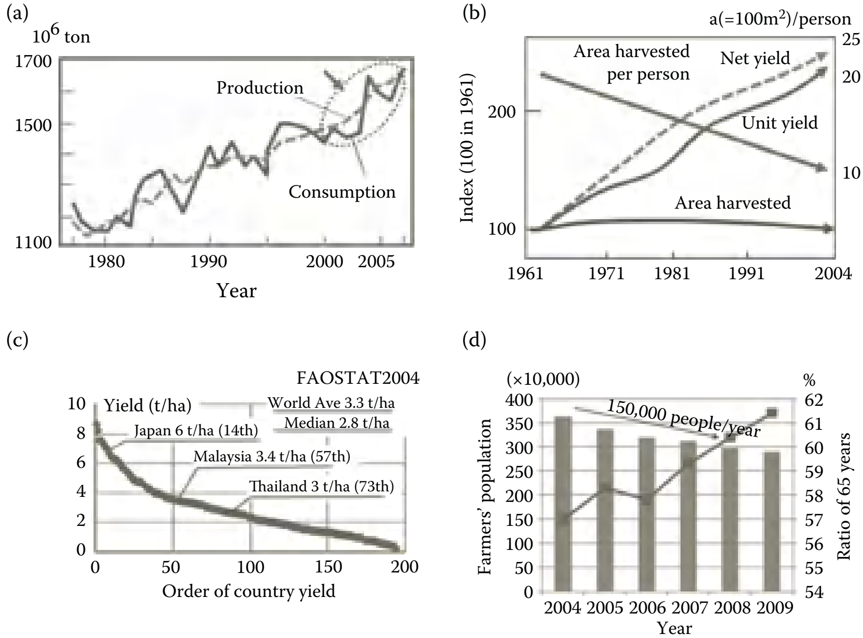


**FIGURE 7.1** The position of Japanese agriculture in the world. (a) Worldwide needs and demand of wheat and coarse grains; (b) land productivity; (c) yield per unit area of country; and (d) rapid decrease of Japanese farmers.

has not increased during the last 50 years, as shown in Figure 7.1b. In general, land productivity depends on the crop variety, agricultural materials and facilities, and farm mechanization, as well as socioeconomic factors such as the organization of growers.

Keeping land productivity higher is one of the advantages of Japanese agriculture, as shown in Figure 7.1c, because of its well-organized community of growers but with small-scale farms. In spite of the high land productivity and top-20 net production in the world (FAOSTAT, 2005), the population of Japanese growers has decreased by 150,000 per year during the last decade, resulting in a decrease to one-tenth of 2.5 million by the year 2030 (Figure 7.1d). This is inducing rapid changes in the structure and system of Japanese agriculture, followed by some countries in the world.

Japanese government statistics in 2012 show that the number of growers was 2.5 million, the number of commercial farmers was 1.78 million, and the number of young farmers was 0.17 million (Figure 7.2b). The same statistics show that there is 368 million ha of arable land with an average scale of 2.2 ha, and that 32% of the arable land belongs to 2% of farmers with a farm scale of more than 20 ha. On the other hand, the Japanese population is decreasing dramatically, by 260,000 per year in 2013 and is projected to decrease by a million per year in 2025, which causes big changes in socioeconomic systems. For example, the needs of consumers tend to shift from price and calories to the safety and functions of foods.

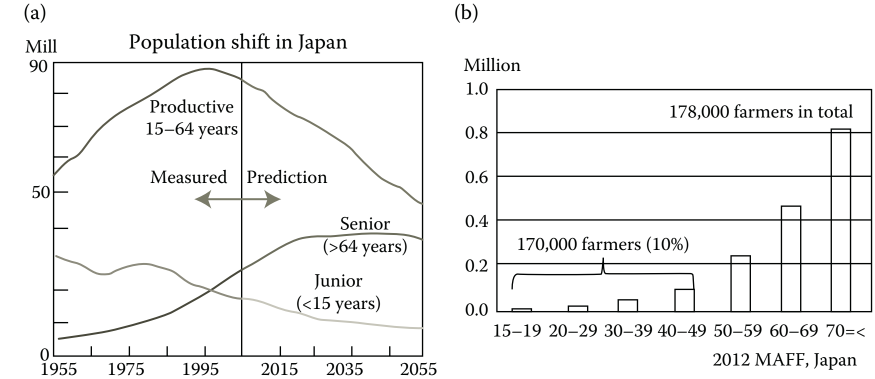


**FIGURE 7.2** Rapid aging and depopulation in Japanese society and agriculture. (a) Population decrease in Japan and (b) aging and depopulating of farmers.

Not only land productivity but also consumers' needs have become targets of current farm management in Japan. Transfer of skills and technology has also become big business from generation to generation, from industry to agriculture, and from agriculture to industry. That is why precision agriculture and its players have become the target of investigation. The community-based approaches of this chapter will provide a hint to creating a way of thinking.

## 7.2 COMMUNITY-BASED PRECISION AGRICULTURE

In this chapter, "community" implies practitioners and/or players of precision agriculture, and precision agriculture implies management practice on the farm. The combination of players and management requires us to rediscover the story of precision agriculture as follows. Community-based precision agriculture is a new regional farming system to gain high profitability and reliability under regional and environmental constraints, promoted by expert farmers and technology platforms, by creating both information-oriented fields and information-added products, with supply chain management from field to table (Shibusawa, 2004). The definition brings us to a home ground where growers, engineers, and business people take action.

During the current quarter of a century, we have experienced five different phases in precision agriculture (Shibusawa, 2004). The first phase was site-specific crop management in the early 1990s. The second phase was mechanization as sensor-based site-specific crop management with variable-rate operation in the mid-1990s. The third phase appeared in the latter part of the 1990s with precision agriculture defined by "a management strategy that uses information technologies to bring data from multiple sources to bear on decisions associated with crop production" (National Research Council, 1997). Furthermore, "a key difference between conventional management and precision agriculture is the application of modern information technologies to provide, process, and analyze multisource data of high spatial and temporal resolution for decision making and operations in the management of crop production" (National Research Council, 1997). The fourth phase appeared in the latter part of the 1990s as cost-driven company-based precision agriculture. And the fifth phase appeared in the early 2000s as value-driven community-based precision agriculture.

The structure of community-based precision agriculture is composed of two organizations, that is, farmers and industry, and five stakeholders to collaborate with, as shown in Figure 7.3. On the side of the farmers, variable management focuses on within-field variability and between-field or regional variability. Within-field variability is embedded in a single field with a single plant variety in general. Between-field variability implies variability among fields in which different crops and farm works tend to be managed. When it comes to describing between-field variability, each field can be treated as a unit of mapping. Which variability should be managed for increased economic returns with reduced cost and how to tackle environmental concerns needs consideration.

There are different stories regarding the practice of management in action when one looks at field variability on different scales. On a single small farm, the farmer can better understand what is going on in each field, which enables variable-rate application for site-specific requirements with the farmers' knowledge and skills. When it comes to covering an area of a few tens of hectares, including lots of small fields, for example, a farm work contractor or a farm company has to manage regional variability due to cropping diversity. They also have to coordinate the farmers with different motivations due to different cropping styles. Here, we have hierarchical variability: within field, between field, and between motivations with different scales and different cropping styles.

Managing hierarchical variability requires two organizations, expert farmers and a technology platform, as shown in Figure 7.3. The groups of expert farmers play

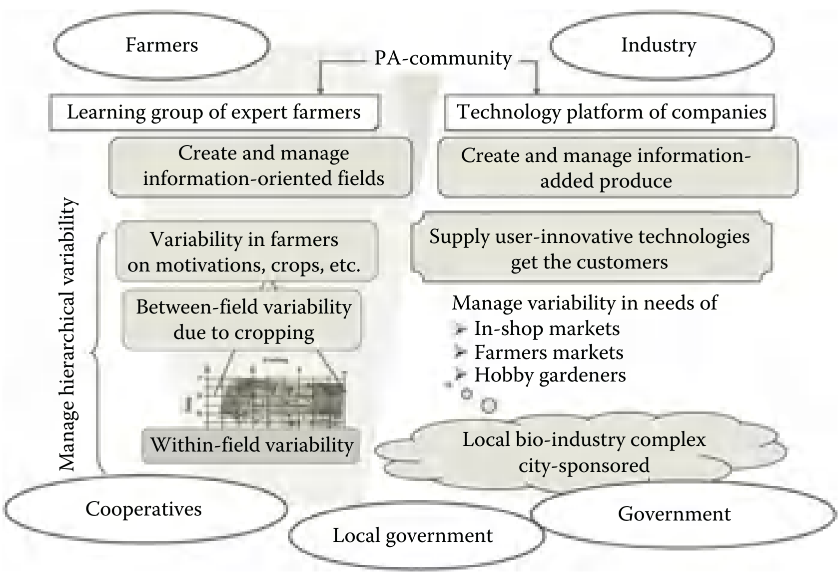


**FIGURE 7.3** Structure of community-based precision agriculture.

the role of top management of innovation in the regional farming system, such as the rearrangement of the five factors of the farming system and the development of scenarios for introducing approaches in precision agriculture. The technology platform develops and provides the technologies available with rural constraints as well as marketing channels for high-quality/traceable agro-products.

A combination of the wisdom/experience of the farmers and the technologies of the platform will produce information-oriented fields and information-added products, as shown in Figure 7.4, which can meet compliance as well as farmer's motivation, such as traceability, productivity, and profitability, and environmental concerns.

Rural development by introducing precision agriculture is an attractive proposition in Japan because people face the serious concerns of depopulation, high aging, a downsizing economy, and exhausted infrastructure in rural villages and cities. The information-oriented fields produced by precision agriculture practices are easy to connect with the multifunctions of agriculture so as to manage environmental conservation and design landscape amenity if it merges with a geographical information system (GIS) covering the whole space of a rural area, aiming at gaining the trust of local inhabitants. The information-added products make access to the market with direct communication with consumers easier.

Shibusawa (2004) discussed adoption of precision agriculture in the cases of the United States and Japan in the early 2000s in terms of scale merit and added value. Adoption of precision agriculture in the United States followed a cost-driven scheme of big-farm management with reduced costs, and its profitability threshold was more than 500 ha in farm size (Vanacht, 2001). Cost reduction was 20% for fertilizer and 50% for herbicide, for example, but less or little increase appeared to occur in yield and total sales. Sales were about 1000 US$/ha for crop growers and 30% of that was expenses for fertilizer and chemicals. The cost reduction effect was around 100 US$/ha. On the other hand, they paid about an extra 80 US$/ha/year for the

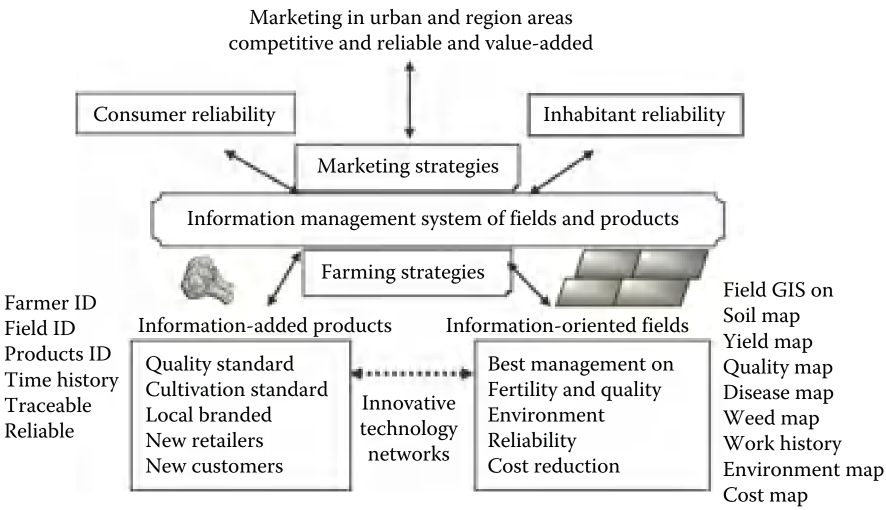


**FIGURE 7.4** Strategy of community-based precision agriculture.

precision agriculture service and purchased machines such as variable-rate fertilizing machines costing hundreds of thousands of dollars. Big retailers pushed farmers for lower prices with the pressure of global food markets. The only avenue for commercial farmers was to obtain scale merit for cost reduction. Profitable farm sizes tended to be large in Central America, for example, 200 ha in the 1990s, 500 ha in the 2000s, and 1000 ha in the 2010s (as heard from consultants).

On the other hand, a small farm in Japan had no scale merit. The expenses for machines and labor were relatively high, compared with the cost of fertilizer and chemicals; that is, overequipment with machinery on a small farm was a fatal issue. Evidence-based collaboration was one avenue. Note that sales were about 10,000 US$/ha for rice crop growers, which was about 10 times as high as the sales of U.S. farmers. This motivated farmers to sell their products at high prices. If they could ensure the needs of consumers and supply quality products to the market, they could be competitive in the food supply chain. The distance between growers and consumers might be very close in Japan, compared with the United States.

## 7.3 LEARNING GROUP OF FARMERS CREATING BRANDED PRODUCE

One learning group was the Honjo Precision Farming Society (HPFS) organized by progressive farmers in April 2002, in collaboration with Waseda University, Tokyo University of Agriculture and Technology, people from the industry, and City Hall. The leader of the farmers recognized that City Hall had promoted zero-emission town planning and was awarded ISO 140001 certification in March 2002, and environment-friendly agriculture was one of the main city projects.

Honjo is a city located 100 km north of Tokyo, having the longest daylight time and rich alluvial soil with rich irrigation water from the Tone river. The population of the city was 80,000, the farmed area was 1300 ha, the population of farmers was 1200, and 25% of these were professional farmers. The net sale of agricultural products accounted for more than 8 billion JPY, and of this, the sale of vegetables was 65%. Around 130 professional farmers formed "New Farmer 21," a society of entrepreneurial farmers, and their leaders organized the HPFS.

A membership qualification of the HPFS was to implement environment-friendly management as "eco-farmers" certified by the local government, creating a homepage of their own, and attending to Internet communications, as well as managing the food quality with the highest price in the market. The next action was to organize seminars and workshops on precision agriculture. They invited professionals and scientists to their evening seminars every month in 2003, with topics on the motivations of buyers, branded produce, emerging technology, agricultural policy of the government, and so on, including an international seminar inviting Marc Vanacht (Figure 7.5). They then conducted a social experiment on in-shop sales of their information-added products.

During the social experiment on in-shop sales, they invented a technology package creating an identification (ID) tag and its usage, as shown in Figure 7.6. At the farm, a grower of HPFS edited and printed his small ID tags with his photograph, and attached it to each package of vegetables in the packing process. At a department

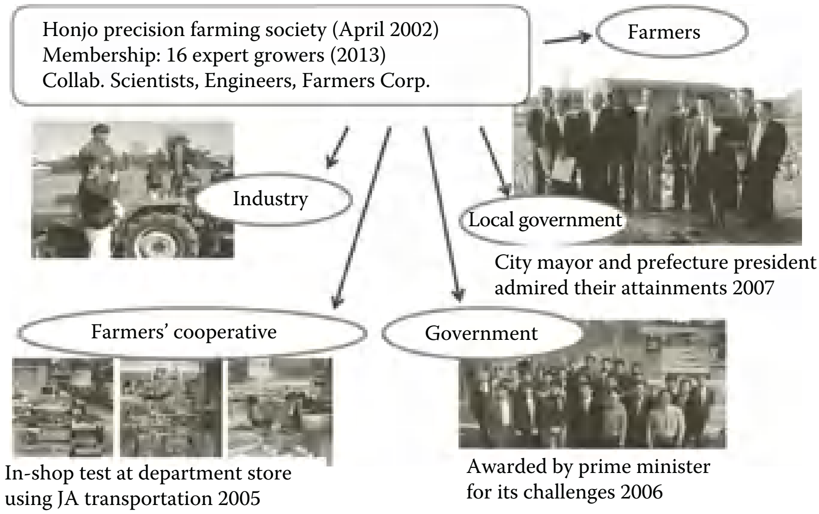


**FIGURE 7.5** Activities of the Honjo precision farming society (HPFS).

store and at a wholesaler's, high-quality vegetables with ID tags were put in the fresh vegetable corner at prices 20%–30% higher compared with the normal. The farmers' cooperative to which they belonged transported the vegetables from the farm to in-shop. It was easy for customers to access the respective growers through their websites by mobile phone by clicking the two-dimensional code on the tag. The growers wrote a farm work diary on their homepages every day, which helped direct

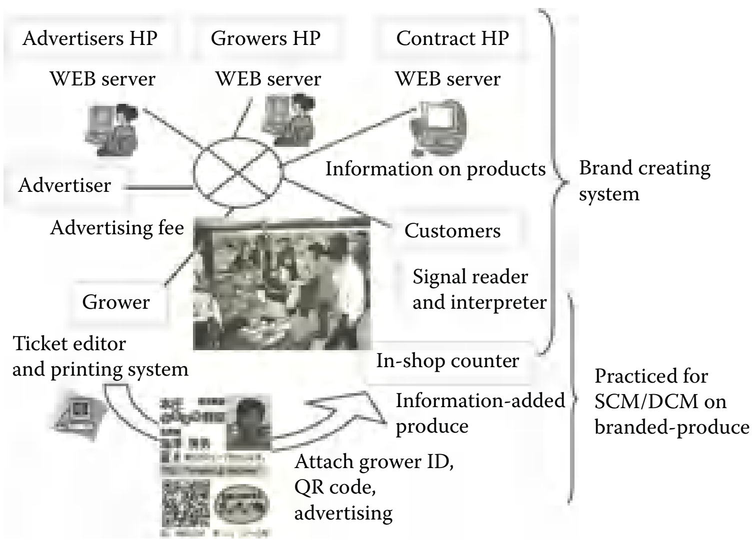


**FIGURE 7.6** Scheme of the branded produce of HPFS.

communication between growers and consumers. They put a simulator of retrieval action in the fresh vegetable corner in the department store. The growers stood at the corner and demonstrated using a mobile phone.

The cost of the ID tags was 3–5 JPY (0.03–0.05 US$) per sheet and nobody was willing to pay for it. A solution was a scheme of voluntary advertisement. The vegetables produced were specialized by environmental-friendly management and quality taste, and the produce could consequently connect environment-oriented people across the food chain from growers to consumers. They asked companies and organizations for a chance to advertise with them, and a couple of companies joined the scheme.

The activity of HPFS received an award from the prime minister of Japan in 2005 for creating branded produce using information technology and specific patented skills.

Another precision agriculture learning group was the technology platform called the Toyohashi Precision Farming Network (Toyohashi PF-net) Society, located in Toyohashi, Aichi Prefecture, founded in May 2002 (Shibusawa, 2006).

Toyohashi is a middle-sized city with a population of 380,000, located in the middle of the main island along the coast of the Pacific Ocean, between the big cities of Tokyo and Nagoya. The net sale of agricultural products here was more than 50 billion JPY in 2000, which was the top sale in the cities in terms of agricultural production. The Toyohashi-Atsumi area produced more than 100 billion JPY of agricultural products. The farmed area was about 15,000 ha, the population of farmers was about 10,000, the average farm size was about 1.5 ha, and 25% of the farmers were professional according to the statistics of 2000. People were motivated to maintain the top sale of agriculture in Japan by introducing a new system of precision agriculture.

The Toyohashi PF-net Society conducted workshops on precision agriculture every 2 months, extending information technology to farmers, and consulting on collaboration between companies and farmers. They also collaborated with the city halls and farmers' cooperatives, resulting in many achievements during the last 5 years.

Atsumi Farmers' Association has undertaken a workshop on real-time soil-sensing technologies and an in-shop test on information-added products. JA Toyohashi, a local agricultural cooperative, has conducted in-shop tests on information-added products through supermarkets in Osaka and Tokyo as well as the Toyohashi area. They also distributed and collected questionnaires and confirmed that consumers asked to know date of harvest, about safety and health, and about the environment as well as price.

Four city halls in the area also encouraged such grassroots movements by promoting a master vision for introducing precision agriculture. The master plan addressed six missions: introducing precision farming, managing the traceability of products, enriching resources of by-products, opening a community market, inviting a conference on precision agriculture, and running agricultural information networks. They organized the National Congress on Agricultural Information Networks with thousands of attendants and the first Asian Conference on Precision Agriculture (ACPA) on August 5–6, 2005.

The achievements of the two learning groups have taught us that the participating farmers (1) were familiar with Internet communication; (2) had higher education levels; (3) grew high-quality produce; (4) had good sales and marketing experience; and (5) were greatly outgoing and sociable. The most important factor was that they had the ambition to become good-practice farmers enhancing local communities and industries. The experience above partly followed the aspects mentioned by Blackmore (2002).

Blackmore (2002) identified eight principles in precision agriculture: that (1) precision agriculture is a management process, not a technology; (2) spatial and temporal variability must be measured; (3) the significance of variability in both economic and environmental terms should be assessed; (4) the required outcome for the crop and the farm must be stated; (5) the special requirements of the crop and the country should be considered; (6) ways to manage variability to achieve the stated outcome are to be established; (7) methods to reduce or redistribute the inputs and assess the risk of failure need to be considered; and (8) crops and soil must be treated selectively according to their needs. An attractive aspect is that the development of precision agriculture is characterized by continuous evolution based on independent thinking associated with multidisciplinary collaboration under the crossover of new ideas from other areas.

## 7.4 COMMUNITY-BASED APPROACH IN INDONESIA

A unique approach that emerged in Indonesia, as a project of education for sustainable development (ESD) based on the concept of precision agriculture, is called the "community learning activity center as the medium for precision agriculture technology implementation with a decision support system to optimize food crop management" sponsored by the Indonesian government (Virgawati et al., 2010). A strong motivation to embark on the project was a shortage of stable food production against demand due to an increasing population and changes of lifestyle in spite of increases in primary food production. Bottlenecks recognized were biophysical factors such as exploitation of land and water resources, economic factors such as shortage of fertilizer because of high cost and low income, social factors such as habits of chemical fertilizer use or stereotypical professional farmers, and technological factors such as less knowledge and poor instrumentation of precision agriculture.

The project team was organized by the Faculties of Agrotechnology, Communication Science, Economics of Development, Agribusiness, and Informatics and Environmental Engineering of the University of Pembangunan Nasional "Veteran" Yogyakarta, Indonesia. The project covered the issues of sustainable economic growth through increased value-added food products, social justice through equal rights and opportunities for access to efficient technologies in food production systems, and preservation of natural resources by maintaining sustainable fertility. Action programs involved mapping the diversity of agricultural land characteristics to build a database; modifying the simulation model of the existing soil–plant–water system; producing precision agriculture technology adapted to local culture; and developing an ESD-based education system. Establishing the Center of Community Learning Activity for Precision Agriculture was a milestone of the project.

**FIGURE 7.7** Community-based approach to education for sustainable development (ESD) in Magelang, Java. (a) Salam subdistrict, a flat site with mining and (b) Windusari subdistrict, a mountainous site.

In 2010, the agricultural agency in Magelang district selected six subdistricts for a social experiment, that is, Windusari, Tegalrejo, Secang, Salaman, Muntilan, and Salam. The activities were categorized by preliminary research, community service, and a socialization program.

