the cost of such technologies within the affordability of small-scale farmers; while promoting awareness through various media platform to reach them. Thus, this technology advancement farming practices not only increase the agricultural yields but also supports to maintain a sustainable ecosystem.

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