The preliminary research consisted of mapping soil variability, identifying the farming system, determining the economic aspects, identifying social aspects, developing a crop management model, and recognizing the requirements for structuring a decision support system. The community service provided six districts with 25 students from four faculties for 40 days of activities, including collecting research data and supporting social activities for research and for local communities. The socialization program involved a field trip for professionals, an open lecture for students, and a workshop on precision agriculture.

The author of this chapter was invited to join the field trip and workshop under the scheme (Figure 7.7). The project team had organized learning groups of farmers in collaboration with local government and people from the university using information and communication technology (ICT) tools. Unfortunately, on October 26, 2010, a great eruption of the Merapi volcano struck the Magelang district and the six subdistricts suffered serious damage. The project was halted by the disaster, but the people soon started restoration work.

## 7.5 PRECISION RESTORING APPROACH

3/11 in 2011 is the day that northeast Japan was hit by a tridisaster: a super earthquake measuring M 9.0, a huge tsunami of more than 10 m high, and the explosion of nuclear power stations. Huge damage was confirmed across the cities and rural communities, including agricultural and industrial sectors. In the last 3 years, the restoration process has changed rapidly. Fukushima prefecture still has issues regarding measuring both radioactive contamination and tsunami damage, while Miyagi and Iwate prefectures are focusing on recovery from tsunami damage.

The Japanese Society of Agricultural Machinery (JSAM, now the Japanese Society of Agricultural Machinery and Food Engineers or JSAM) provided help for recovery from the damage caused by the disasters (Shibusawa, 2012a). They had limited experience of combating such a huge catastrophe of complex disasters. One useful approach was in precision agriculture that was applicable not only to agricultural sectors, but also to the environment and to the field of construction (Shibusawa, 2004; Berry et al., 2005), which led to evidence-based approaches with precision thinking.

On March 12, the first action started with a call for confirmation of the safety of the members of JSAM through e-mails, cellular phone, Internet service, and so on. It took 1 week for the Kanto area and 2 weeks for the Tohoku area to be completed. Unfortunately, information was received that three student members had been killed by the tsunami at Sendai airport.

Information through media and direct calls led to the organization of the working team of JSAM on March 30, 2011. The missions of the team were (1) to validate the facts and information on the disasters since there was confusion and complexity; (2) to investigate the damage in terms of agricultural machinery and farm management; and (3) to propose better solutions to reconstructing community-based agriculture. The working team reconfirmed the potential of Tohoku's agriculture with references. The statistics compiled by the Tohoku regional agricultural administration office in Sendai in 2010 stated that agricultural production was worth 1359 billion JPY, comprising 16% of the total production in Japan, including 496 billion JPY of rice, 383 billion JPY of livestock, and 228 billion JPY of vegetables. The number of growers was 463,000 with a ratio of 16% to all growers in Japan. The ratio of growers above 65 years of age was 30% and it was lower than the national average of 58% in Japan. Local self-sufficiency in food production in the Tohoku region was more than twice the national average. Apples of Aomori prefecture occupied 53% of the entire production of Japan, cherries of Yamagata prefecture accounted for 71%, and the share of peaches of Fukushima prefecture was 20%.

On September 12 and 13, the working team visited paddy fields in Kitakami of Ishinomaki city and fields of protected horticulture in Watari of Natori city in Miyagi prefecture. One site that they visited was the Kitakami riverside around 10 km distant from the coast, as shown in Figure 7.8. The people suffering from the tsunami emphasized the following: (1) The tsunami brought a large amount of rubble on a path of over 10 km distant from the coast and it had still not been removed (Figure 7.8c). (2) They cut and removed the weeds in the paddy fields to prepare for the next cropping season (Figure 7.8a). (3) They were less concerned about salty sludge since the sludge used to be applied in the paddy for soil improvement. (4) They needed recovery of transportation, repair of drain pumps, and recovery of machines and facilities in order to restart farm work. A local dealer continued work on repairing machines flooded with seawater (Figure 7.8d). It was difficult to repair them perfectly because of salt and sludge invading unseen spaces.

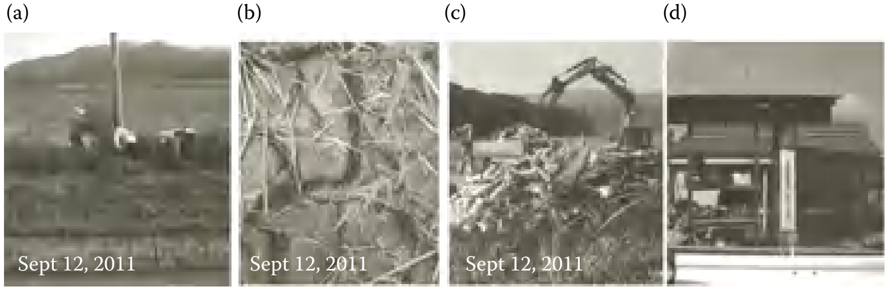


**FIGURE 7.8** People's combat against tsunami disasters in Ishinomaki, Miyagi. (a) Weed control of overflooded paddy for the next cropping season. (b) Sludge of 10-cm thickness fully covering the paddy field. (c) Dumped rubble produced by the tsunami 7 km from the coastline. (d) On-service local dealer of agricultural machinery.

Based on the results of the survey, the JSAM proposed five recommendations: (1) to develop a strategy for land consolidation and for education of newcomers to be professional farmers; (2) to protect the intellectual properties of farmers; (3) to repair the service network of agricultural mechanization; (4) to simultaneously reconstruct the system for both producers and retailers; and (5) to maintain farm assurance and standard farm management such as GLOBAL G.A.P.

The Ministry of Agriculture, Forestry and Fisheries has launched many national projects for recovery from disasters, such as intensive arable farming (Figure 7.9), a highly automated greenhouse system, highly effective orchard cultivation, and an

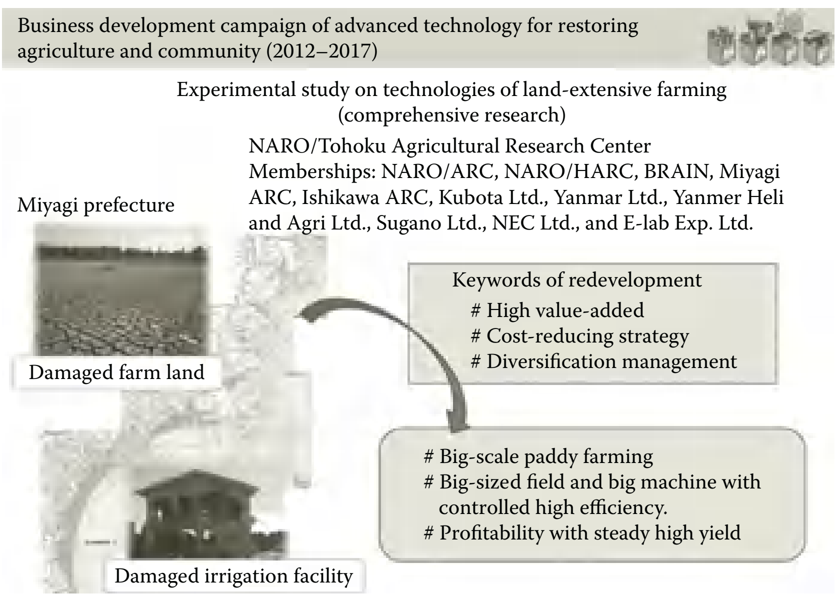


**FIGURE 7.9** National project of arable cultivation, Koya Corp. in Miyagi prefecture.

intensive system of aquaculture. A major target was a business development campaign of advanced technology for restoring agriculture accompanied by the local community. Figure 7.9 shows a project of national institutes and private companies for arable farming employing cereal crop rotation using a technology package of precision agriculture, such as a field mapping system and variable-rate technology. Then, the agricultural corporation KOYA joined the project. KOYA Corporation was founded by five local growers in 2003, and 90% of its 100 ha paddy fields suffered damage from the tsunami; in addition, the machinery and facilities were washed away. They restarted cultivation just after the catastrophe and the national project helped them.

Goto et al. (2013) have organized a JST (Japan Science and Technology Agency)-funded 3-year project on precision restoring agriculture in the Fukushima area in 2012, as shown in Figure 7.10. The project team is composed of organizations who had suffered from the tsunami: the agricultural corporation Denpata, the manufacturing company Kanda Ltd., support organizations, ADS Ltd., the National Institute of Advanced Industrial Science and Technology (AIST), and the Tokyo University of Agriculture and Technology (TUAT). These organizations suffered serious damage not only from the East Japan earthquake disaster, but also through rumors related to the collapse of the nuclear power plant. They also had rural issues of farmers' aging, depopulation in the village, the "food desert" phenomenon, and so on. Therefore, they hungered for a future vision as well as sought measures against rumor damage. One idea was an evidence-based farm management scheme.

The goal of the project was to create an information-oriented field to meet the requests of consumers in the market. Within a limited budget, a real-time soil sensor was introduced to monitor the within-field soil condition, and sensor posts were set

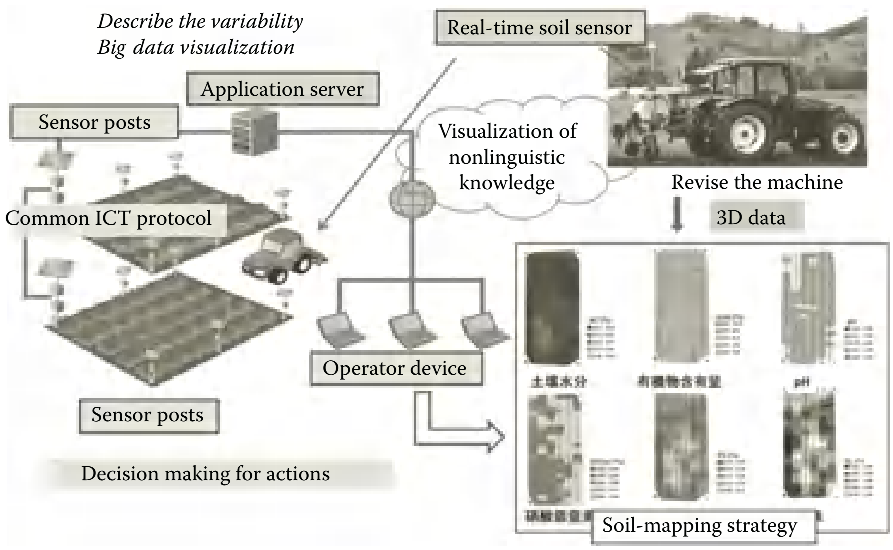


**FIGURE 7.10** **(See color insert.)** Precision restoring agriculture in Fukushima toward traceable management against rumor damage.

up in the field to monitor the degree of radiation, wind velocity, wind direction, rainfall, etc. Yanmar Ltd. joined voluntarily to provide a combine harvester with a yield monitor in 2014. The project is still developing with community-based approaches.

## 7.6 AGRO-MEDICAL FOODS

The strategy for agro-medical foods was formed in 2009 when the concept of community-based precision agriculture encountered the concept of preventive medicine at the meeting of Dr. Sakae Shibusawa and Dr. Toshikazu Yoshikawa, and it then drove many collaborative projects in the fields of medicine, agricultural science, engineering, and industry, though it was not introduced in English (Shibusawa, 2012b). This agro-medical approach promises to expand the fields of precision agriculture, and that is the reason it is introduced here.

*Agro-medical foods* are defined as agricultural products with a high content of functional materials with evidence of effects on health and wellness produced by precision agriculture, and they are created by an agro-medical initiative, as shown in Figure 7.11. The agro-medical initiative is a research group of medical, agricultural, and engineering scientists, aiming at the cure of lifestyle-related diseases by developing agricultural products with a high content of functional materials.

Figure 7.11 shows a research cycle of agro-medical foods. The agricultural sector supplies fairly controlled products to the medical sector, which requires controlled protocols of production with traceable management. The medical sector confirms the evidence of effectiveness against disease prevention and wellness in medical science.

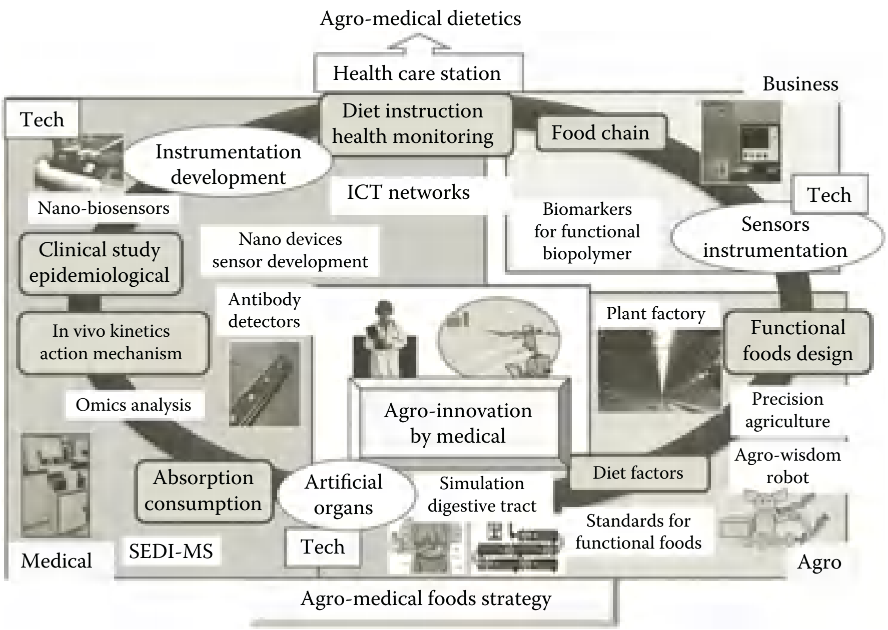


**FIGURE 7.11** Concept of producing agro-medical foods (AMF).

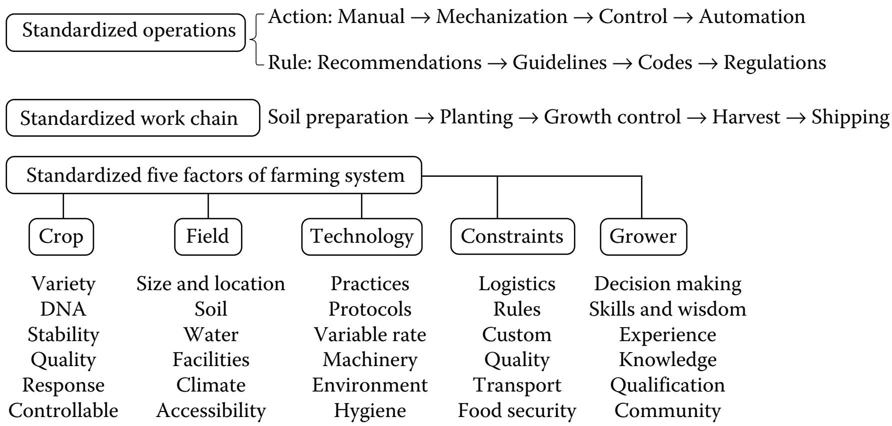


**FIGURE 7.12** Needs for a standard in agricultural systems for AMF.

The nutrition and dietetics sector provides personalized diets using agro-medical foods. The business sector commercializes the agro-medical foods and diets. The engineering sector provides biosensing and control technology to manage the system and communicate beyond disciplines.

Figure 7.12 shows a standard scheme of production in the categories of operation, work chain, and farming system. The operation standard involves the specification of mechanization and guidelines. The work chain requires the protocol of process jobs from soil preparation to shipping. The farming system is composed of the five factors of crop, field, technology, constraints, and motivation, and each factor has a substructure of farming elements such as crop variety and tillage machines. At least three production categories need clear description when they are put into practice in the shape of precision agriculture.

Table 7.1 shows a framework or roadmap of how to produce agro-medical foods. There are three control points and nine check items. The first control point is the target syndrome and medical examination with the four check items of cell culture, animals, intervention, and cohort. The second control point is the target material and analysis method with the two check items of food body base and biospecimen base. The third control point is crop variety and management with the three check items of breeding, cultivation, and processing/cooking. The test crops were onion, green tea, orange, soybean, spinach, tomato, and eggplant in 2011. Many more crops and functional materials will be examined in a couple of years.

## 7.7 SUMMARY

This chapter described the last 15 years' experience of a Japanese model of community-based precision agriculture accompanied by a learning group of farmers and a technology platform of companies. Community-based precision agriculture aims at high profitability and reliability under regional and environmental constraints, promoted by the expert farmers and/or the technology platform, by creating both

**TABLE 7.1**
**A Framework for Standardizing Research into the Production of Agro-Medical Foods**

| Crop | Syndromes under Medical Examination | | Method of Analysis | | Crop Variety and Management |
|---|---|---|---|---|---|
| | Cohort Intervention | Animals Cell Culture | Food Base | Biospecimen Base | Breeding Process/ Cooking Cultivation |
| Onion | Metabolic syndrome dry mouth/eyes, cognitive impatient | | Quercetin | | Quercetin-rich crop |
| Green tea | Immunopotentiative, antiallergic | | Strictinin, epigallocatechin | | Strictinin-rich crop, epigallocatechin-rich crop |
| Orange | Metabolic syndrome fatty liver/diabetes | | Not yet | | Beta-cryptoxanthin-rich crop |
| Soybean | Metabolic syndrome, osteoporosis dry mouth/eyes, macular degeneration | | Isoflavone | | Isoflavone-rich crop |
| Apple | Metabolic syndrome, diabetic arteriosclerosis, osteoporosis | | Procyanidin | | Procyanidin-rich crop |
| Spinach | Macular degeneration, dry eyes | | Lutein | | Not yet |
| Tomato egg plant | Metabolic syndrome, diabetic | | Not yet | | Osmotin-rich crop |

information-oriented fields and information-added products, with aggressive access to food chains. The two participating local learning groups were the technology-driven Precision Farming Network of Toyohashi-Atsumi (PFNET) in Toyohashi and the farmers' learning group Honjo Precision Farming Society (HPFS) in Honjo. The first action of the two groups was market research using information-added produce through in-shop experiments. The scheme of the community-based approach has been applied to a trial of ESD on Java island of Indonesia, to restoration post the catastrophe of the East Japan earthquake and tsunami in 2011, and the production of agro-medical foods in collaboration with professionals in the fields of medicine, agriculture, engineering, dietetics, and business.

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# 8 Precision Agriculture in China
## *Sensing Technology and Application*

*Hong Sun and Minzan Li*

**CONTENTS**

## 8.1 INTRODUCTION

The cultivated land is the human survival and development. As is well known, China has 9.6 million square kilometers of land area. According to the *China Statistical Yearbook 2007*, the area of farmland resources in China was about 1.326 billion hectares, in which cultivated land refers to the area of land reclaimed for the regular cultivation of various farm crops, including crop-cover land, fallow, newly reclaimed land, and land lying idle for less than 3 years.

Cultivated land in China is divided into four regions: the eastern, central, western, and northeastern regions. It is also divided into three categories: paddy fields, irrigated land, and dry land (GB/T21010-2007). According to the agriculture census, the distribution of cultivated land is unbalanced in the country, the area of cultivated land in the western region being more than the others, and accounting for 36.9% of arable land; the area in the eastern, central, and northeastern regions being 21.7%, 23.8%, and 17.6%, respectively. For cultivated land categories, the area of dry land accounts for 55.1% of arable land, while the area of paddy field and irrigated land are 26.0% and 18.9%, respectively.

In recent years, economic development has had a profound impact on land-use patterns in China. There is increasing conflict between limited arable land resources and the requirements of agricultural production. Serious land degradation such as soil erosion, depletion, secondary salinization, and pollution is caused by long-term use. Mining activities also damage and take over a lot of cultivated land resources. Precision agriculture (PA) is a farming management method that allows farmers to optimize their resource inputs to achieve high yields (Wang et al., 2003; Wang, 2011; Zhao et al., 2003). Modern technology promotes the development of agricultural mechanization. Thus, information perception, the Internet of Things (IoT), and technology application are introduced in this chapter (Wang, 1999).

## 8.2 KEY TECHNOLOGIES OF AGRICULTURAL INFORMATION PERCEPTION

In agricultural information perception technology, research in China and abroad all focus on two aspects: agricultural resource investigation and farmland production information perception. Fast acquisition, processing, and understanding of farmland information were the key points of development for PA.

Agricultural resource investigation includes the investigation of cultivated land resources, district plantation, atmosphere, level of agricultural production, etc. 3S (geographic information system [GIS], global navigation satellite system [GNSS], and RS) technology is utilized comprehensively. Some basic information such as cultivated land area, vegetation distribution, and atmosphere dynamics is acquired and analyzed based on remote sensing technology. Distribution characteristics of all kinds of data are calculated based on GIS and global positioning system (GPS). Transition characteristic analysis and visualization expression of agricultural resources in time and space are realized by historical data. At present, much research has been conducted and many application achievements have been made in rating the quality of cultivated land, regional distribution of agricultural plantation, monitoring of crop growth and disease status, and agricultural atmosphere analysis (Kuang and Wang, 2003).

Farmland information perception is based on the research and development of advanced sensors, which concentrates on each link of agricultural production. It mainly focuses on fast acquisition of growth and physiological parameters of soil and plants, and distribution of insect pests and weeds, and can provide decision support for PA.

### 8.2.1 Rapid Acquisition of Soil Information in Farmland

The detection of soil information could be divided into two types, laboratory measurement and *in situ* measurement. In laboratory measurement, samples should be collected in the field and taken back to the lab to conduct pretreatment such as drying, grinding, and sieving (Peng et al., 1998; Yu et al., 2002; Sha et al., 2003). Then these pretreated soil samples are analyzed by traditional chemical analysis methods or modern atomic absorption spectrometer, and chromatographs. Analysis results are accurate, but time consuming and energy consuming. Therefore, in order to meet the real-time and practical demands in field fertilizer management, the *in situ* measurement technology directly toward the soil is becoming a hot spot of research with many methods of *in situ* measurement attempted. Among those, near-infrared spectroscopy (NIRS) analysis method only simply disposes the original soil to perform the analysis of soil (Bao et al., 2007; Song and He, 2008; Zhu et al., 2008; Zheng et al., 2009), and there is no need to do soil sampling from the field (Sun et al., 2006; Chen et al., 2008; Yuan et al., 2009). The analysis result indicates that there is a high correlation between the NIRS predicted value and the laboratory chemical analysis value. Thus, it is feasible to use NIRS in the determination of contents of soil total nitrogen, soil organic matter, and soil alkaline hydrolysis nitrogen, and it may be used in the rapid analysis of soil in the field. In recent years, Chinese research teams have devoted themselves to the research of soil information acquisition based on spectroscopy, including soil moisture, soil total nitrogen, soil nitrate nitrogen, soil organic matters, etc. They have made breakthroughs by developing highly precise prediction models. Besides theory analysis, they have also focused on the development of soil sensors based on spectral technology and have successfully developed a soil organic matter content sensor and soil nitrogen content rapid detector (Li et al., 2010).

#### 8.2.1.1 Development of Soil Organic Matter Content Detector

A practical portable detector for soil organic matter content was developed based on optical devices (Tang et al., 2007). The working mode is shown as Figure 8.1a. The optical signal at the NIR wavelength was transferred to the crop root zone (a depth of 300 mm). When the incident light reached the target soil, one part of the light was absorbed by the soil, and another part of the light was reflected from the soil as diffuse reflection light. If a certain wavelength is the sensitive waveband to the soil organic matter, the absorbed light is proportional to the content of soil organic matter. In other words, the intensity of the diffuse reflection light is inversely proportional to the content of soil organic matter. As a result, soil organic matter content can be estimated by soil reflectance value.

Based on the working mode above, the developed detector consisted of an optical unit and a circuit unit as shown in Figure 8.1b. The optical unit included light source, incident and reflected optical fiber, and a photoelectricity conversion device. The circuit unit included a light-emitting diode (LED) drive circuit, an amplifier circuit, a filter circuit, an analog-to-digital converter (A/D) circuit, a liquid crystal display (LCD), and a U-disk storage component. When measuring, the probe part was pushed into soil in order to form a confined space. There were incident and reflected optical fibers installed in the probe with the optical fiber opening at the top. The light from the LED was transferred to the top of the probe through the incident fiber. The light then reached the soil around the probe. The reflected light from the soil was transferred to the photoelectrical conversion device through the reflected fiber.

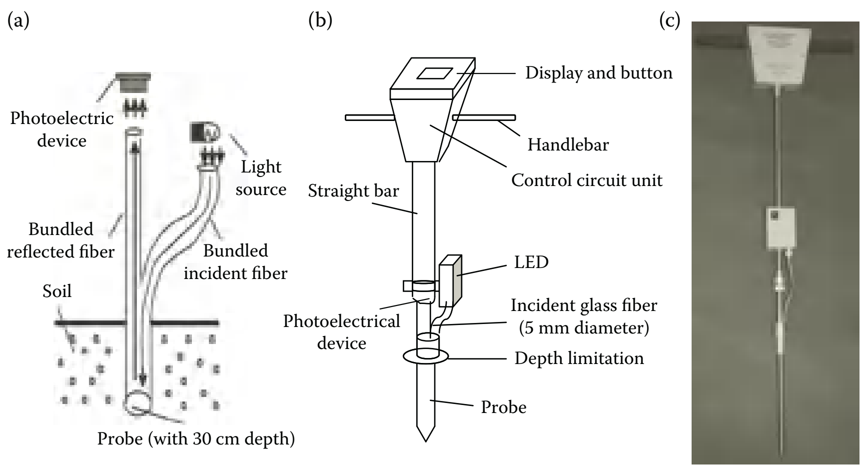


**FIGURE 8.1** Overall structure of the soil organic matter detector. (a) Optical system structure, (b) detector sketch, and (c) detector prototype.

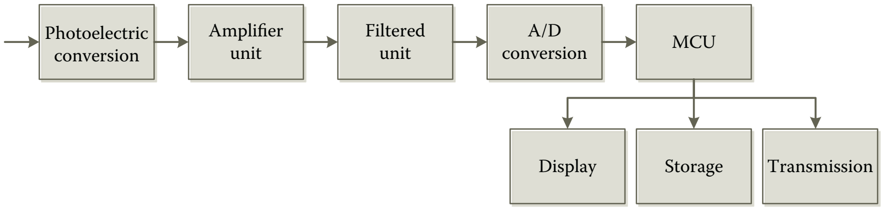


**FIGURE 8.2** Block diagram of circuit unit.

Subsequently, the electrical signal was transferred to the circuit unit to be amplified, filtered, A/D converted, displayed, and stored.

To minimize the loss of incident light and reflected light, the Y-type glass fiber consisted of a light-incident port, a light-reflected port, and a port with both irradiation and detection. The diameter of the incident and reflected optical fiber bundle was 5 mm. The incident port was connected with a light source to receive the incident light. The reflected light measuring terminal was connected to the photoelectric sensor through reflective fiber. The incident fiber and the reflected optical fiber were gathered into a bundle at the soil detection port (diameter of 7 mm). The fiber bundle served the purpose of simultaneous transmission of incident light and reflected light. Glass fiber can make a tiny loss in the transmission process, and meet the requirements of Y-type structure because of its soft performance.

The circuit unit included an amplifier circuit, an A/D conversion circuit, an LCD, and a U-disk storage circuit. The block diagram of the circuit unit is shown in Figure 8.2. The optical signal was relatively weak, and the obtained electrical signal was weaker after conversion by the photodetector. Furthermore, there would be the influence of various noises. Therefore, the design of the amplifier played a very important role in the stability and reliability of the whole system.

#### 8.2.1.2 Development of a Portable Soil Total Nitrogen Detector

The operation of the soil total nitrogen detector is similar to the soil organic matter content detector. The soil total nitrogen used seven wavelengths in the NIR region (780–2526 nm) (An et al., 2014). The detector also consisted of an optical unit and a control unit. The optical unit included six near-infrared LEDs in separate housings, a shared LED drive circuit, a shared incidence and reflectance Y-type optical fiber, a probe, and a photoelectric sensor. The control unit included an amplifier circuit, a filter circuit, an analog-to-digital converter (A/D) circuit, an LCD , and a U-disk storage component.

The LEDs were then rotated manually to align them with the Y-type optical fiber. The optical signal at each wavelength was then transferred from the LED to the surface of the target soil. The reflected light from the soil surface was acquired and transferred to the photoelectric sensor, through which the optical signal was converted to an electrical signal. Subsequently, the electrical signal was digitized, and the absorbance at each wavelength was calculated. All six absorbance values were used as input data for the soil TN content estimation model. Finally, the calculated soil TN content was displayed on the LCD and at the same time stored in the U-disk. Figure 8.3 shows the system overall structure design.

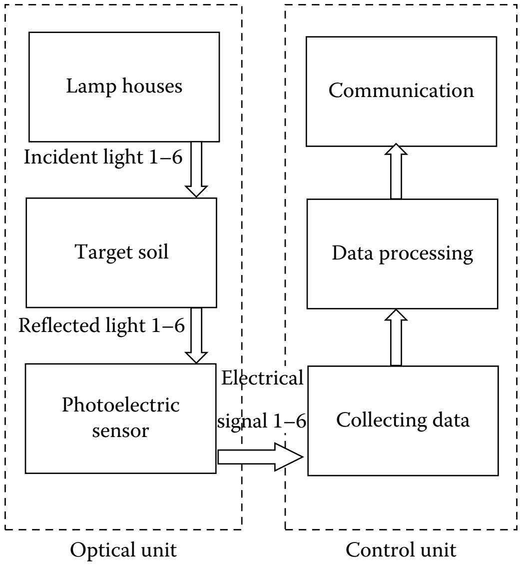


**FIGURE 8.3** Overall structure of the portable soil total nitrogen detector.

The designed Y-type fiber is shown in Figure 8.4. In order to reduce the complexity of the circuit, the manual operation mode was adopted to control the seven light sources (1550, 1450, 1300, 1200, 1100, 1050, and 940 nm). The LED traversed the incident optical fiber position in a test cycle. Optical fiber mechanical structure and optical dial distribution are shown in Figure 8.5a and b, respectively.

Because the light source was weak with noise interference, a filtering operation was done before A/D conversion. In this module, an average filtering method was used to perform data filtering, whereas the hardware filtering method was a one-order R–C low-pass filter. The filtering method included two steps: amplitude limiting and mean. All data were taken an average of 10 times when the data were between 20 and 2000 mV. If the data were either below 20 mV or above 2000 mV, the data were deleted as outliers. Then, LCD display, USB storage, and serial communication of the processed data were realized by a single-chip microcomputer.

Figure 8.6 shows the flowchart of the main program. When the detector starts working, the system completes initialization and LCD detection first. The system

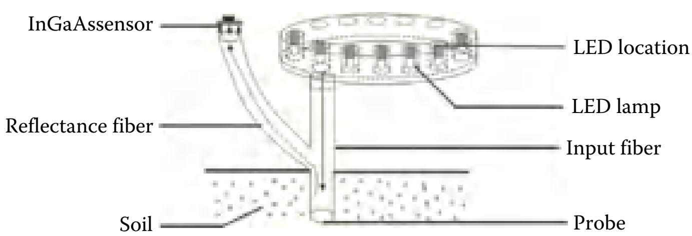


**FIGURE 8.4** Overall diagram of optical fiber structure.

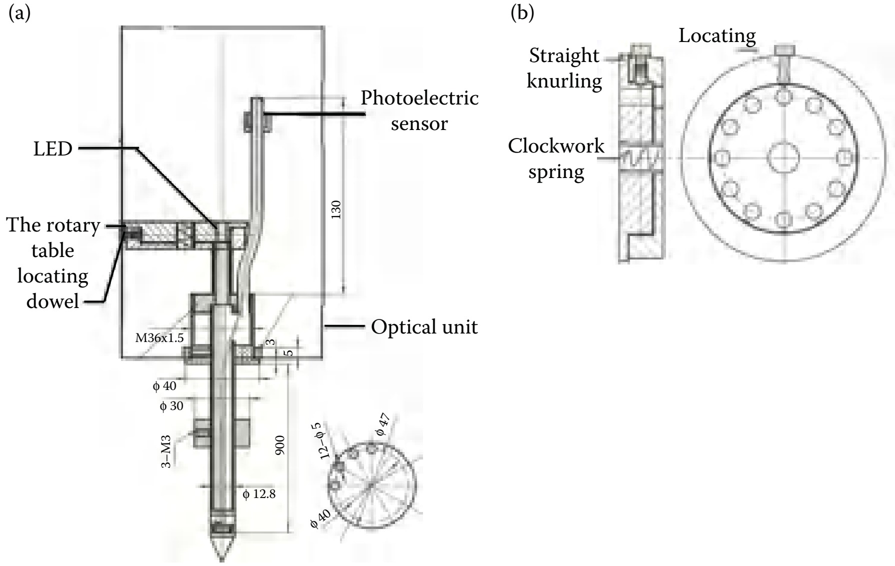


**FIGURE 8.5** Structure of optical fiber and distribution of LEDs. (a) Optical fiber structure. (b) Distribution of LEDs.

then enters sleep mode until it receives an interrupt. If an interrupt 0 is present, the detector begins to collect data. After the A/D conversion, the program enters the data processing subroutine. All the processed data are temporarily stored in a variable. When detecting an microcontroller unit (MCU) period, all the collected data are calculated in the MCU. The result can be read in the LCD by using the LCD subroutine. After the result is displayed, the software then judges whether an interrupt 1 is present, in which case the result is stored in the U-disk. The program then returns to the initial interface. Otherwise, the software directly returns to the initial interface to start the next detecting period. The subroutines are shown in Figure 8.7.

### 8.2.2 Quick Detection of Crop Growth and Physiological Parameters

Acquisition of crop growth status information is very important to the precision management of crops in field. By using advanced detection methods, external and internal crop growth information can be acquired in field (Li et al., 2006). Since the size of field in China is quite small and topdressing is necessary to Chinese farmers, it is important to develop portable and low-cost sensors of crop growth and physiological parameters.

Spectroscopy is an effective method to detect and acquire crop growth information and nutrition status (Xue et al., 2004), which had achieved significant results in both basic theory research and practical application (Liu et al., 2004). Researchers had proposed several spectral indexes to describe crop growth, which were ratio vegetation index (RVI), normalized difference vegetation index (NDVI), agricultural vegetation index (AVI), multitemporal vegetation index (MTVI), normalized

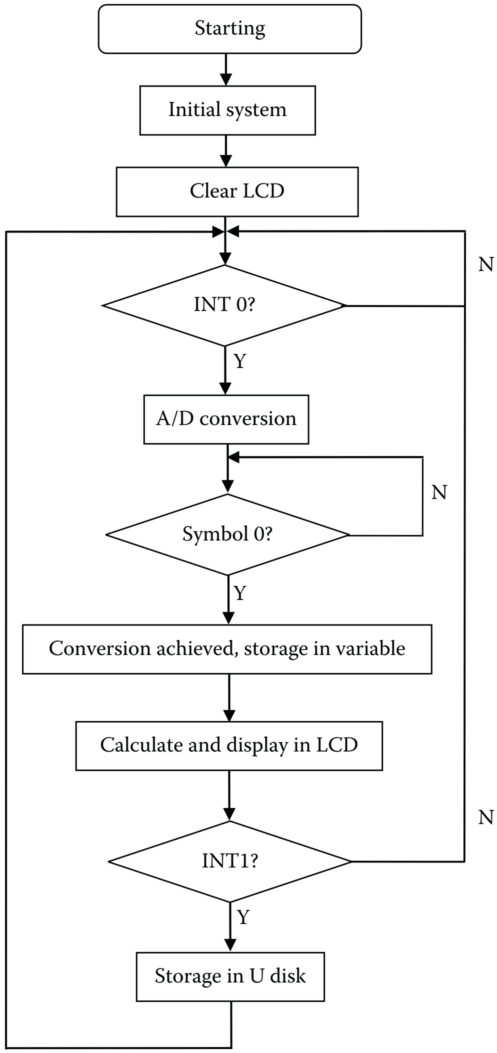


**FIGURE 8.6** Flowchart of the main program.

differential green index (NDGI), normalized difference index (NDI), red-edge vegetation index, and differential vegetation index (DVI) (Feng et al., 2009; Yang et al., 2009; Tian et al., 2010). Among all these indexes, NDVI is the most sensitive to green crop, and thus can be used to detect crop growth and predict rainfall in semiarid regions, and can also be used in regional and global vegetation condition research (Chen et al., 2010). It is also the most commonly used vegetation index and plays an important role in vegetation analysis and monitoring in remote sensing.

Crop information detection is an important part of PA, and the development of the NDVI detector has a wide application environment (Yao et al., 2009). There are

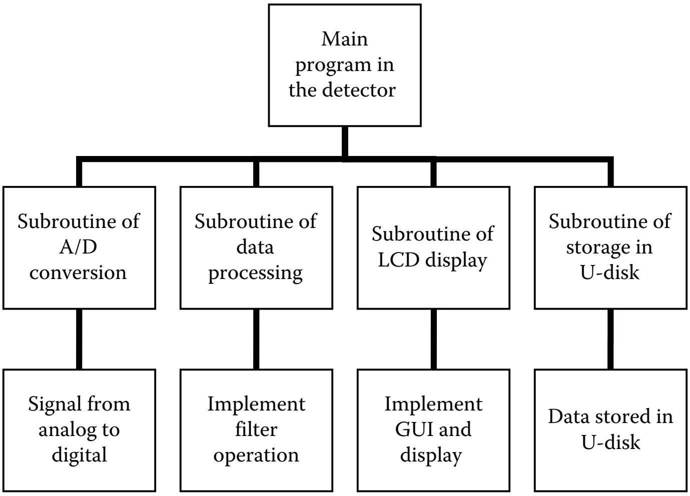


**FIGURE 8.7** Subroutines in software.

several marketed instruments such as the GreenSeeker spectral detector, which have been used. Although this equipment can detect the precise NDVI value of vegetation, it comes at a higher price to Chinese farmers. Also, some parameters are not suitable to the agricultural environment in China, thus making the promotion and application of this equipment difficult in China. In order to solve these problems, much research was carried out to develop a low-cost NDVI detector, which could detect and analyze crop growth information, and which would also be suitable to Chinese agriculture.

#### 8.2.2.1 Development of Crop Growth Detector with Optical Fiber

The principle of the crop growth detector with optical fiber was modeled based on NDVI, whose calculation required the reflectance in two different wavelengths, NIR and red. According to the correlation coefficients, two characteristic wavelengths were found in two highly correlated regions.

Choosing one wavelength from 410 to 650 nm and another wavelength from 660 to 850 nm, NDVI values were then calculated based on these two wavelengths. A linear regression analysis was then conducted on NDVI value and leaf nitrogen content. These steps were repeated for a combination of different wavelengths, and the combination with the highest correlation coefficient was chosen as the best combination for the NDVI detector (Zhang et al., 2004).

This detector has been used in greenhouse cucumber, and two characteristic wavelengths are 530 and 765 nm. The correlation results are shown in Figure 8.8.

The correlation coefficient of calibration was 0.808, RMSEC was 0.880, and $F$ test value was 43.730, which meant the model passed the $F$ test. By using data from the validation set to test this model, the complex coefficient of determination was 0.740; RMSEV was 0.836, which proved that the model was solid and reliable.

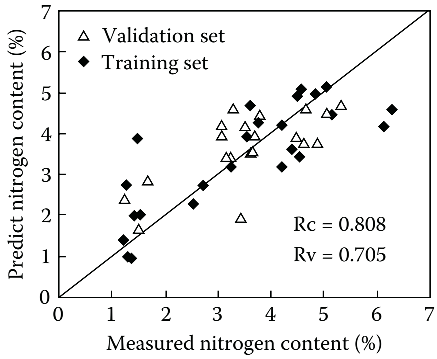


**FIGURE 8.8** Calibration and validation of the NDVI linear regression model.

Since the detector used spectral analysis technology to detect crop growth, it needed to conveniently and accurately acquire the leaf reflecting light. As the collecting area for optical fiber was easy to control, optical fiber was chosen for the collecting part to avoid complexity from too many mechanisms. The overall structure of the detector is shown in Figure 8.9. It contains four parts: reflecting light collecting unit, metering unit, signal conditioning unit, and data acquiring unit (Zhang et al., 2006).

The fiber was Y-shaped to separate the collected light for individual filtering and processing. Using this simple mechanism could easily provide incident light at both sensitive wavelengths. The incident light was introduced to the metering unit through the optical fiber, and filtered and converted to an electrical signal in the metering unit. As the incident light under this condition was too weak for photoelectric conversion, a signal conditioning unit was designed after the metering unit, which included amplifier and noise canceler circuits. The signal processing unit was

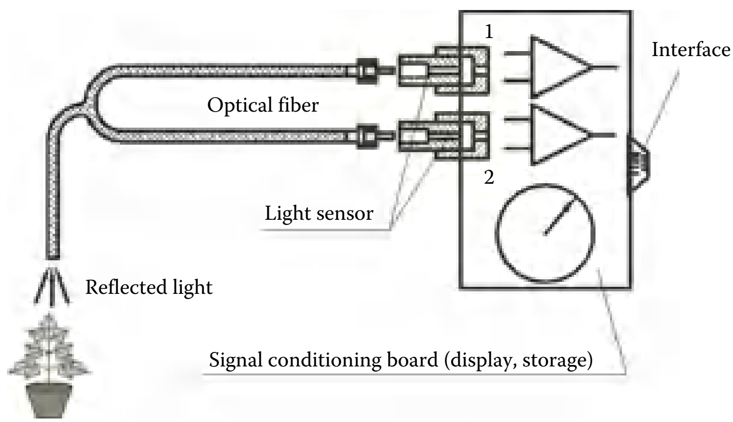


**FIGURE 8.9** Overall structure of the crop growth detector with optical fiber.

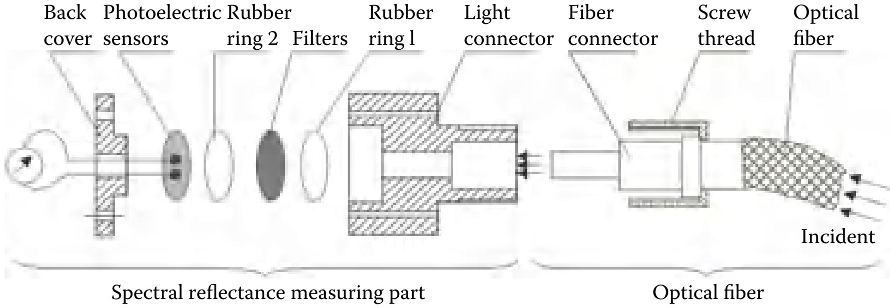


**FIGURE 8.10** Spectral reflectance measuring device.

designed to process data afterward, including A/D conversion circuit, data processor, data storage, and result display. In order to store results in other storage devices or in the host computer, the detector had a communication interface (usually serial communication interface).

The structure of the metering unit is shown in Figure 8.10, which includes filter, photoelectric sensor, metering interface, and back cover. The metering interface had a jack on one side to connect with the output end of the optical fiber, and the metering chamber on the other side to place the filter and photoelectric sensor. The back cover was used to seal the metering chamber. The converted electric signal was drawn through the wire passing through the back cover. This unit can measure the reflecting light from the crop canopy and other parts, and change sensitive wavebands when necessary. The seal of the metering chamber can exclude external interference and reduce the distance between the photoelectric sensor and the exit end of optical fiber to increase metering efficiency.

Common photoelectric sensors include photoresistor, photodiode, phototransistor, and photocell. After comparing all four photoelectric sensors, a silicon photocell was chosen as the photoelectric sensor. Using a photocell can provide a large photosensitive area, high-frequency response, and linear photocurrent change.

The center wavelengths of the filter were 530 and 765 nm, and the half band width was 30 nm. As shown in Figure 8.10, the metering unit can collect the reflecting light from the standard plate or the leaf through the optical fiber, and then convert the light to an electrical signal via the photocell. The output signal from the photocell was amplified and converted to a digital signal for data storage and processing to get the final result. The final result could be displayed on the LCD screen and be stored in other storage devices or in the host PC.

#### 8.2.2.2 Development of Hand-Held Crop Growth Detector with ZigBee

In order to easily evaluate crop growth status in a farm, a hand-held crop growth detector based on spectroscopy and ZigBee was developed (Li et al., 2009). As shown in Figure 8.11, the crop growth detector was made up of a sensor and a controller. The sensor and the controller were connected with ZigBee, a kind of wireless sensor network (WSN) technology. Since the distance between the sensor and the controller can vary according to requirement, it was easy for use in an open field. As

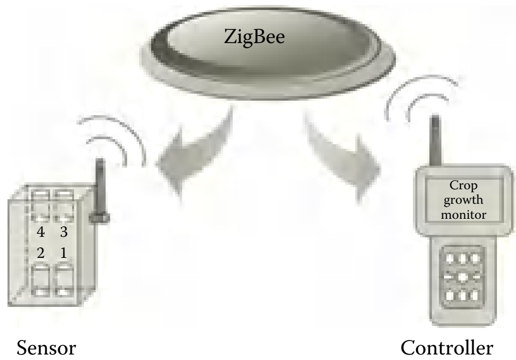


**FIGURE 8.11** Structure of the hand-held crop growth detector with ZigBee.

the coordinator of the whole WSN, the controller was used to receive, store, process, and display the data from the sensor. The sensor was designed to collect, amplify, and transmit the optical signals. Because the system used sunlight as a light source, the sunlight intensity should be measured as well besides measuring the crop canopy reflectance spectra.

(1) *Hardware Design:* The block diagram of the sensor hardware is shown in Figure 8.12. The sensor consisted of an optical unit and a circuit unit. There were four optical channels in the optical unit. Channel 1 and channel 2 were used to detect the reflected light of crop canopy, and channel 3 and channel 4 were used to detect the sunlight. Channel 1 and channel 3 were sensitive at the red waveband, and channel 2 and channel 4 were sensitive at the NIR waveband. The circuit unit in the sensor included signal amplification, an A/D converter, and a wireless transceiver. The four optical channels had nearly the same components: an optical window, filter, convex lens, and photodiode. In order to avoid the influence of the changing angle of the incident sunlight, milky diffused glass was used as the optical windows of the two upward channels. The sensor is to be put vertically on the crop canopy while measuring, almost 20 cm, then the light went through the four optical channels and

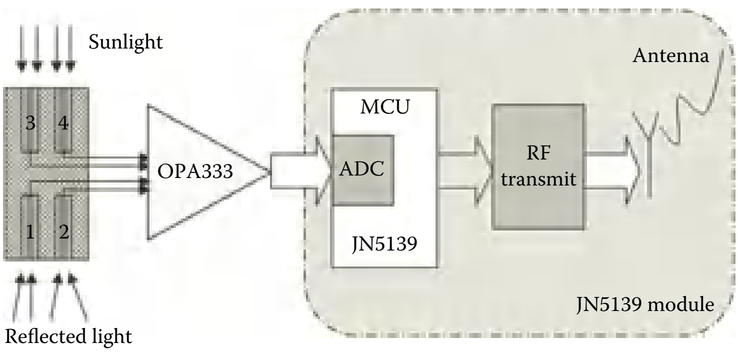


**FIGURE 8.12** Block diagram of the hardware of the sensor.

was converted to a current signal by the photodiodes and then amplified to a comparatively large-voltage signal and finally collected and transmitted to the controller by a wireless module JN5139.

The JN5139 wireless module (Jennic Co, UK) was applied as the core element of the detection system. It provided all RF components and various peripherals, and gave users a comprehensive solution with high radio performance. A JN5139 microcontroller as MCU was integrated into that module to implement IEEE802.15.4 or ZigBee compliant systems. This microcontroller included a 4-input 12-bit A/D converter unit and was easy to use.

The block diagram of the controller is shown in Figure 8.13. The wireless transmission modules JN5139 were also used as the MCUs of the controller. An antenna interface and a flash with a volume of 128 KB were integrated into this module, so the controller could implement the functions of receiving and processing data, and displaying and storing the result within the single module. The display was connected to the MCU via two digital IO ports by means of serial communication. The keypad with nine keys provided several common functions such as reset, storage, review, format, and upload data.

(2) *Software Design:* The sensor and controller built up a simplest network (point-to-point network) together. The sensor was the end device of this network. Comparing with the application in the controller, the most distinct characteristic was its sleep mode. Once initialized after being started, the application activated a timer and then entered into sleep mode. It would be wakened by the interrupt, which was caused by the overflowing of the timer, then data would be collected and sent to the controller and then it went into sleep mode again. The sampling frequency was adjustable according to different requirements. One Hz was recommended in this development. The flowchart of the software in the sensor is illustrated in Figure 8.14.

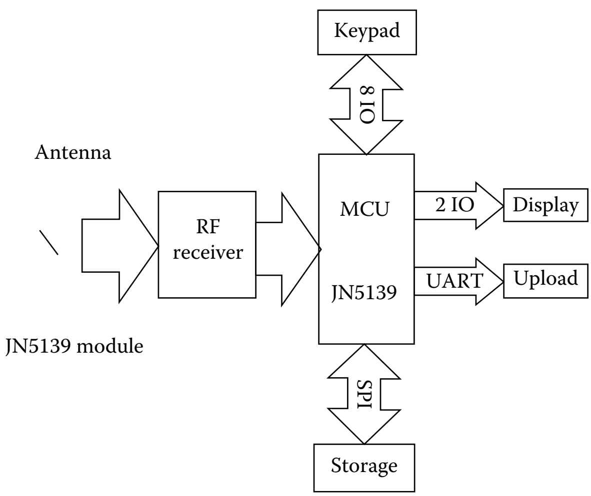


**FIGURE 8.13** Block diagram of the controller.

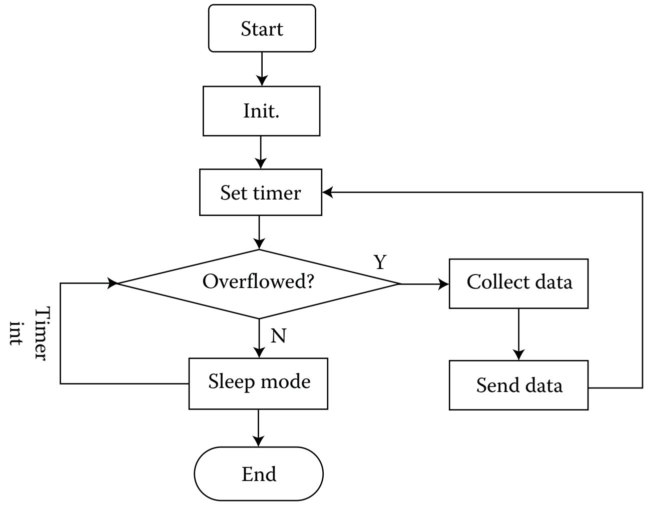


**FIGURE 8.14** Flowchart of the software of the sensor.

The controller was the coordinator of this network. The coordinator was the core of the network and kept on working all the time as long as the network was active, and no sleep mode was allowed. The power consumption was about 60 mA, much higher than it was in the sensor. The flowchart of the software in the controller is illustrated in Figure 8.15. The controller would be initialized once powered, and then

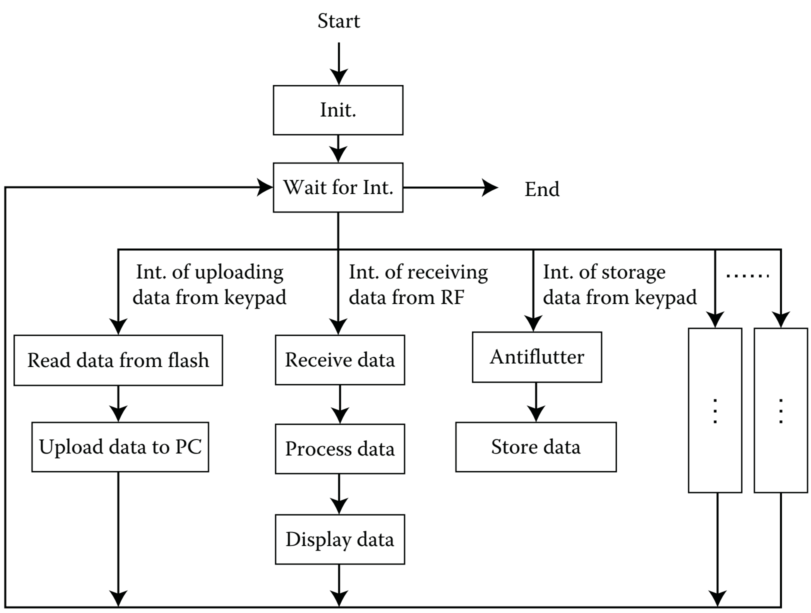


**FIGURE 8.15** Flowchart of the software of the controller.

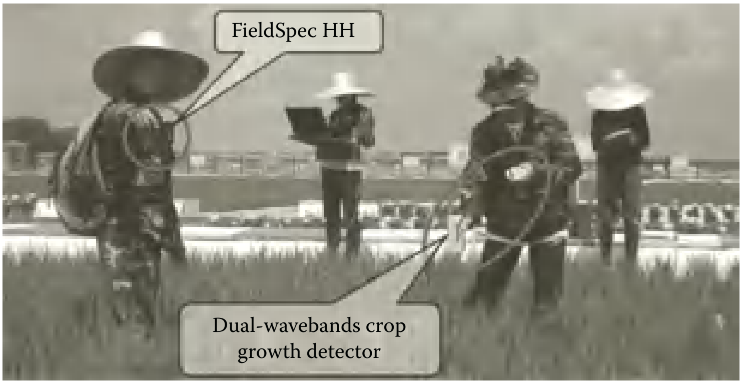


**FIGURE 8.16** Field test at the Chinese state farm located in the Heilongjiang Province.

searched and built up an independent ZigBee network. After that, it would enter into an idle mode to waiting for interrupts. Once an interrupt occurred, the system would check which interrupt source it came from; if it was defined, the proper function would be executed, and if it was not defined, the system would return to idle mode. The interrupt from RF reception had top priority and could lead the system to the subfunction of data reception. In this subfunction, the received data were immediately processed and calculated to NDVI value, then displayed on the LCD. Seven other interrupts from the keypad were also defined in this application. Before recognizing which specific interrupt it was, an antiflutter function was strongly requested to eliminate the flutter caused by key pressing. In Figure 8.15, only three typical interrupts were listed.

The detector was applied in a Chinese state farm located in Heilongjiang Province, Northeast China. As shown in Figure 8.16, many field tests were conducted in the paddy fields of Qixing Research Center, Jiansanjiang Sub-bureau of Reclamation, Heilongjiang Province, on June 2008. After calculation, the prediction model of the chlorophyll content of rice was established based on NDVI (550,850), R (650), and R (766).

#### 8.2.2.3 Development of Vehicle-Mounted Four-Waveband Crop Growth Detection System

In order to further extend the function of the crop growth detector, a new four-waveband crop growth detection system was developed to work as a ZigBee WSN with one control unit and one measuring unit. The measuring unit included several sensor nodes, which were used to measure crop canopy (Li et al., 2011). All the units were installed on an onboard mechanical structure so that the detection system could measure crop spectral characteristics on-the-go and in real time.

As shown in Figure 8.17, the system consisted of two parts: the control unit and the measuring unit. The control unit was a CS350 type of personal digital assistant (PDA) with an attached ZigBee wireless communication module (JN5139 module). As the coordinator of the whole wireless network, it was used to establish the wireless network, waiting for the sensor nodes to join in, and receiving, displaying, and

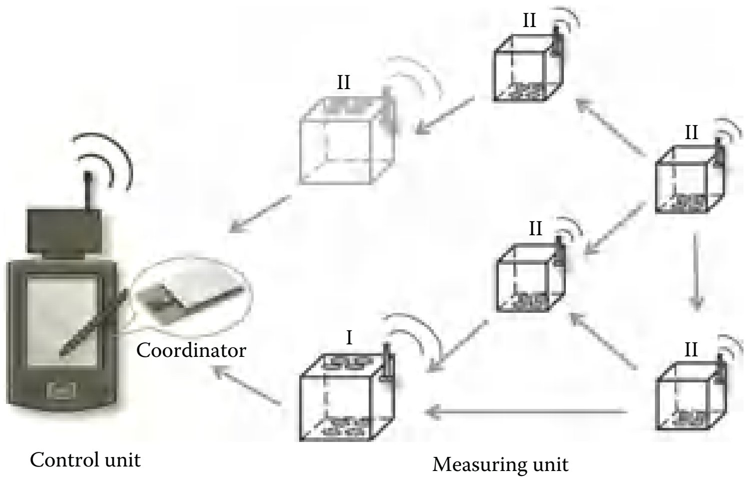


**FIGURE 8.17** Structure of the vehicle-mounted crop detection system.

storing all the data from the different sensor nodes. Theoretically, each network can accommodate the maximum number of nodes for 65535.

The measuring unit consisted of several optical sensors, and each optical sensor was used as a sensor node in this WSN. Each sensor node consisted of an optical part and a circuit part. The optical part contained eight optical channels at four wavebands. Since the detection system used sunlight as the light source, besides the reflected light from the crop canopy, sunlight intensity should also be measured as a reference. Therefore, two solutions were put forward:

1. A full function sensor node had to contain eight optical channels, the upward four for the sunlight and the downward four for the reflected light.
2. Select one sensor node to measure the sunlight, as the type I sensor shown in Figure 8.17. Other sensor nodes were used to measure the reflected light, as the type II sensor shown in Figure 8.17.

Under the premise of measurement precision, this kind of design greatly reduced the production cost. As discussed above, the advantages of the four-waveband crop growth detection system mainly reflected in the following:

1. The structure of the optical channel. The four optical channels were designed to integrate with compact structure and light. The filter can be replaced conveniently without opening the sensor node, which enhances the universality of the system.
2. The signal process circuit. In the circuit part, the current signals were amplified and converted to voltage signals. A time-division multiplex chip (ADG704) was applied to share the amplification unit and an OPA333 amplifier, which had the properties of high-precision, low-quiescent current, and low power consumption, was chosen to amplify.


**FIGURE 8.18** Field test of the vehicle-mounted crop detection system.

3. Flexibility and portability of the system structure. The sensor and controller can set up the communication network in many ways. The networking mode between the hand-held and vehicle-mounted can be transformed into each other. The transmission distances can be up to hundreds of meters, which realized the real-time, continuous measurements of crops in the field. Furthermore, it increased the flexibility of the detector installation.
4. The independence of the sunlight measuring unit. A sensor node was selected to measure the sunlight, and then the whole network shared the sunlight value. Under the premise of measurement precision, this type of design greatly reduced the cost of the system.
5. Friendly operation platform. Using a personal digital assistant (PAD) as the controller of the system, and developing a visual interface for data acquisition, it was convenient and user-friendly, and easy for further development.

The newly designed system increased the optical channels and realized measured crop spectral characteristics on-the-go and in real time after being installed on an onboard mechanical structure (Zhong et al., 2013). Figure 8.18 shows the field test in Shaanxi Province. The distribution of chlorophyll content of wheat detected by the new system is shown in Figure 8.19.

## 8.3 APPLICATION OF IoT IN AGRICULTURE

The IoT is defined by the Chinese Academy of Information and Communication Technology (CAICT) as follows: “Internet of Things is an expanded application and a network extension of a communication network and the Internet. It uses sensing technology and intelligent equipment to perceive and recognize the physical world, and communicate through a network to compute, process, and mine data. It can

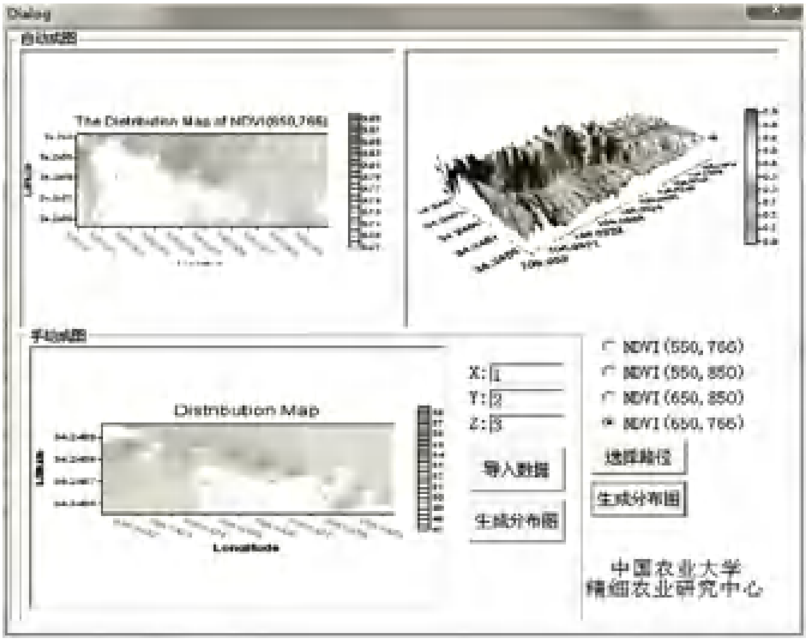


**FIGURE 8.19** (**See color insert.**) Distribution of chlorophyll content of wheat.

exchange information and create seamless links between human–things or thing–things, thus to realize real-time control, precise management and scientific decisions of the physical world." Based on this definition, it is concluded that the IoT is an integration of the WSN, microelectromechanical systems (MEMS), and the Internet. Figure 8.20 shows the structure of the IoT. Usually, it includes three layers: perception layer, network layer, and application layer. As the nerve endings of the IoT, the perception layer achieves the function of the acquisition, identification, and control of all necessary information through sensors, radio-frequency identification device (RFID) readers, cameras, GNSS modules, smart meters, mobile phones, IC cards, etc. It is mainly related to sensors, bar codes, RFID, audio and video codec, and GNSS technology. The network layer is the nerve center of the IOT, and is used to transmit information. It uses WSN, Wi-Fi (wireless fidelity), communications networks including the Internet, GPRS (general packet radio service) network, 3G or 4G network, LAN (local area network such as IPV4 and IPV6), radio and television networks, and the next generation of broadcast networks). The application layer is the brain of the IoT, and can realize the data processing and application. The fields used in the application layer include enterprise resource planning, expert system, cloud computing, system integrate, industry application, agricultural application in crop cultivation, husbandry, aquaculture, greenhouses, etc. (Li, 2012).

Currently, Chinese agriculture is in the process of moving from traditional agriculture to modern agriculture, and the development of modern agriculture requires the support of information technologies during the production, sale, management, and service process. With the progress of the IoT, the development of modern

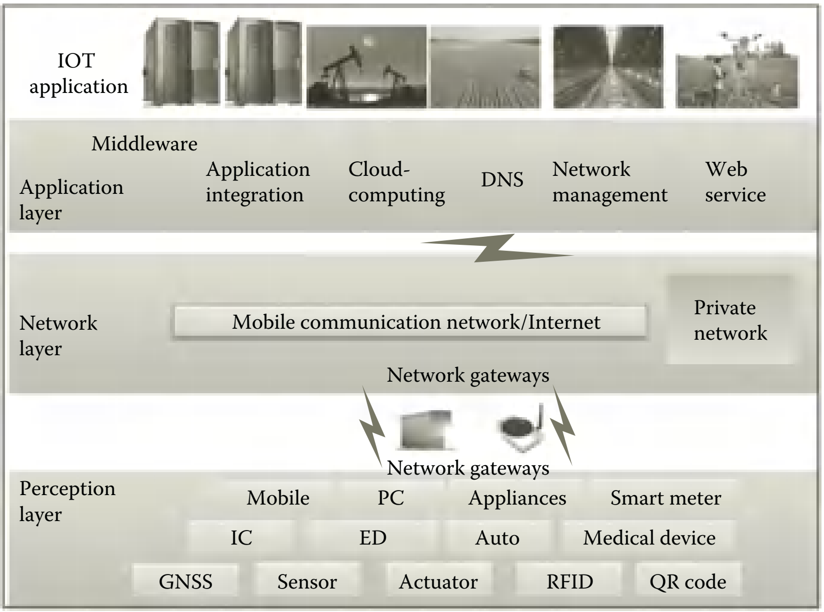


**FIGURE 8.20** Structure of IoT.

agriculture has greater opportunity than ever before. Modern agriculture urgently requires the IoT to provide digital design, intelligent control, precise operation, and scientific management to agricultural elements in agricultural industries such as field planting, protected horticulture, livestock breeding, aquaculture, and agricultural logistics. Thus, it is possible to realize "overall perception, reliable transmission, and intelligent processing" for a variety of agriculture elements, and achieve the goal of high yield, high efficiency, ecological sustainability, and safety.

### 8.3.1 Key Technologies of Agricultural IoT

Figure 8.21 shows the structure of agricultural IoT. The perception layer involves all the factors in field information acquisition with advanced sensing technology. After information acquisition, the network layer connects the sensing equipment to the transmission network, which provides the path for the upload of sensing data. Through a wired or wireless communication network, information and data can interact and share in real time. In the application layer, agricultural information management and intelligent decisions can be made based on the knowledge provided by acquired agricultural information using intelligent computing and processing. Owing to this, transmission and processing of agricultural data are other key technologies besides sensing technology.

WSN and mobile communication are two important technologies of agricultural information transmission. Since WSN is a self-organized wireless communication network system, it can deploy a large number of sensor nodes in the detection area and monitor and collect information about all the subjects in the detection area, and

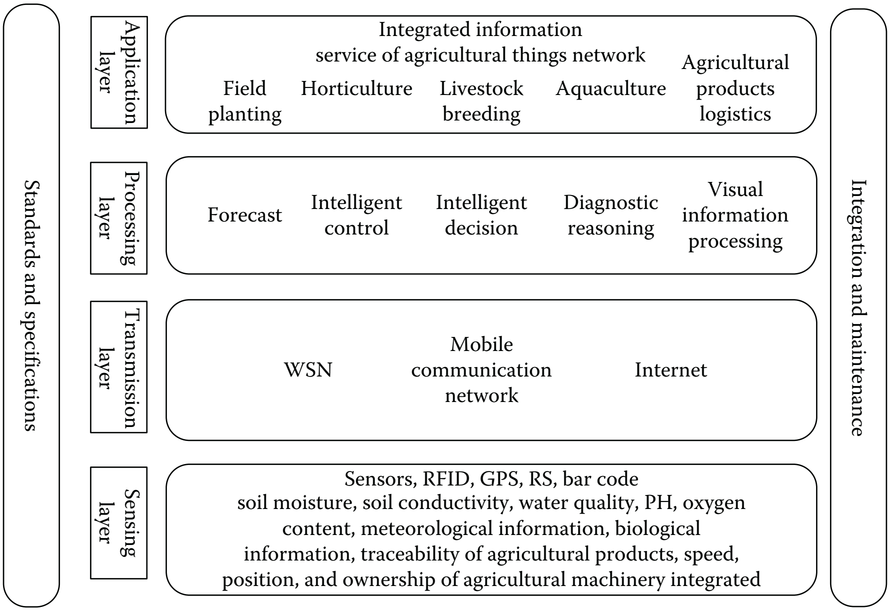


**FIGURE 8.21** Structure of agricultural IoT.

then send this information to gateway nodes to conduct detection and tracking on targets within a complex specified range. It is easy to deploy and hard to destruct. Currently, in Agriculture WSN, ZigBee technology is widely used.

Researchers worldwide have been using WSN technology in field information acquisition. By combining ZigBee and GPRS wireless communication technology, NDVI data can be wirelessly transferred to a server thus making it possible to analyze crop growth and support field management. In order to meet the needs of measuring farmland environmental parameters, the monitoring system of soil temperature and moisture in farmland was developed. The system included a field wireless sensing network and a remote data center. Using a JN5121 wireless microprocessor as the core of the sensor nodes, the wireless sensing network was built based on ZigBee protocol. The gateway nodes were developed based on an ARM9 microprocessor embedded Linux system, which could realize data aggregation and remote data forwarding using GRPS. The management system FieldNet was installed in the remote data center, which could monitor the real-time change and analyze spatial variation by using the implemented ESRI GIS ArcEngine Library. The design and development of the system provided an effective tool for the research of spatiotemporal variability and irrigation decisions in PA.

With the improvement of agricultural IT, mobile communication technology has become an important tool in remote transmission of agricultural information. Figure 8.22 shows the structure of a wireless field acquisition system for soil moisture based on GSM technology. It includes a fast positioning system (GNSS device), a GSM module, a terminal computer, and other communication equipment. The

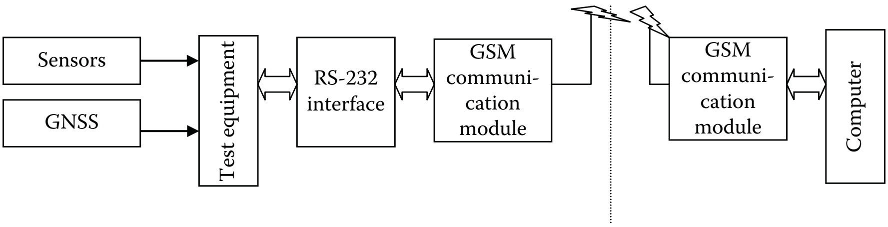


**FIGURE 8.22** Structure of wireless field information acquisition system.

GNSS device can detect the position and moisture information of farmland, which will be sent to monitoring computer by text message through the GSM network. It is low-cost and reliable, and can also cover a wide range and transmit through an unlimited distance. It can provide an efficient solution for field information acquisition, transmission, and processing.

### 8.3.2 Agricultural IoT and Management Decision in Precision Agriculture

Management decisions based on agricultural information play an increasingly important role in agricultural modernization and digitization. Nanjing Agricultural University has developed an agricultural spatial information management and decision supporting system based on WebGIS (Liu et al., 2006). This system provided a great data management platform for PA information. Using a systematic approach and mathematical modeling techniques, a distributed network platform based on B/S structure was built, and a regional agricultural spatial information management and decision support system was designed and developed. Figure 8.23 shows the whole structure of the system. It included several subsystems such as Basic Map Operation, Data Query and Analysis, Cropping System Evaluation, Ecological Zoning, Potential Analysis, Precision Farming Management, Visual Outputs, and System Maintenance. It can perform the position query, topic query, and logical query, and can carry out the evaluation of climate adaptability, soil suitability, and comprehensive conditions. It can also conduct analysis on monoculture production potential and multicrop production potential.

In addition, the decision support system (DSS) of precision fertilization has also made great progress. An information system of soil and fertilizer was developed by the Chinese Academy of Agricultural Sciences (CAAS), which realized functions such as variation prediction of soil and fertilizers, expert system of soil and fertilizers, and output of agricultural maps. Based on this research, the National Engineering Research Center for Information Technology in Agriculture (NERCITA) has proposed a DSS for precision fertilization. The overall structure of the system is shown in Figure 8.24. In order to solve the promotion and extension problems of precision fertilization software in China, this DSS was developed based on component-oriented technology. It had distributed the tasks in precision fertilization into several different service units, which were mapped to corresponding service components. Furthermore, it had also provided a method how to develop a component-oriented

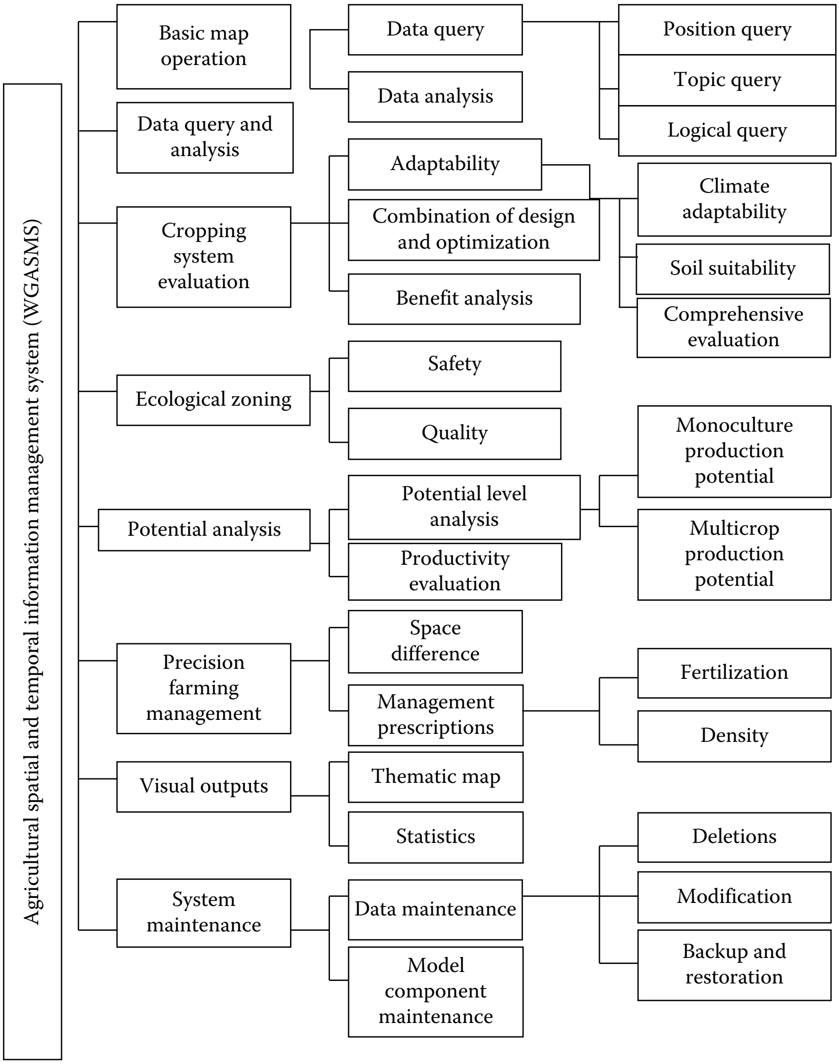


**FIGURE 8.23** Structure of field spatial information management and decision support system.

DSS of precision fertilization to meet personalized needs. Experiments showed that the component-oriented DSS of precision fertilization had great advantages in widespread promotion and application.

### 8.3.3 Agricultural IoT and Field Information Acquisition

#### 8.3.3.1 Soil Moisture Monitoring System in Farmland Based on IoT

In northern China, drought is still a problem in agriculture. In order to prevent spring drought from damaging the growth of winter wheat, it is necessary to use soil moisture information to guide irrigation and prevent drought. There is a serious shortage

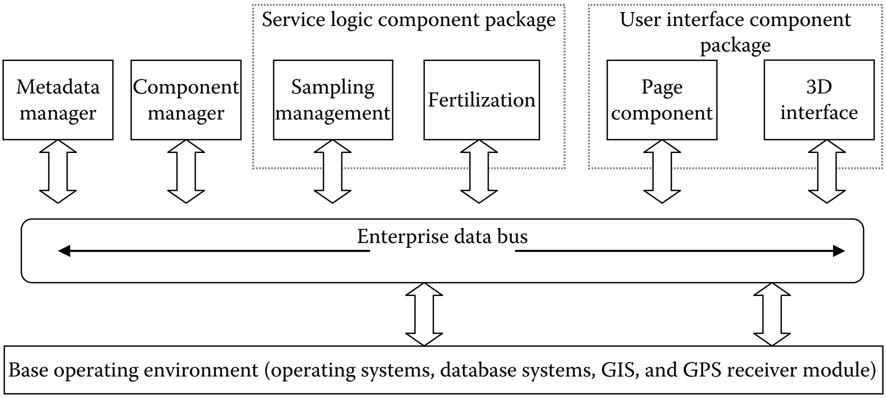


**FIGURE 8.24** Overall structure of precision fertilization decision support system.

of water resources in China and other problems such as low utilization rate of water resources. In this case, it is very important to improve water resource efficiency in PA. By adapting advanced communication and sensing technologies, a monitoring system was constructed to realize accurate dynamic monitoring of agriculture water resources, thereby promoting scientific management and rational use of water resources.

A soil moisture monitoring system based on the IoT was constructed in Huaitai County, Shandong Province, China, as shown in Figure 8.25. WSN were constructed

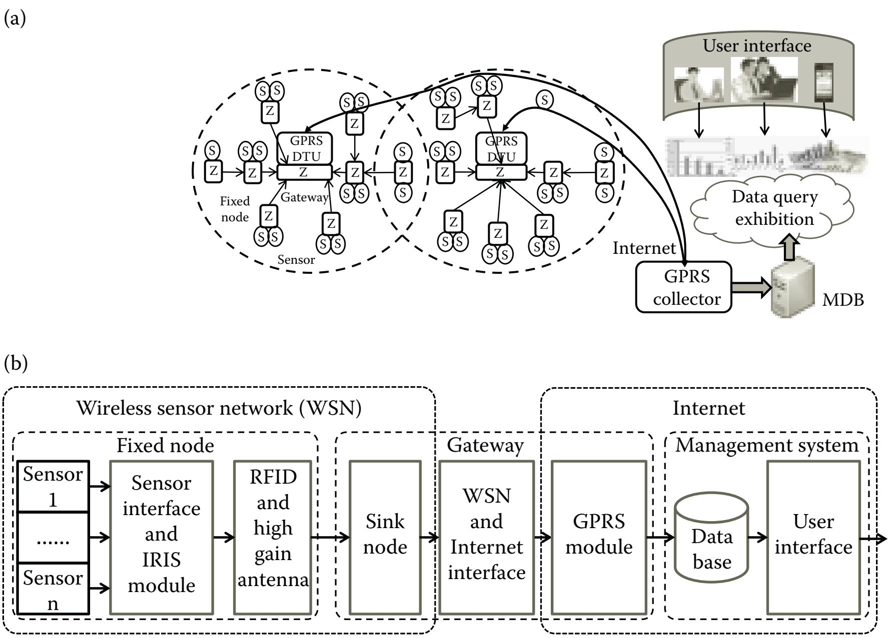


**FIGURE 8.25** Soil moisture monitoring system based on IoT. (a) Structure. (b) Block diagram.

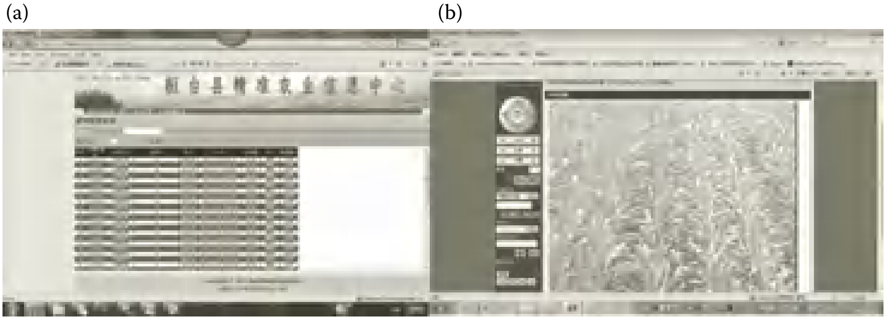

**FIGURE 8.26** Demonstration platform of Huantai precision agriculture information management. (a) Interface. (b) Video monitoring module.

to monitor the variation of soil moisture in a farmland using 6–10 monitoring nodes. The data of soil moisture content were integrated to a gateway node, and then uploaded to a web server (database) by using GPRS network or the Internet, dependant on the site's condition. Thus, remote collection and monitoring of soil moisture were performed. The data can be browsed in a webpage (The Demonstration Platform of Huantai Precision Agriculture Information Management, http://www.htpa.cn/).

The Demonstration Platform of Huantai Precision Agriculture Information Management includes basic information management of farmland, soil moisture information acquisition and management, and video monitoring and information publication, which is shown in Figure 8.26. The basic information management module of the farmland is in charge of storage and maintenance of soil nutrition maps, precision fertilization information, and basic information such as area and facilities. The acquisition and management module of soil moisture information is in charge of management and analysis of the soil moisture data collected in real time by wireless sensor nodes. It can display information such as node number, data collecting time, and soil moisture data. Users can choose whether to display all the data or just the data from some particular sensors. The video monitoring module is in charge of monitoring the field environment. Users can adjust the focal length and tripod head of the camera.

#### 8.3.3.2 Integrated Agricultural Information Monitoring and Precision Management System Based on IoT

In order to obtain real-time crop growth information to enable scientific decisions and management, CAU has developed and built the Zhunge'er Intelligent Agriculture Information Platform for the cooperation project with Zhunge'er County of Inner Mongolia, as shown in Figure 8.27. The platform used B/S mode and could collect and store the data of greenhouse temperature, humidity, light intensity, $CO_2$ concentration, and video, and had the functions of data analysis and alarm output. The application experiment in Zhunge'er County showed the platform was stable, easy to use, structured, and managed data effectively.

The Zhunge'er Intelligent Agriculture Information Platform included "one platform and four systems," which were the intelligent agriculture information platform,

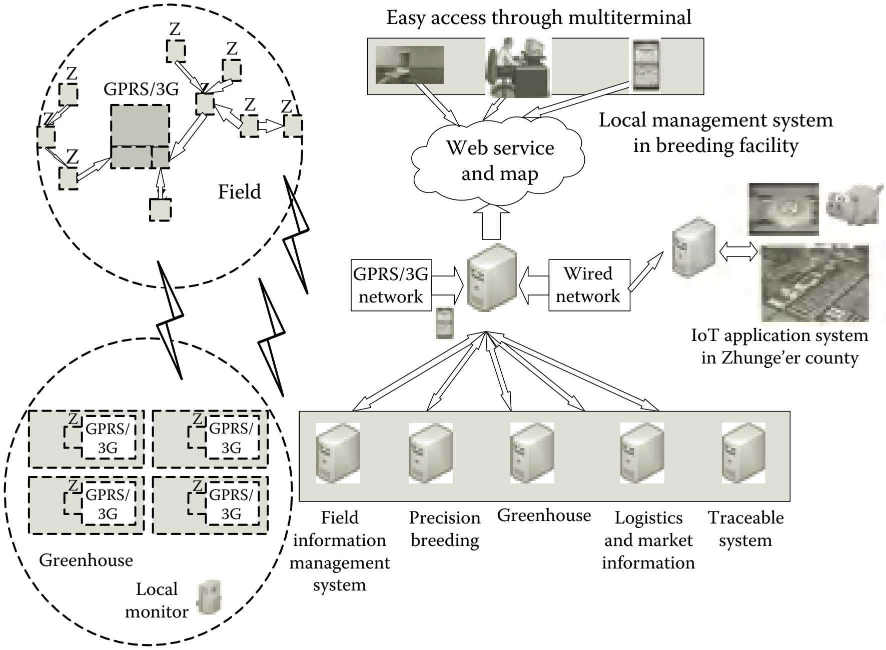


**FIGURE 8.27** Zhunge'er integrated agricultural information monitoring and precision management system based on IoT.

and the precision management system for field crop production, precision management system for greenhouse, precision management system for animal production, and traceability system of agricultural products.

In the precision management system for greenhouse, for example, the subsystem of data acquisition and remote transmission consisted of several sensor nodes, gateway nodes, and relay routing nodes. The sensor nodes were connected with temperature, humidity, carbon dioxide, and light, which could be deployed at the center of different greenhouses. Sensing data could be transmitted to the gateway node through the ZigBee wireless network, and were then sent to the local PC through serial communication. The stand-alone monitoring software also runs on this PC to receive data by scanning serial communication and furthermore processing and analyzing these data. The greenhouse administrator could check data in real time on this PC. The video camera was connected to a local PC and server platform through the Internet, which was used to monitor crop growth and pest conditions. The server platform was designed based on B/S mode. Users can access web applications to manage or query monitoring data. Authorized users can watch the greenhouse monitoring video in real time.

### 8.3.4 Agricultural IoT and Agricultural Machinery Scheduling

With the rapid development of large-scale agricultural production in China, it is important to execute rational allocation and effective scheduling of agricultural machinery resources to ensure the completion of agriculture production on time, and to improve the utilization of agriculture machinery to avoid waste in resources and loss in agricultural production. By using GIS, GNSS, and wireless communication technology, agricultural machinery monitoring and scheduling based on agricultural IoT has been realized.

NERCITA has designed and developed an agricultural machinery scheduling system based on GPS, GPRS, and GIS technology (Li et al., 2008). As shown in Figure 8.28, the system consisted of a vehicle terminal base on PDA and agricultural machinery monitoring and dispatching center. The vehicle terminal can perform fast collection and real-time display of agricultural machinery information combined with GPS receiver, sensors, and MapX Mobile GIS component. The data collected were then sent to the data processing server through GPRS network in real time. The MapObjects component was used to develop the machinery management system. According to the operation schedule, the management system could monitor the working status, dispatch, and track the historical information of the agricultural machinery. This system has provided a practical solution for remote information collection, real-time monitoring and effective scheduling of agricultural machinery (Wang et al., 2010; Wu et al., 2013).

The agricultural machinery monitoring and scheduling system contains three parts: the vehicle terminal, monitoring server, and user surveillance terminal.

1. The vehicle terminal is a terminal device mounted on the agricultural vehicle, which has an integrated GPS locating module, GPRS wireless communication module, center control module, and multiple sensors. It can acquire position data of agricultural machinery by the GPS module, and real-time condition data of agricultural machinery by a series of sensors such as fuel

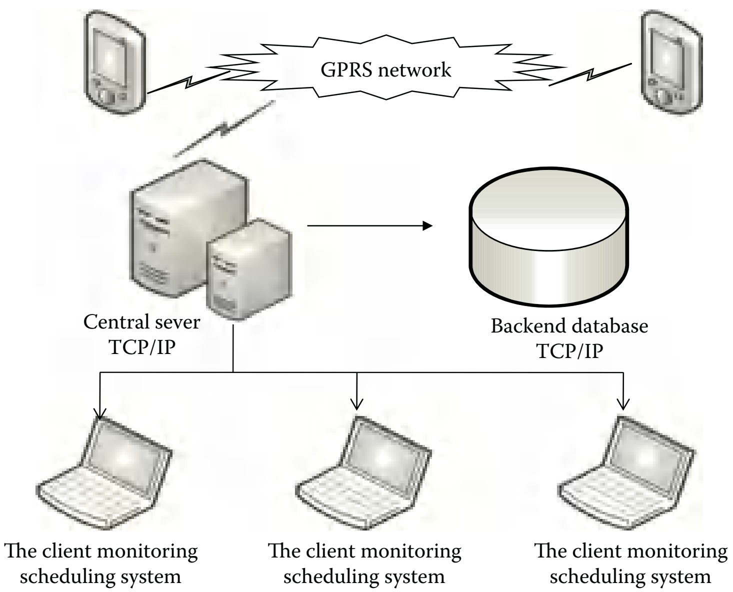


**FIGURE 8.28** Agricultural machinery scheduling system based on GPS, GPRS, and GIS technology.

cost sensor, signal sensor, and speed sensor. Finally, it can upload all these data to the monitoring server through the GPRS wireless network.

2. The monitoring server consists of a vehicle terminal server, monitoring terminal server, and database server. The vehicle terminal server is in charge of communicating with the vehicle terminal to receive data from different terminals and to store these data in the database in the scheduling center. It can also send scheduling commands and information to the vehicle terminal. The monitoring terminal server is in charge of interfacing with the client scheduling center, parsing and responding to the request from the clients, and extracting data from the database to clients. The database servers are in charge of storing and managing agricultural machinery data such as position, condition, and operating parameters. It will also regularly back up and dump historical data, which provide data support for the vehicle terminal server and monitoring terminal server.
3. The clients surveillance terminal can provide real-time remote monitoring and processing of agricultural machinery production position and condition, visual display of agricultural machinery position on a digital map, data query and statistical analysis for agricultural machinery operation monitoring data, and the release of agricultural machinery scheduling information to managers. The surveillance terminal can also post scheduling commands by telephone, thus realizing real-time scheduling of agricultural machinery.

In general, an agricultural machinery scheduling management system can provide real-time information of working conditions and positions to agricultural machinery management and agricultural cooperation organizations based on a GSM digital public communication network, GPS, and GIS technology. The agricultural machinery scheduling system can suggest the optimal number and route for agricultural machinery usage by analyzing information such as area and position of production according to tasks given by the manager. Meanwhile, the supportive module can examine the efficiency and fuel cost of historical production, to suggest the optimal operation of agricultural machinery. By processing the data uploaded by the vehicle terminal, the system can accurately obtain information such as real-time position and fuel cost. The current condition of agricultural machinery can be displayed in real time and tracked on the monitor. Statistical analysis of effective mileage of operation and fuel cost can be provided. Also, by providing the historical track of agricultural machinery, remote monitoring of production can be achieved, which can support the scheduling of production, thus increasing the efficiency of agricultural machinery usage.

## 8.4 SYSTEM INTEGRATION AND APPLICATION OF PRECISION AGRICULTURE

### 8.4.1 Development and Application of Intelligent Agricultural Equipment

Information and communications technology (ICT) and computer technology have brought about a revolution in traditional agricultural machinery. By introducing sensing and detection technology, automatic control technology, information acquisition and fusion technology, machine vision technology, and field bus technology, agricultural machinery has partly or overall realized automation.

The studies on the automation system of agricultural machinery include sensors, actuating devices or units, data fusion and processing software, field bus, visualization of monitoring interface and control software, and overall system performance and structure. In order to increase performance/price ratio of agricultural machinery, electronic, sensor, power, mechanical, computer, and intelligent control technologies were applied to the design, manufacture, and application of agricultural machines. Consequently, production efficiency was greatly improved. Especially with the development and extension of PA ideas or technologies, it promotes the development and application of intelligent agricultural equipment. Many fruitful results have been achieved in automatic navigation technology, variable operating control technology, vehicle-mounted agriculture operation technology, and agricultural robot technology in agricultural machinery.

#### 8.4.1.1 Application of VRT in Agricultural Machinery

The core of PA is variable agricultural resources management based on spatial and temporal variation. It is in accordance with the crop yield, environmental factors that affect crop growth, and growing requirements. Hence, variable-rate treatment (VRT) technology is the core of PA, while agricultural machines for VRT are important and necessary (Wang et al., 2003).

VRT technology can be divided into two categories: map-based VRT and sensor-based VRT. Thus, the variable targets are taken in two forms: previously generated electronic map and real-time decision data generated during machine movement.

For map-based VRT, a four-step procedure is needed to generate the prescription map. The first step is obtaining the spatial and temporal variation information of a crop yield, soil parameters, etc. The second step includes establishing models on plant growth, environmental conditions, weather, germination rate, growth, and nutrient requirements. The third step involves generating the desired prescription map based on the previous comprehensive analysis by using GIS and DDS. The fourth step is implementing variable inputs in accordance with the prescription map by using corresponding VRT agricultural machinery.

NERCITA has developed a kind of variable fertilization machine matching with the domestic tractor. With the help of the GPS navigation system, it can realize variable fertilization according to the prescription map designed in advance. The structure of the Geneva wheel was used as the fertilizer measuring device of the VRT machinery. By adjusting the rotation speed of the outside Geneva wheel, it can adjust the fertilizer quantity. The structure of the VRT fertilizing machine is shown in Figure 8.29.

After determining the soil fertilizer prescription based on the soil information of a field, the prescription map in the format of a .shp file was input into the AgGPS170 computer by a TF card. A tractor mounted with receiving antennas received GPS signals and differential signals from the radio base station.

After processing the DGPS signals, the system software can determine the geographic location of the machinery. The AgGPS170 computer would put the on-site

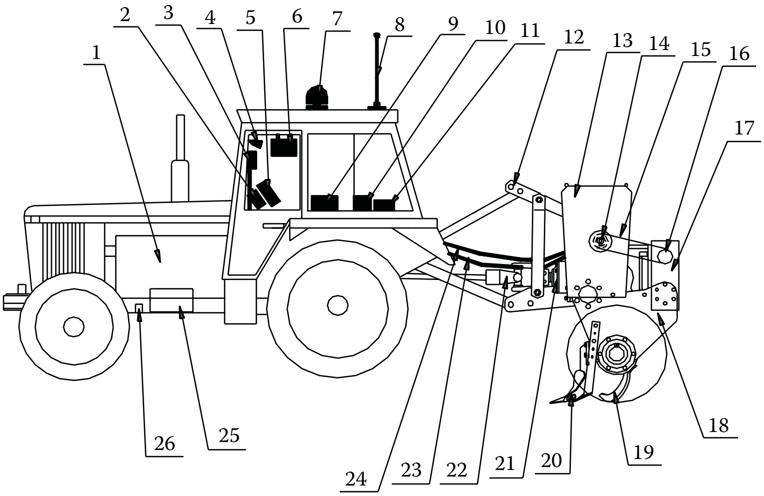


**FIGURE 8.29** Variable rotary tillage and fertilizer machinery structure diagram. (1) Tractor. (2) Data exchanger. (3) AgGPS170 computer. (4) Guiding light bar. (5) Fertilization control switch. (6) Fertilization controller. (7) GPS-receiving antenna. (8) Radio-receiving antenna. (9) Junction box. (10) Branch box of power source. (11) GPS moving station. (12) Three-point suspension hitch. (13) Fertilizer can. (14) Transmission shaft sprocket. (15) Transmission chain. (16) Hydraulic motor. (17) Motor supporting structure. (18) Rotary tillage side panel. (19) Rotary blade. (20) Subsoiler. (21) Gearbox. (22) Cardan shaft. (23) Oil return pipe. (24) Oil feed pipe. (25) Storage battery. (26) Speed measuring radar.

fertilizer application rate from the prescription map into the fertilization controller through a data switch exchanger, and then, the fertilizer distributor controlled the hydraulic motor speed to achieve the goal of changing the fertilizer application quantity. The start and stop of fertilizer distribution can also be compulsively controlled by the fertilization control switch in the driving cab, and the running of the tractor in the field is instructed through the guiding light signal.

The AgGPS170 computer will then display the next location coordinates of the tractor, and the fertilizer prescription data on the screen. The fertilizer was discharged from eight rows of distributing wheels installed at the bottom of the fertilizer box, evenly scattered on the surface by the distributing plate, and then the back of the high-speed rotary tillage blade stirred the fertilizer into the soil.

#### 8.4.1.2 Laser-Control Land Leveling System

In a cyclic process of farmland operation, land leveling is an important measure to improve irrigation quality and therefore plays an important role in PA (Jia et al., 1997). It can effectively improve farmland management and seedbed conditions, and realize precision irrigation so as to achieve the purpose of water saving and increased production. As the world's most advanced mode of land leveling, laser control technology has been widely used in Europe, America, and other developed countries in the early 1970s. In the last decade, developing countries such as India, Turkey, Pakistan, China, and others have also successively used laser technology and

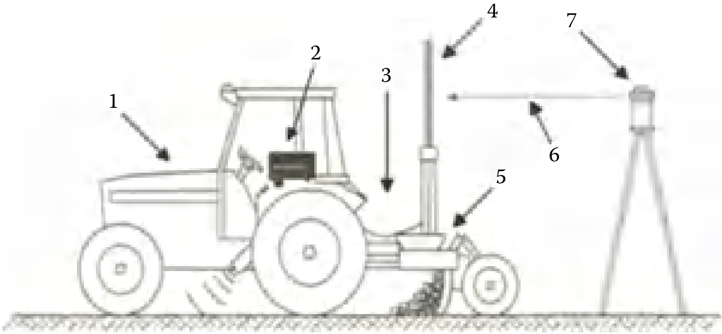


**FIGURE 8.30** Principle diagram of laser land leveling system. (1) Tractor. (2) Controller. (3) Hydraulic system. (4) Receiver. (5) Land-leveling bucket. (6) Datum plane. (7) Laser emitter.

achieved better economic benefit. Figure 8.30 shows the principle diagram of laser land leveling system (Li et al., 2007; Hu et al., 2009; Li and Zhao 2012).

Aiming at precision land leveling operation for dry fields in Northern China, China Agricultural University has developed a low-cost laser land leveling system as well as three-dimensional topography measurement system. The receiver of the system adopted double optical filters, the controller utilized a fuzzy control algorithm, and the hydraulic system adopted a gear pump as the power output. Figure 8.31 shows a land leveler in field operation. Equipped with a domestic JP300-type laser emitter, the system can work stably with high accuracy. The receiver has an accuracy of 3 mm, and the controller has good compatibility with both domestic and foreign hydraulic control valves (Lin, 2004; Zhao et al., 2008; Si et al., 2009; Li et al., 2012).

NERCITA has designed and developed a 3D-terrain rapid data acquisition system based on all-terrain vehicle (ATV), which used high-precision RTK-GPS to


**FIGURE 8.31** Land leveler in operation.

**FIGURE 8.32** Operation of the laser land leveler in paddy field.

automatically measure 3D terrain data. The onboard computers can record real-time 3D terrain data. Furthermore, auxiliary parallel navigation devices can direct the data acquisition vehicle to implement regional coverage measurement, as well as improve the quality and efficiency of data collection. Field measurement tests showed that the 3D terrain automatic data collection system based on ATVs had a good consistency with artificial RTK-GPS measurement, and the maximum average deviation was 3.54 cm, and the largest standard deviation was 2.48 cm (Liu, 2005; Lang et al., 2009; Meng et al., 2009).

South China Agricultural University has developed a laser land leveling system for paddy fields, which has made an important breakthrough and entered the stage of application. The research of the laser control system focused on the level control system of the bucket. Different sensors were used to detect the dip angle of the bucket, among which two ultrasonic sensors were adopted to measure the distance between both ends of the bucket and the surface of reference, and then calculated the dip angle using a triangle relationship. When tested on flat cement ground, the tilt angle measurement error of the level control system was less than 1.0°. Therefore, the paddy field leveling accuracy could be controlled within 3 cm. Figure 8.32 shows the operation of the laser land leveler in a paddy field.

### 8.4.2 Management Platform of Agricultural Information

The management platform of production-related data is the core of the PA management system. It is responsible for the input, processing, spatial, and temporal variation analysis of all farmland data and the formulation of correct farming and implementation plans. At present, the agricultural information management platform for PA is usually created based on GIS software, such as ArcGIS, MapInfo, and SuperMap, or based on components of GIS for secondary development, such as ArcEngine and MapX. Except for general GIS functions, the platform also supports data interface related to PA, professional models, special analysis functions, etc.

The database is the bas of the farmland information management platform, as shown in Figure 8.33. The data come from field measurement, local investigation, historical data, economic data, etc. According to the functions, it includes the following four parts:

1. Farmland geographic information database
   a. Used as a geographical background of varying resolution satellite image data, aviation image data
   b. Using GPS data of the distribution of farmland infrastructure such as canals, wells, and place for crop drying
   c. Using GPS data of farmland terrain, such as land distribution, and land type (cultivated land, garden land, forest land, grassland, etc.)
   d. Distribution of GPS control units

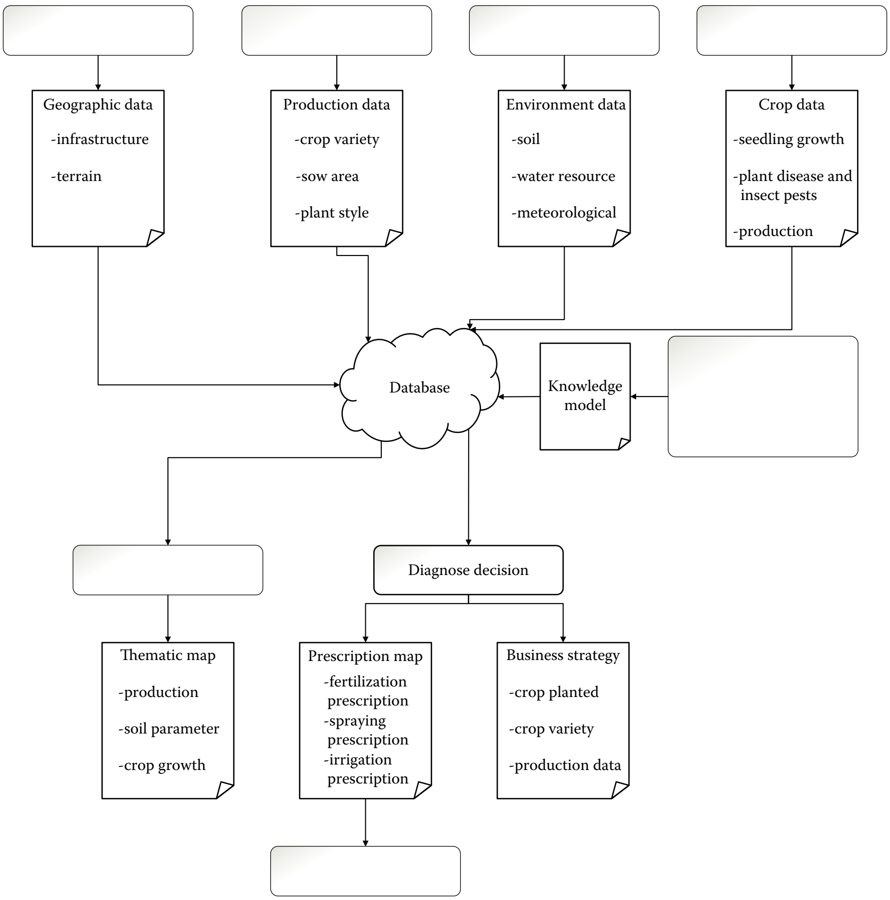


**FIGURE 8.33** Process diagram of precision agriculture.

2. Basic database of production
   a. Crop type, crop varieties, ecological adaptability, agronomic shape, resistance, quality, etc.
   b. Sow area, planting method, production level, etc.
   c. Fertilizer input, condition of irrigation, volume of pesticides, etc.
   d. Food prices and market demand, price of seed, fertilizer, pesticide, etc.

3. Environmental database
   a. Soil parameter data: Soil type, soil profile, soil texture, soil bulk density, soil nutrient content, soil organic matter content, soil total nitrogen content, soil total phosphorus content, soil total potassium content, soil alkali solution nitrogen content, soil available phosphorus and available potassium content, soil trace element (boron, manganese, copper, zinc, etc.), soil moisture, soil permeability, field capacity data, etc.
   b. Meteorological data: Daily sunshine duration, average temperature, air relative humidity, wind speed, precipitation, air pressure, etc.
   c. Water resources data: Water quantity, water quality, etc.

4. Crop information collection
   a. Seedling growth data: High-resolution sensors are used in different crop growing periods to comprehensively monitor seedling growth status. Spectrophotometer or multispectral camera can be used to monitor the chlorophyll density, and analyze the relationship with nutrients.
   b. Disease, insect, weeds distribution data: The type, period, distribution, and scale of farmland crop diseases and insect pests can be recorded through analyzing the remote sensing data or portable GPS field inspections.
   c. Production distribution data: When harvesting, a combine harvester with yield monitor can be used to record crop yield distribution in farmland. At the same time, the accumulated historical data can be used for comprehensive analysis.

To establish all the above databases, data collected through various forms, some historic and some real time, are needed. When establishing the platform, data acquisition begins. After gradually accumulating data, databases such as geographic data, basic production data, and some parameters of soil and water resource data are created. These data acquisition is not restricted by the crop growth season, with lower sampling frequency. However, real-time data need to be collected in the crop growth season, such as crop growth, plant disease, insect pests, distribution of production, soil moisture, soil nitrogen content, and meteorological data. It needs higher spatial and temporal resolution and more rapid detection technology support.

Generating a thematic map is the basic function of a GIS system, which is able to show the spatial distribution of attribute data. Therefore, after real-time data such as soil parameters and crop information are collected, the farmland information management platform can analyze the data for the thematic map and understand the status of crop growth and development.

### 8.4.3 Diagnosis Decision-Making Expert System

Compared with traditional farming, precision farming can help to make better resource management decisions by utilizing various types of information. In order to make a full and accurate diagnosis-based decision in precision crop management, an expert system (ES) in the farmland information management platform is needed for intelligent diagnosis and decision making. ES can integrate the expert's knowledge and the crop growth model into the process of making a production decision scheme. It can make decisions according to the specific circumstances of each sampling point. The decision scheme of the whole area could be calculated through computer interpolation. In this process, the knowledge of an expert can make the decisions more reasonable. Figures 8.34 and 8.35 illustrate the PA practices in wheat and corn production management with a decision-making ES.

A wheat production management ES provides a scientific basis for production targets (Bao and He, 2001; Chen et al., 2008). It can implement the production plan according to special software, and improve the foresight of scientific management. It can also forecast the wheat growth in good time, and adjust and control the population structure with the prediction, ideal plant type, and factors of wheat yield. Therefore, it can increase effective growth and accumulation. The ES can recommend the varieties that are suitable for the region. The following can also be determined by the ES:

1. Quantity of fertilizer, ratio of fertilizer elements, and fertilizing method according to soil fertility and yield target
2. Reasonable planting density according to sowing time and fertility level
3. Irrigation time and water volume according to the soil moisture content, weather, rainfall, and crop growing status
4. Integrated system cultivation and management techniques according to the wheat growing process, population structure, and plant morphology
5. Optimization of the management decision and practical scheme according to the local condition and crop growth information

A corn production management ES can set the proper field target based on local production conditions and the level of productivity. It can predict the growth of corn, adjust and control the group structure, and decide the ideal plant type and factors of the field. It can make decisions for different corn fields according to the requirements of different growth periods. The decisions include farm management technology such as planting farming technology, seed treatment, corn cropping systems before farming, crop varieties making full use of the resources of light and heat, reasonable density, seeding time, planting form, seeding method, seeding rate, seeding inspection, reseeding, replant, timely thinning, fix seeding, hoe weeding, and the use of growth regulators. According to the production targets, reasonable fertilization techniques, water saving irrigation technology, and disease pest prevention and control technology are adopted. The reasonable harvest time and irrigation postharvest can be determined according to the corn growth indexes.

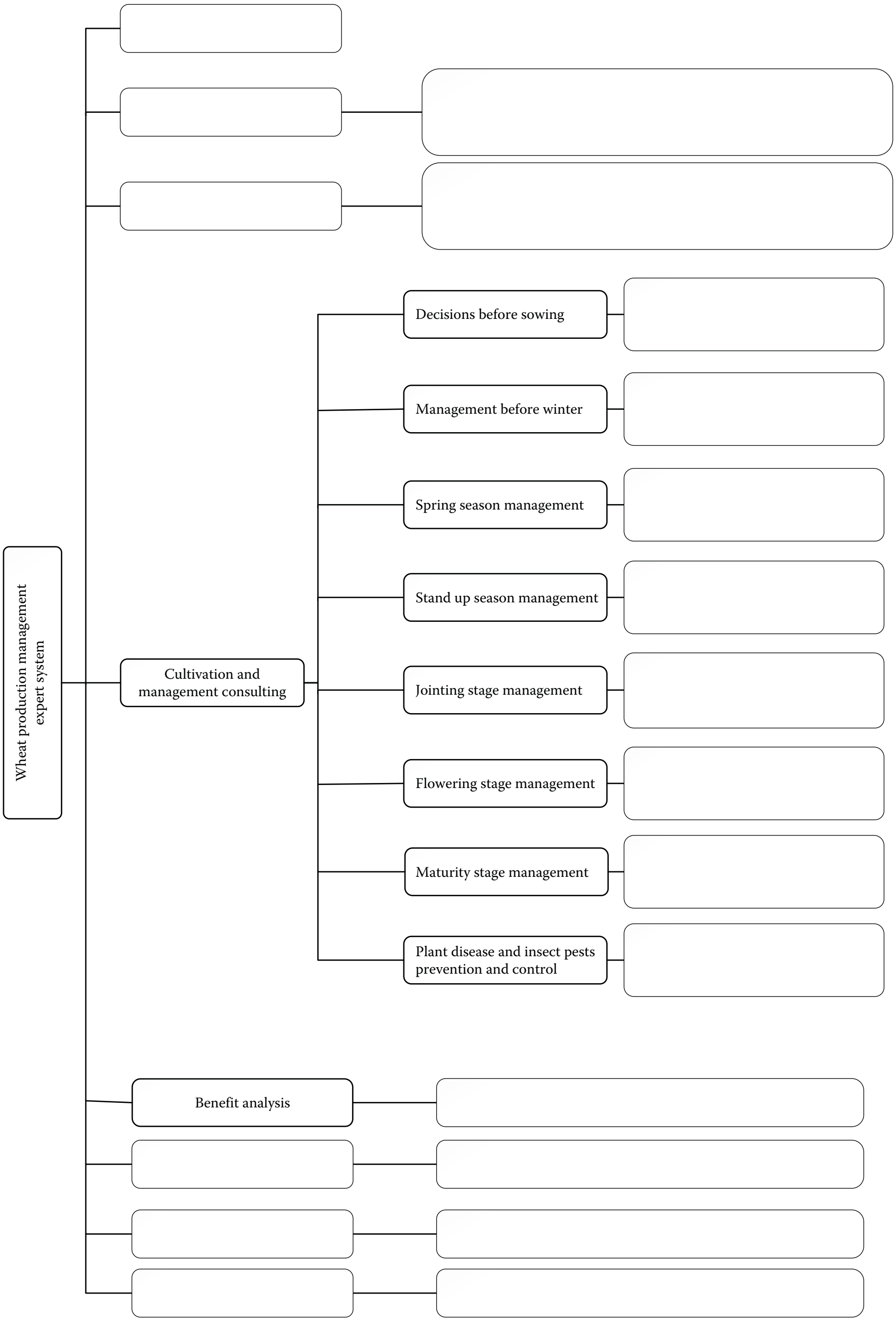


**FIGURE 8.34** Wheat production management expert system.

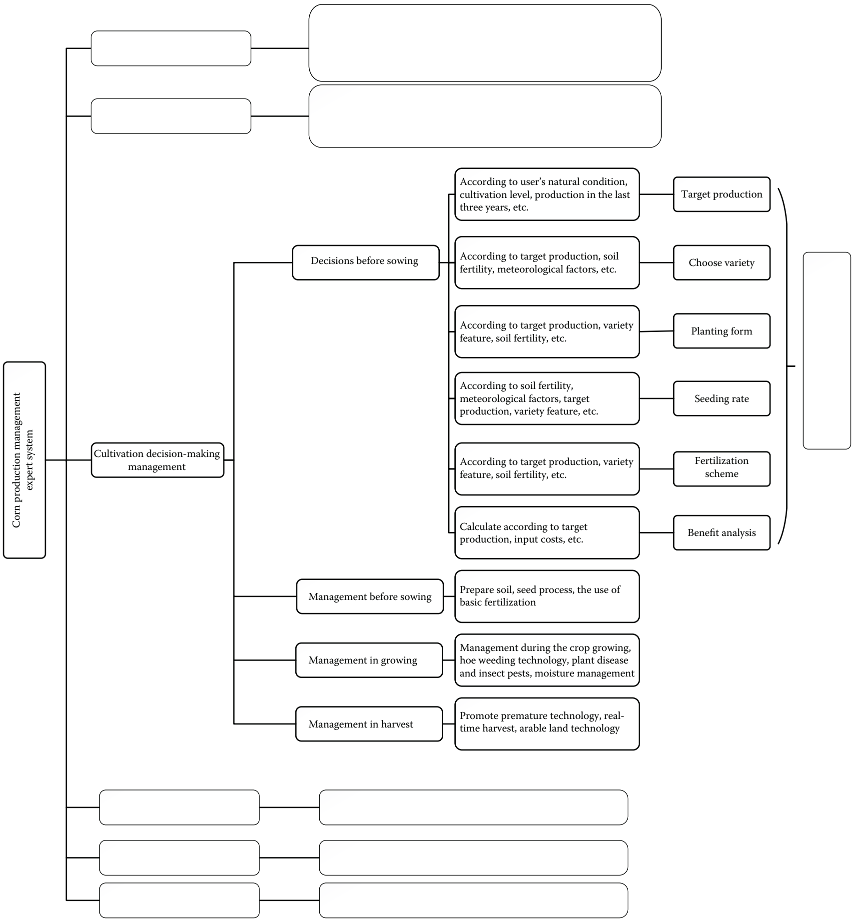


**FIGURE 8.35** Corn production management expert system.

### 8.4.4 National Demonstration Base for Precision Agriculture in Beijing

As agricultural industrialization and modernization are fast developing, China has established several development and demonstration bases for PA to promote PA applications and make it become the incubator of new agricultural technologies as well as the new agricultural industry. These have propeled the introduction and absorption, research and development, and demonstration and application of PA technologies (Wang, 2011).

Since 2000, the National Development and Reform Commission of China and the Beijing Municipal Government invested together to establish the first National Demonstration Base for Precision Agriculture. Several large-scale demonstration bases of PA were constructed with a high level of mechanization and production in the northeast of China, Inner Mongolia, Xinjiang, etc. Here, we take two examples, one in Beijing and one in Heilongjiang, to introduce the application of practices related to PA as well as to provide a research overview.


**FIGURE 8.36** National Demonstration Base for Precision Agriculture (Beijing).

The National Demonstration Base for Precision Agriculture is located in Xiao Tangshan Modern Agriculture Technology Demonstration Park in Beijing (Figure 8.36). It has introduced and applied a large number of advanced domestic and foreign PA machines, devices, and instruments, which included the combine harvester with automatic yield monitor, the large-scale lateral move sprinkling machine, the DGPS positioning and navigation system, the VRT control system, etc. The base has the functions of scientific experiments, data analysis, system integration, and exhibition of achievements. Currently, the base has achieved fruitful results in terms of PA resource management GIS, field information collection systems, airborne remote sensing platform applications, intelligent production and measurement systems, and VRT machinery applications.

### 8.4.4.1 Precision Agriculture Resource Management GIS

In PA practice, the establishment of the agricultural resources management platform based on GIS is one of the crucial steps. Through efficient management of field information and timely spatiotemporal difference analysis of all kinds of farmland data, it can provide accurate information for the generation of prescription map and production management decisions. The various farmland databases in the demonstration base have been developed as shown in Figure 8.37.

Except the basic GIS functions, the system designed and developed the display functions including layer operations, and remote sensing images superposition according to the specific practice of PA. Especially for non-GIS professional users, the functions of map labeling, land measurement, hot links, data query, data analysis, and management were developed to realize the visual marking of the software interface, the record of field special features in the form of images, the accurate measurement of fields, assisting complete data conversion, analysis, and management. For example, a set of yield data from the combine harvester and the soil data

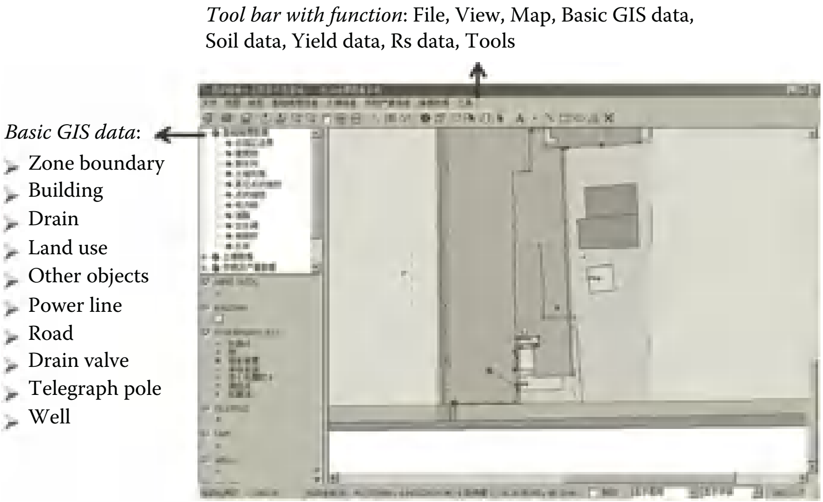


**FIGURE 8.37** Precision agriculture resource management GIS.

of a field can be imported and then used to generate a map. Through the functions of the software, the yield data were analyzed and processed to meet the needs of the following analysis. According to the soil nutrient data collected, the software can achieve the calculation of fertilization scale effect to determine the best fertilization scale unit that should be used in production management.

#### 8.4.4.2 Field Information Collection System

Field information collection system based on a PC or PDA can collect farmland data through the coordination between GPS positioning equipment and different sensors, as shown in Figure 8.38. The system has the functions of communication and data processing of GPS systems from different manufacturers, the basic GIS functions, collecting and recording spatial distribution and attribute information of farmland objects, soil grid sampling, and navigation. It can also acquire the position of farmland and various factors that affected crop growth environment, such as soil nutrients, crop diseases and insect pests, and water content of weeds. It provides the basis for PA management decisions.

#### 8.4.4.3 Airborne Remote Sensing Platform Applications

China has made great progress on aviation remote sensing and analysis system of crop information based on airborne hyperspectral imaging device PHI and operative modular imaging spectrometer (OMIS). It included a remote sensing platform and related application methods and laid the foundation of airborne remote sensing applications in PA. The system has been successfully applied in research fields such as assessment of winter wheat growing, wheat yield analysis, and crop growth analysis.

In terms of winter wheat growing assessment, several statistical models of remote sensing were established by using red edge position and Red Valley location. Through analysis of false color composites, crop growth and nutrient distribution

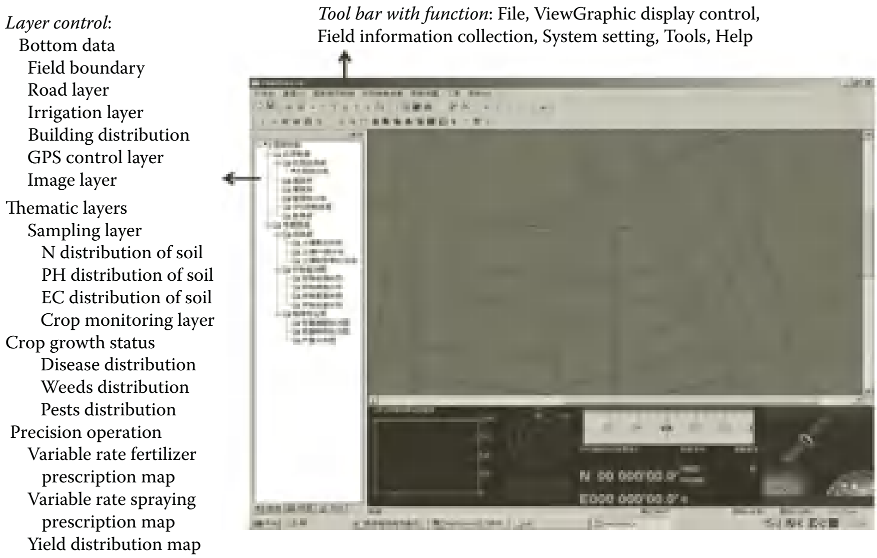


**FIGURE 8.38** Field information collection system for precision agriculture.

maps on chlorophyll, total nitrogen, soluble sugar, leaf water, and other biochemical parameters were obtained as shown in Figure 8.39.

#### 8.4.4.4 Intelligent Production and Measurement Systems

The National Demonstration Base for Precision Agriculture introduced a 2366 Combine Harvester with an AFS (advanced farming systems) yield monitoring system. It was used to harvest wheat and corn in summer and autumn, respectively.

After harvesting, yield maps were obtained according to test data, and the causes of yield variations were analyzed to provide a reference for future decisions. Different types of yield maps are shown in Figure 8.40. The yield was divided into six grades. It can be observed that the boundary section of the plots have lower yields, mainly due to the serious soil compaction near the block boundary. In addition, in some plots with lower yields, a lot of weeds were found. The analysis results of wheat and corn production show that errors were introduced in the data and could mainly be attributed in cutting amplitude and width setting error, filling time error, and delay time error. Thus, the processing of error correction was necessary.

The National Demonstration Base for Precision Agriculture introduced a U.S. Mid-Tech variable fertilization control system. The system mainly consisted of a console, a hydraulic control mechanism, and a fertilizing executing mechanism, and Figure 8.41 shows the structure diagram of the variable fertilizer spreader. To cope with variable fertilizing operations, the system also needs a field computer, a GPS, assisted navigation, radar guns, and other equipment.

In VRT fertilization, it is first necessary to import a fertilizing prescription map to the field computer. The computer also received real-time GPS data as well as radar speed data and real-time fertilizer amount in the prescription map. The fertilizing control instructions in the current fertilizing location were transmitted to the

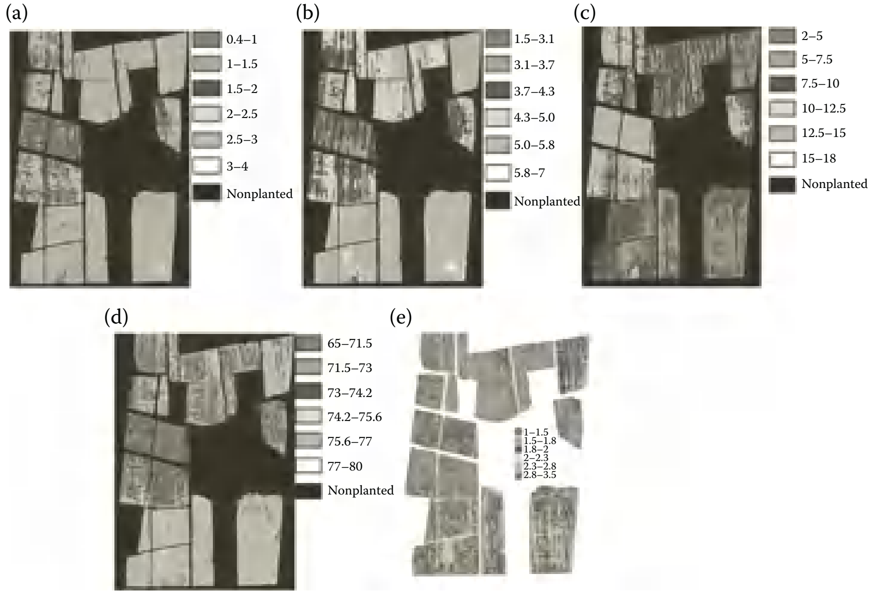


**FIGURE 8.39** (**See color insert.**) Maps of chlorophyll, total nitrogen, soluble sugar, and water of leaf biochemical parameter. (a) Chlorophyll content (mg/g), (b) nitrogen content (%), (c) soluble sugar content (%), (d) water content (%), and (e) LAI.

central controller of fertilizing control system, and the central controller converted the digital signal into an analog signal, and then the valve opening was adjusted by an electrohydraulic proportional control mechanism. At the same time, the actual fertilizer amount was fed back to the field computer by the control systems, which would later be used for data processing and analysis.

The data were monitored and stored using a Trimble Ag170 field computer. The fertilizing operation was controlled and navigated by using a Trimble Ag132 DGPS receiver and a navigation light bar. The data with submeter positioning accuracy can meet the needs of the VRT fertilizing operations. The system showed good static and dynamic performances with better work precision. Comparing the prescription map with the practical distribution map of the fertilizer amount, it was indicated that the system could conduct the VRT fertilizing operation in accordance with the fertilizing prescription map.

### 8.4.5 Practice of Precision Agriculture in Heilongjiang Province

Heilongjiang Province, as the major grain base of China, has already established several demonstration farms of PA across the province. Heilongjiang Agricultural Reclamation Bureau (HARB) is an administrative institution of state farms located in Heilongjiang Province. HARB started the practice of PA in 2002 and introduced a great number of advanced PA machines from John Deere and Case IH, and DGPS systems from Trimble. As an example, the Precision Agriculture Center of Hongxing

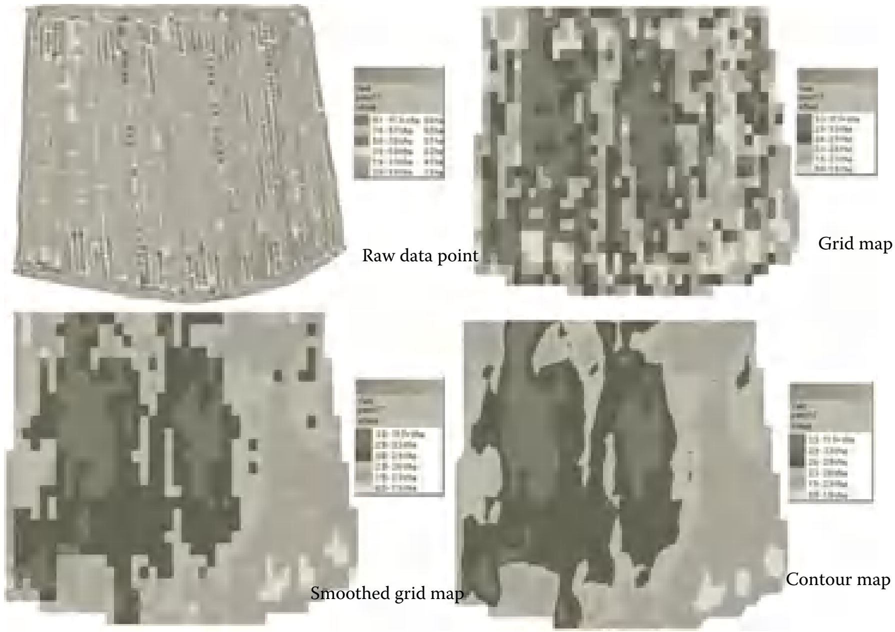


**FIGURE 8.40** (**See color insert.**) Four different yield maps of winter wheat from the same field.

Farm, one of the 113 state farms in HARB, has integrated and utilized PA technologies such as farmland information computers, wireless sensor networks, navigation and management of agricultural machines, VRT agricultural machinery, and other PA equipment. The intellectualization, informatization, and mechanization of agricultural production were all improved. The practice of PA also brought economic benefit for farmers, and played a demonstrable and leading role in agricultural production.

#### 8.4.5.1 Remote Sensing Image and Data System (RS)

Hongxing Farm has uploaded remote sensing images of 2.5 m resolution to the digital information network from September 2007. At this resolution, farmers can find buildings, roads, reservoirs, and other infrastructure on the farm and measure the distance between any two points and the area of any region on the map. Since October 2008, Hongxing Farm has updated the remote sensing images to a 1.0 m resolution. Farmers can clearly find trees and buildings on both sides of the road on the farm from updated remote sensing images.

#### 8.4.5.2 Geographic Information System

Hongxing Farm has built a GIS for its field based on RS data. Different management zones were divided into different colors based on individual farmers. The farmers can use the system to measure the distance between any two points and the area of any region. Clicking the query button, users can visually see brief information of each zone (zone name, area) and the details of the land, such as soil pH, soil

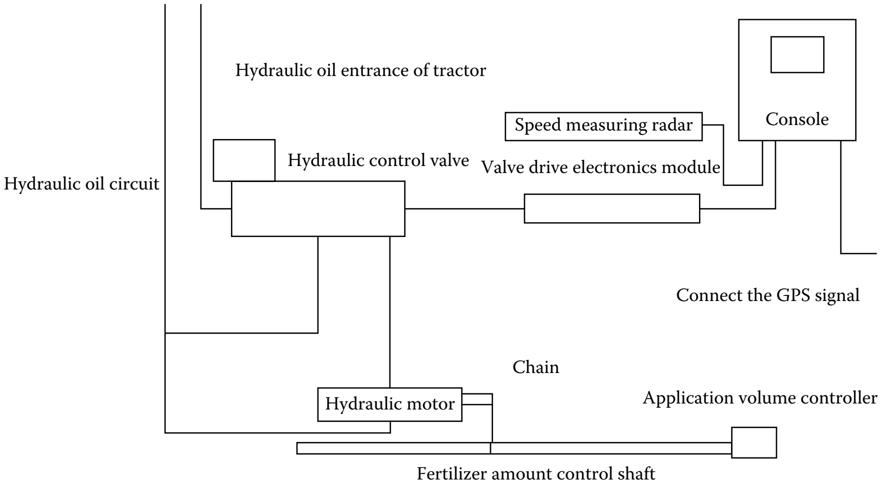


**FIGURE 8.41** Structure diagram of variable fertilizer spreader.

nutrients, soil organic matter content, crops, land management, the pest control situation, and the harvesting situation. Depending on the records of the previous years of each zone, it is convenient and rational to design or plan rotation and fertilization for the next year. This GIS system established the foundation of precision crop management in Hongxing Farm.

#### 8.4.5.3 Dynamic Tracking System of Agricultural Machines

The dynamic tracking system of agricultural machines of Hongxing Farm was also built on the basis of remote sensing and GIS. With this system, farmers can see the operation situation of agricultural machines within a farm or across farms. Some machines were equipped with GPS navigation devices. Those machines can upload parameters such as location and speed to the website of the dynamic tracking system of agricultural machines by mobile signals. The staff in the control center can log on to the system at any time to query the parameters of the agricultural machines such as latitude and longitude, operating time, speed, direction, status of network, and other data. Within the effective range, the controller can talk with the driver through the intercom, and observe the workspace, profit and loss of the machine and other information. In addition, the dynamic tracking system can also store the records of a year and provide services for historical data queries and program management in the future. Based on the technologies mentioned above, the Hongxing Farm PA systems integration platform was developed, including public map service subsystem, digital farm management subsystem, and intelligent decision subsystem. The public map service subsystem provides basic map information, basic map tools (such as zoom, display, and measurement), query tools, and other general-purpose modules. The digital farm management subsystem provides management tools for managers, including production information management, soil information management, and crop pest information management. The production information management subsystem includes zone

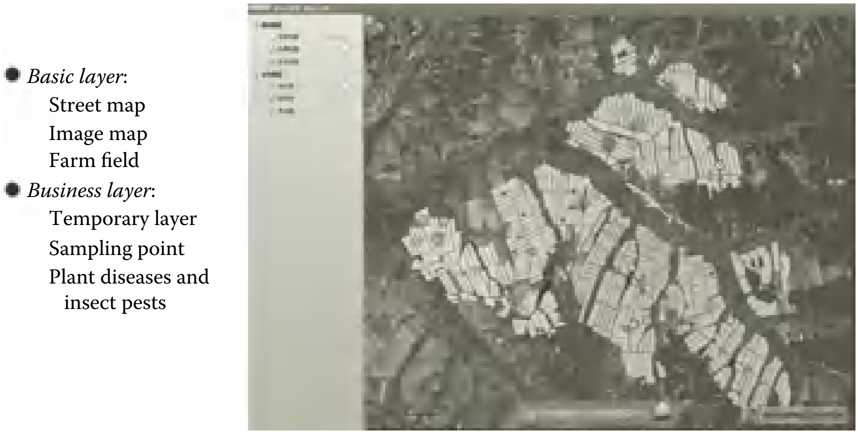


**FIGURE 8.42** Main interface of the dynamic tracking system for agricultural machines.

archives, information maintenance, and production plan information maintenance. The information management subsystem includes soil samples maintenance, administrative region maintenance, and index maintenance. Crop pest management includes pest, diseases, and pathogens control. The Hongxing Farm intelligent decision subsystem provides analytical tools for the decision maker, including production archives statistical analysis, soil sensing and fertilization, and pest diagnostics. The main interface of the software is shown as Figure 8.42, which was divided into three modules: public map module, digital management module, and intelligent decision-making module.

The Map Search toolset was used for querying production archives of farm plots, attributes, and sampling point attributes. The query tool for production archives was used to query the production archives information of farm plots over the past several years. Clicking the farm plots button, production archives information can be sorted and shown by year, as shown in Figure 8.43. Clicking the more information button, the production archives information of the selected year can be displayed in detail, as shown in Figure 8.44.

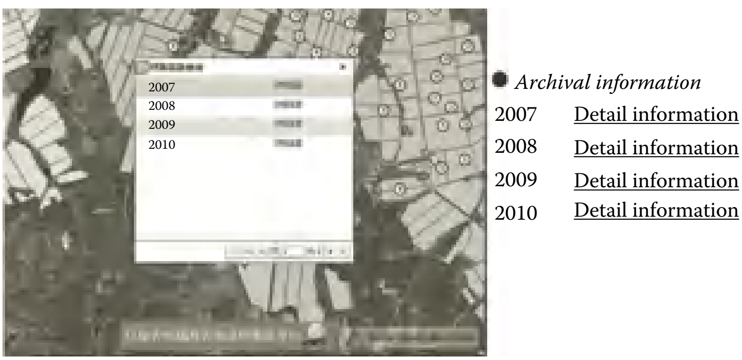


**FIGURE 8.43** Production archive query.

Archival information
*Field information*: Field number, area, year, crop, variety et al.
Soil preparation
Ridging
Sowing
Fertilization
Tillage management
Extermination of disease and insect pests
Weed control
Natural calamities
Harvesting

**FIGURE 8.44** Production archive details.

The attribute query tools for plot and sampling point were used to query the attribute information of a plot or a sampling point, respectively, including basic information, natural conditions, production conditions, crop information, soil information, and nutrient information.

#### 8.4.5.4 Straight Navigation of Agricultural Machines and Remote Scheduling of Field Operations

By using a good GPS base station infrastructure construction, a straight navigation system of agricultural machines and a remote scheduling system of agricultural operations were developed to improve work quality and operationing efficiency.

The straight navigation system of agricultural machines was developed for PA. It consisted of navigation software and a light target. Navigation software can receive positioning signals from the GPS receiver. After setting the navigation path, it can conduct straight and automatic navigation. By using a DGPS device, it can navigate the farm machine precisely straight without repeat or miss, and calculate the operation area. The system was installed on CASE 450 tractor (450 hp) and John Deere 9520 tractor (450 hp). Since tractors have electrohydraulic control, they are easy to operate and drive, and are comfortable and stable. These type of tractors can pull a large wide variable-rate fertilization seeder and improve the reliability of the unit work. It can also work at night, which extends the operating time and improves the operating efficiency.

A rRemote scheduling system for agricultural operations was installed for Hongxing Farm. When it was started, the GPS receiver on the mobile terminal provided the longitude, latitude, altitude, time, speed, heading, and other data in 1 s interval. The status of the agricultural machine was then sent to a remote monitoring server via the GPRS, so that farmers could monitor all agricultural operations in real time on a web browser. It realized network GPS vehicle monitoring based on B/S structure, and furthermore incorporated user rights management to make it possible for multiuser online monitoring. The system supported massive spatial data and had a variety of statistical functions for users to compare with historical data. It also had an alarm function to make it intelligent for vehicle monitoring.

## 8.5 SUMMARY AND DISCUSSION

China is at a critical stage for the practice of agricultural ICT. Thus, it is necessary to attach importance to international scientific progress and experience in the research of PA, digest and absorb advanced and relatively mature foreign technology, and focus attention on the research of application and innovation technologies suitable for the situation in China. With the development of scientific technology, a large number of emerging information collection and processing measures, such as the IoT and cloud computing, have provided a new platform for the development of PA. PA can guarantee the sustainable development of agriculture in technology and with the efforts of agricultural scientists and the attention and support of the Chinese government, the practice of PA in China will make great progress.

## ACKNOWLEDGMENTS

We would like to express our deepest appreciation to colleagues and the faculty members of the Research Center for Precision Agriculture at China Agricultural University, particularly, Professor Wang Maohua, Professor Liu Gang, Dr. Zhang Man, Dr. Zheng Lihua, Dr. Zhang Miao, Dr. Li Li, and Dr. Yang Wei for their support and contribution to Chapter 8. We would also like to thank our students, Zhang Yao, Pei Xiaoshuai, Zhang Meng, Mi Xiuchen, Wu Lixuan, Song Yuanyuan, Zhao Yi, and Wen Yao for collating the text and drawing figures.

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# 9 Good Agricultural Practices, Quality, Traceability, and Precision Agriculture

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**CONTENTS**



## 9.1 INTRODUCTION

Agricultural production is part of a long chain of activities that starts from seeding (or even earlier) and stretches all the way to the consumer. It should meet consumer expectations in terms of quality, safety, and also value or price. Many intermediate steps are involved and these often involve handling, storage, and transportation across national borders or continents. Information should be transferred across this chain. The automation that will be a major part of future agricultural and biological production systems also faces some challenges posed by system characteristics that will have to be dealt with. When we look at the processes in agricultural production systems, we can say that they are complex in nature. Indeed, as we gain a better understanding of biological processes, we also find that they have a great complexity and that in many cases this complexity remains difficult to formulate in exact terms. Complexity means that the system comprises numerous parts or processes that interact and yield outcomes that are not easily predicted. These processes and interactions occur in and across different spatial and temporal scales.

Crop growth is the result of photosynthetic activity and transport processes in the cells, in the leaves, and in the different organs of single plants. There is a close interaction with the physical environment around these single plants, such as solar radiation, temperature, humidity, soil texture, and its nutrient or water content. Of course, there is also the influence of neighboring plants within a field. There is also an interaction with many associated biota such as insects, pests, and microorganisms on the plant or near the plants and fields as well as soil microorganisms and invertebrates. All these biotic and abiotic effects can be variable in a field and also vary with time. At the farm level, there are complex interactions within the enterprise where many different activities occur, and with communities and economic operators. All these interactions affect the decision making at this level.

Society has high expectations from food production. However, at the same time, food production is increasingly subject to international agreements on trade. This makes competition between producers or regions of production an important factor in decision making. Nevertheless, this competition should not impair food safety to consumers or long-term food security for society. Transparency of the entire food chain for ensuring safety is a must. There are also needs for technology development because of the need to reduce land degradation or to optimize water use. For example, as a result of the (bio)technological revolution, genetically modified crops or crops for green chemicals need different planting, tending, harvesting, and handling equipment. There is also a growing concern for maintaining biodiversity to preserve the abundant genetic resources as well as to have a basis for more efficient crop production or pest management. A broad range of definitions dealing with transparency exist in the literature. However, that transparency is only reached if everybody with stakes and interests in food production and consumption understands the relevant aspects of products, processes and process environments, and other factors that allow them to make informed decisions (Schiefer and Deiters, 2013).

Since agricultural products are stored and shipped over long distances and time periods, there can be a considerable change in quality. So, one would like to know how quality will evolve after harvest. This may affect the timing of the harvest, the required storage conditions for maintaining a certain level of quality, or the available time between harvest and consumption.

## 9.2 FOOD SAFETY AND GOOD AGRICULTURAL PRACTICES SCHEMES

Consumers show increasing concerns about food safety and about the properties of the food they eat. Indeed, food scandals and incidents in the food supply chain have raised public concern over agricultural practices and the handling and processing of food. Reports of food poisoning incidents and deaths due to contamination of fresh, minimally processed, and processed fruit and vegetables and the occurrence of other emerging food pathogens have reduced consumer confidence in the safety of food systems (Opara and Mazaud, 2001). As a result, there have been major developments in the world related to food safety and traceability. Some of the initiatives have come from governments to protect the health of their citizens, while others are private initiatives by growers and retailers in order to meet the expectations of their customers with respect to food safety and environmental sustainability. Everyone in the food chain assumes that these expectations can be satisfied if production is done in line with good agricultural practices (GAP). To ensure this, the qualified authorities or food safety departments at manufacturers or retailers demand that the origin and destination of animal feed, materials, and food in all stages of production and distribution are known and available as information.

All stakeholders in the food production chain now consider food safety to be an important issue and producers of food are increasingly subjected to greater scrutiny of their production practices. It is also then recognized that there is an increasing need for greater quality assurance, transparency, and traceability in the food supply chain (Opara and Mazaud, 2001). It has also been shown that traceability, in the absence of quality verification, is of limited value to individual consumers. Bundling traceability with quality assurances has the potential to deliver more value (Hobbs et al., 2005).

High-quality food, integrity, and associated services and information should be guaranteed. Consumers call for food that can be fully trusted. They ask for safety guarantees and information with integrity to confirm their trust. In this context, integrity of information is defined as follows: "the information provided is in conformance with the reality it depicts." Information that is accurate, relevant, precise, timely, and complete for a particular purpose can be termed to be "fit for purpose" (Trites, 2013). It also implies that tampering of the data is not possible. The call for integrity of information is voiced in particular by retailers who state transparency requirements to be met by their suppliers. Part of that transparency is concerned with realizing tracking and tracing systems as primary objectives to enable efficient recalls on the chain level when necessary, on proactive monitoring quality along chain processes, with an objective early warning in case of a possible emerging problem, and/or aiming at optimizing the remainder of processes along the supply chain downstream (Beulens et al., 2005). In recent years, there have been major developments related to food safety regulations and international trade. Van Plaggenhoef et al. (2003) reviewed the legislation and standards and classified the regulations as follows.

### 9.2.1 International Institutions That Deal with Food Safety

These institutions are (Van Plaggenhoef et al., 2003)

- Codex Alimentarius. The Codex Alimentarius Commission (CAC) was created in 1963 by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) to develop food standards, guidelines, and related texts such as codes of practice under the Joint FAO/WHO Food Standards Programme.

- Sanitary and Phytosanitary (SPS) Agreement of the World Trade Organization (WTO). The SPS agreement relates to protection of human, animal, and plant health and life. The basic aim of the SPS agreement is to maintain the sovereign right of any government to provide the level of health protection it deems appropriate, but to ensure that these sovereign rights are not misused for protectionist purposes and do not result in unnecessary barriers to international trade.
- Legislation from the European Community. The European Food Law (European Commission, 2012; Regulation EC No 178/2002) establishes the general principles upon which international trade in food shall be based. Food producers have the primary responsibility for the safety of food and the member states have to develop codes of good practice at the national level.

### 9.2.2 Internationally Acknowledged Food Safety Systems

A number of food safety systems with a worldwide application range are listed by SAI Global (http://www.saiglobal.com/assurance/food-safety/), a company specialized in certification of quality management systems:

- **FSSC/FS 22000** (Food Safety System Certification standard) is a certification scheme for food manufacturers.
- **ISO 22000** takes a whole chain approach to food safety, providing a standard that goes all the way from the farm to the fork, including packaging and ingredient suppliers, caterers, storage and distribution facilities, and chemical and machinery manufacturers, and can be applied to primary producers such as farms.
- **BRC** is one of the choices for retailers worldwide looking for confidence from food suppliers.
- **SQF** is one of the world's leading food safety and quality management systems to assure that a supplier's food safety and quality management system complies with international and domestic food safety regulations.
- **HACCP** (hazard analysis and critical control points) is a risk management system that identifies, evaluates, and controls hazards related to food safety throughout the food supply chain.
- **IFS** (International Food Standard) is a quality and food safety standard for retailer (and wholesaler) branded food products, which is intended to assess suppliers' food safety and quality systems, with a uniform approach that harmonizes the elements of each.
- **GFSI**: Under the umbrella of the Global Food Safety Initiative (GFSI), seven major retailers have come to a common acceptance of GFSI-benchmarked food safety schemes.
- **GlobalGAP** (GlobalGAP, 2012) was introduced by FoodPLUS GmbH, but is now managed in the form of a retailer–producer alliance to raise standards in primary agricultural production. Certification to the standard ensures a level playing field in terms of food safety and quality, and proves that growers are prepared to constantly improve systems to raise standards.

The GAP standards can be considered as the basis for food safety. They are in general based on the following concepts:

- Food safety: The standard is based on food safety criteria, derived from the application of generic HACCP principles.
- Reducing the inappropriate use of chemicals in general, and especially the use of chemical plant protection products (PPPs), or reducing the level of residues found on food crops.
- Environmental protection: The standard consists of environmental protection GAP, which are designed to minimize negative impacts of agricultural production on the environment.
- Occupational health, safety, and welfare: The standard establishes a global level of occupational health and safety criteria on farms, as well as awareness and responsibility regarding socially related issues.
- Animal welfare (where applicable): The standard establishes a global level of animal welfare criteria on farms.

As an example, the GlobalGAP (GlobalGAP, 2012) scheme covers the whole agricultural production process of the certified product, from before the plant is in the ground (seed and nursery control points) to nonprocessed end products (produce handling control points). In response to the challenges posed by fast-changing crop protection product legislation, the GlobalGAP organization developed guidance notes to help farmers and growers to become fully aware of the maximum residue levels (MRLs) in operation in the markets where the product will be sold. A general regulations document explains the structure of certification to the GlobalGAP standard and the procedures that should be followed in order to obtain and maintain certification. The requirements for GAP certification are bundled in a document with control points and compliance criteria (Figure 9.1). Several other GAP schemes also have similar requirements although the emphasis may be different depending on the country where it was initiated or applied.

## 9.3 PRECISION AGRICULTURE, GAP, AND "LICENSE TO OPERATE"

Precision agriculture (PA) technologies share the underlying ideas of GAP and may become important tools for complying with regulations and for documentation of the production conditions as a proof of compliance.

PA can be seen as a summary of GAP that rely on (De Baerdemaeker, 2013)

- Correct information (soil, previous crops and treatment, etc.)
- Correct observation
- Correct analysis
- Correct genotype
- Correct dose
- Correct chemical/biological compound
- Correct place
- Correct time
- Correct (climatic) conditions
- Correct equipment

| Nº | Control Point | Compliance Criteria |
|---|---|---|
| CB 8.3.6 | Justification for application? | The name of the pest(s), disease(s) and/or weed(s) treated is documented in all plant protection product application records. If common names are used then they must correspond to the names stated on the label. No N/A. |
| CB 8.3.7 | Technical authorization for application? | The technically responsible person making the decision of the use and the doses of the plant protection product(s) being applied has been identified in the records. No N/A. |
| CB 8.3.8 | Product quantity applied? | All plant protection product application records specify the amount of product to be applied in weight or volume or the total quantity of water (or other carrier medium) and dosage in g/l or internationally recognized measures for the plant protection product. No N/A. |
| CB 8.3.9 | Application machinery used? | The application machinery type (e.g. knapsack, high volume, U.L.V., via the irrigation system, dusting, fogger, aerial, or another method), for all the plant protection products applied (if there are various units, these are identified individually), are detailed in all plant protection product application records. No N/A. |
| CB 8.3.10 | Pre-harvest interval? | The pre-harvest interval has been recorded for all plant protection product applications where a pre-harvest interval is stated on the product label or if not on label, as stated by official source. |

**FIGURE 9.1** Example of control points in the fruit and vegetables checklist of GlobalGAP. (Adapted from http://www.globalgap.org/uk_en/for-producers/crops/FV/.)

It is clear that when such principles are adhered to, the requirements of GlobalGAP can be met. For example, a GAP scheme requires that fertilizer application doses are based on soil analysis and should be applied at a rate that can be taken up by the crop. The application equipment should be in good condition such that the operator can be sure about the dose. Pesticides should only be applied in the framework of a pest management scheme, for example, integrated pest management (IPM), that is based on the observation or risk of a pest or disease, while beneficial organisms must be preserved as much as possible. Application should not be done within the required preharvest time interval as stated by the government conditions for use. Of course, only approved pesticides or herbicides can be used. While applying the chemical protection, sufficient distance from water sources must be maintained to avoid contamination of the surface waters. To ensure that all these principles have been respected, a record has to be kept of all the steps and treatments carried out during production.

A report on the environmental impacts of products (EIPRO) (Tukker et al., 2006) has identified those products with the greatest environmental impact. The results are based on a life cycle analysis of the products consumed in the European Union. They found that three areas of consumption have the greatest environmental impact in Europe: housing, food and drink, and private transport. There is no clear ranking, as products in the three areas identified are of approximately equal importance. Together, they are responsible for 70%–80% of the environmental impact of consumption, and account for some 60% of consumption expenditure. Life cycle analyses help to understand the environmental impacts of individual products on carbon, water, eutrophication, etc. across all the stages of the value chain: from the production of agricultural inputs, farming, processing, transport, and storage on the production side, to shopping, cleaning, cooking, home storage, and recycling behavior on the consumer side (European Food SCP Round Table Working Group 2 on “Environmental Information Tools,” European Food SCP Round Table Report, 2011; European Food Sustainable Consumption and Production (SCP) Round Table). The principles of PA can become a major tool for communicating along the food chain, including to consumers, farming activities that have an environmental impact. The technology makes it possible to do so in a scientifically reliable and consistent way, understandable and not misleading.

Changes in society and consumer attitudes are such that agricultural practices will be increasingly questioned in the future. This will go further than “say what you do” and “do what you say,” but will also imply that communities will give a “license to operate” only when stringent production requirements are met and documented. It is not only that global consumers require GAP when buying products, but that local consumer action groups will only allow production when certain conditions are met and documented.

## 9.4 MEETING THE TRACEABILITY REQUIREMENT

Precision farming and the use of global positioning systems (GPS) on agricultural machinery provide location and time information for all treatments. This is of course very important for automation such as navigation during the different treatments or the collection of data on crop status, diseases, and yields.

### 9.4.1 Site History and Site Management

Planting a suitable crop (and variety) at the correct place implies that the farm manager or the decision support tool is aware of the soil condition and of what crops were grown in the previous seasons and what treatments were given. In a number of cases, residues from fertilizers, herbicides, or pesticides from treatments in a previous season may still be high because of environmental conditions that were less favorable for their degradation or breakdown. It is then important that the farmer or decision support algorithm can retrieve the data (dose, time, and location) about these earlier treatments to make informed decisions. The risk of chemical leaching in the soil may vary by location and soil type and can be taken into consideration for crop production decisions. In other cases, a sequence of crop rotations should be respected to avoid the effect or the spreading of soil-borne diseases. This means that there is also a need for a traceability system that is linked to a field and not just to a crop that is grown and commercialized.

### 9.4.2 Fertilizer Application

GAP implies that the correct dose of fertilizer is applied at the correct moment and in the correct way. Automation and control in fertilizer application can be of great value toward satisfying this GAP requirement. Accurate measurements of soil macronutrients (i.e., nitrogen, phosphorus, and potassium) are needed for efficient agricultural production, including site-specific crop management (SSCM), where fertilizer nutrient application rates are adjusted spatially based on local requirements (Kim et al., 2009). Optical diffuse reflectance sensing has been reported to show potential for rapid, nondestructive quantification of soil properties, including nutrient levels (Roy et al., 2005; Maleki et al., 2008; Chacon et al., 2014). Kim et al. (2009) also discuss electrochemical sensing based on ion-selective electrodes or ion-selective field effect transistors that have been recognized as useful in real-time analysis because of their simplicity, portability, rapid response, and ability to directly measure the analyte with a wide range of sensitivity. They also give examples of optical and electrochemical sensors applied in soil analyses, while advantages and obstacles for their adoption are discussed.

### 9.4.3 Crop Protection and Integrated Pest Management

#### 9.4.3.1 Weed Control

Core technologies (guidance, detection and identification, precision in-row weed control, and mapping) are required to meet the GAP criteria for weed control (Christensen et al., 2009). Detection and identification of weeds under the wide range of conditions common to agricultural fields remains the greatest challenge. Various methods have been developed for weed detection (Vrindts et al., 2002; Slaughter et al., 2008). They are all in some stage between research and commercial application. Most are based on spectral characteristics and/or image-based shape recognition to discriminate between weeds and the crop. In case population dynamics models are sufficiently developed, they can help to decide not to treat if the weeds pose no direct threat to crop production or quality. An overview of the modeling approaches to field weed dynamics is given by Holst et al. (2007). These models may become more accurate after each observation in time. The subsequent treatment can be a mechanical or thermal action or herbicide application. Precise herbicide treatment using microdosing nozzles on the most sensitive parts of the plant further reduces the chemical use (Young and Giles, 2013). When the detection and application systems are equipped with a GPS receiver, place and time of weed populations and the applied treatments could be automatically registered in the GAP database as well as in the field database (in a field passport).

#### 9.4.3.2 Pest and Disease Management

GAP reduce the incidence and intensity of pests and diseases, and also the use of chemical control methods. This also implies that observation and monitoring practices are established and that nonchemical approaches must be considered. Where possible, biological control and the use of natural predators should be favored. Specific chemical control should only be considered when the economic value of the crop would be affected if this is not done.

The European Community Directive 128/2009 on the Sustainable Use of Pesticides establishes a strategy for the use of PPPs in the European Community to reduce risks to human health and the environment. Integrated Pest Management (IPM) is a key component of this strategy, which will become mandatory in 2014. IPM is based on dynamic processes and requires decision making at strategic, tactical, and operational levels. Rossi et al. (2012) state that, relative to decision makers in conventional agricultural systems, decision makers in IPM systems require more knowledge and must deal with greater complexity. Different tools have been developed for supporting decision making in plant disease control and include warning services, on-site devices, and decision support systems (DSSs). These decision support tools operate at different spatial and temporal scales, are provided to private sources, focus on different communication modes, and can support multiple options for delivering information to farmers (Rossi et al., 2012).

There are indications that automatic observation of diseases may be possible at an early stage, but at this moment, a good visual and instrumental strategy must be used for scanning the crop for disease initiation and if possible combined with population dynamics models to make a treatment decision. Sankaran et al. (2010) reviewed advanced techniques for detecting plant diseases. Some of the challenges in these techniques are (i) the effect of background data in the resulting profile or data, (ii) optimization of the technique for a specific plant/tree and disease, and (iii) automation of the technique for continuous automated monitoring of plant diseases under real-world field conditions. The review suggests that these methods of disease detection show a good potential with an ability to detect plant diseases accurately. Spectroscopic and imaging technology could be integrated with an autonomous agricultural vehicle for reliable and real-time plant disease detection to achieve superior plant disease control and management. Some examples are the detection of diseases in wheat using spectroscopic methods, which could potentially be developed further into airborne hyperspectral detection systems (Bravo et al., 2003; Mewes et al., 2011).

The spatiotemporal challenge for disease detection is also discussed by Mahlein et al. (2012) in the case of sugar beet. They reported that sugar beet diseases differed in their temporal and spatial development as well as in their effects on plant tissue associated with reflectance characteristics. High spatial resolution is crucial in particular for the detection of leaf diseases with discrete, roundish symptoms. The spatial resolution of the hyperspectral camera used in their study provided information even on subareas of disease symptoms. Nevertheless, the tiny uredinia of *Uromyces betae* and limited spatial resolution of the sensor resulted in a high number of mixed pixels. Depending on the shape of the symptoms, pixel size should be smaller than the object of interest by a factor of 2–5. This rule from remote sensing still restricts the (early) sensing of plant diseases to proximal sensing technologies. Specific effects of diseases, disease stage, and the impact of disease severity on spectral characteristics of plants are complex. The development of patterns in time and space, recorded by hyperspectral imaging, may help to identify disease or stress influencing crops at the tissue level and on the canopy level.

Since diseases are stressors of plants, this usually also affects the production and emission of volatile chemical compounds. If these could be detected in the field at an early stage and with sufficient spatial resolution, they could be the basis for decision making. Sensing systems of insects or animals or even plants are also a source of inspiration for novel developments, because of their uniqueness in type or sensitivity or also in the amount of information that is acquired and processed. For example, insects are able to perceive volatiles released by damaged plants in order to find food sources or mating partners. In order to use the highly developed olfactory sense of insects for analytical purposes, the biological nose of insects has to be combined with some electronic instrument via a bioelectronic interface to yield a bioelectronic nose (Schütz et al., 2000). Such a bioelectronic sensor system is very sensitive to detect volatiles released from damaged plant parts or at the onset of fungal infection. For *Phytophtora* detection in potatoes, this could lead to interesting applications.

The same is the case for pest control where traps are frequently used, but the readout of the traps is still time consuming and requires a lot of field travel because the traps must be spread out over a large area. However, there are also indications that it may be possible to identify insects and their population density through optical detection of the wing beat characteristics (van Roy et al., 2014).

#### 9.4.3.3 Application Equipment

It is clear that any chemical treatment must be registered and correct application can only be done if the equipment is in good working condition. In the future, application systems may be made such that the use of a specific chemical compound is only possible according to the license as specified on the label: the site or crop, pest stage or crop stage, application rate depending on the pest or soil type, the timing of application according to season, application method and type of equipment, and number of applications allowed per season. In addition, one has to respect a preharvest interval in order not to exceed the MRLs, which can be country specific. At the time of pesticide application, all information about the crop would already be up to date in the farm database. The label information for a specific compound is also available or could be scanned before the active ingredient is loaded in the sprayer. In that case, an alarm could be given if an erroneous treatment is planned, or maybe the equipment might be locked into a safe mode. Of course, such a system must be made reliable and foolproof to be effective. Measures should also be taken to avoid some chemicals contaminating neighboring crops by monitoring wind speeds and estimating the spray drift (Nuyttens et al., 2011). The development and use of such technology should be part of a management and decision system. Dose level and disease threats are one aspect of the decision; the other ones are the harvest plan and decision. Moreover, both aspects must be fine-tuned and can be spatially and temporally dependent.

Another possibility would be to use smartphones in the field to take pictures of perceived diseases or pests and send these together with the GPS coordinates of the location in the field where the picture was taken to the cloud. After some computations in the cloud, the system could provide information on the kind of disease and the potential or desirable treatment. This treatment advice would then be based on the crop information (type of crop, planting date, and expected harvest date) that is stored in the cloud. The advice can also include the required dose depending on the biomass density (Uschkerat, 2013) or even the microclimate variations in the field. The risk of spray drift and required distances to waterways can be calculated based on information on local weather conditions. Next, a scan of the barcode on the package of the pesticide will tell the operator if the treatment is allowed. Afterward, the applied dose and dose variation, together with the relevant information, would be recorded in the database of the field and the crop as part of the traceability system. It is expected that such a traceability system could improve disease and pesticide management as well as reinforce the confidence of the consumers in the safety of agricultural crops. Most elements of such a system have already been demonstrated in Japan (Nanseki, 2007).

### 9.4.4 Microbial Safety

Microbial contamination can occur during the field stage and at harvest and postharvest. Worker hygiene is very important here, and systems could be contemplated to enforce hygiene of workers and repeated cleaning of harvesting and transport equipment.

The early detection and removal of an infected item, if possible even before it reaches the main parts of the harvesting machine or grading line, can help to avoid problems. This implies that design engineering must now also have a strong emphasis on design for food safety. For example, modular design with suitable cleaning procedures and the use of noncontact sensing tools are one way for reducing risks. Eventually, additional microbial sensing technology should be installed to warn the user in case of a problem item. This may alter the future concepts of harvesting, handling, sorting, and packing equipment. All detections and subsequent removal and cleaning actions should be registered as part of the traceability system.

The core of this enhancement would allow farmers to include either climate forecasts or the latest measurable site-specific field condition data into the resource management decision-making process by best utilizing the historic yield data in similar conditions to adjust the input(s) responsively to the situation. Mid- to late-vegetative growth stage variable-rate nitrogen side-dress application is a good example of responsive control. Either based on the data obtained from in-season canopy reflectance sensing or from late spring soil nitrate tests, N-deficient crop plants will respond to additional nitrogen fertilizer being side-dress applied. It could potentially achieve higher yield efficiency with a smaller amount of total nitrogen fertilizer being applied if the amount of side-dressed fertilizer could be correctly determined.

## 9.5 CROP CONDITION SENSING

For all treatments such as fertilizer use, irrigation, or harvest scheduling, it is very important that the crop condition is known and also that the crop response to a treatment is observed, such that this can be taken into account for subsequent actions. It is of interest that the acquired data can yield information on physiological processes through the use of underlying physiological models rather than just statistical correlation models. In this way, control actions can be based on a better understanding of the physical and physiological processes. Optical measurement methods are considered to be the most appropriate for observing crop conditions and will be briefly discussed here.

Photonics offers many opportunities because photons are ultrafast, extremely focusable, and function contactless. This opens a number of possibilities for agricultural diagnostics. Photonics can be the basis for measurement systems to observe plant responses at different spatial and temporal scales. Indeed, growers can also visually recognize when a problem arises or when there is a large variation in crop condition in the field. Human observation is mostly limited to a qualitative interpretation. In the search for a more quantitative approach, numerous articles and reviews have been published on optical properties of crops and image analysis in relation to fertilizer use, crop stress, disease or weed detection, and product quality. In most of these cases, correlations have been established between a spectrum or an image and the particular crop characteristic that one wants to evaluate. These are then mainly empirical studies that have resulted in some practical implementations (Sims and Gamon, 2002; Reyniers et al., 2004, 2006; Lenk et al., 2007; Saeys et al., 2009; Gorbe and Calatayud, 2012; Tremblay et al., 2012).

There is a growing desire to link the measurable optical characteristics to physical and physiological processes in the crop, to increase the understanding of what is happening and then to better pinpoint potential actions. One approach is the use of biophysics-based mathematical models that link physiological processes to observed radiation and then apply model inversion. This model inversion may not always yield sufficient sensitivity to the different physiological components that can affect radiative transfer. Models at different spatial scales are used and, sometimes, they are integrated, which increases the computational complexity.

From the beginning of optical remote sensing, radiative transfer models, based on biophysical theory, have helped in the understanding of light interception by plant canopies and the interpretation of vegetation reflectance in terms of biophysical characteristics. The canopy radiative transfer models attempt to describe absorption and scattering, the two main physical processes involved, and are useful in designing vegetation indices, performing sensitivity analyses, and developing inversion procedures to accurately retrieve vegetation properties from remotely sensed data (Jacquemoud et al., 2009).

The processes and mathematical formulae that are used to simulate sensing signals depend on the scale of the system. In general, most models either simulate leaf-scale signals or canopy-scale signals (Atherton, 2012). At the canopy level, the model inversions typically require inputs of many canopy parameters that cannot be readily estimated from remote sensing data.

Four principal crop characteristics determine the reflection, absorption, and transmission of electromagnetic waves (Tucker and Garratt, 1977):

1. Internal structure or the histological arrangement of tissues and cells is responsible in part for the diffusion or internal scattering of incident irradiance. Spectral absorbance, reflectance, and transmittance are thereby greatly determined by the mean optical path length of incident radiation.
2. The pigment composition, concentration(s), and distribution(s) control the absorption of UV, visible, and IR radiation. Light absorption in food matrices is molecule-specific and theoretically described by Beer's law.
3. The concentration and distribution of leaf water determines the absorption of radiation in the NIR and IR region of the spectrum.
4. The surface roughness characteristics and the refractive index of the cuticular wax of the upper epidermis determine the spectral reflectance from this surface.

It should be noted that a number of crop characteristics or processes of interest are linked and highly correlated, and that inverse modeling based on optical measurements does not easily allow separate estimation of these characteristics.

Plant growth or vegetation development involves several processes that each occur on a different spatial as well as temporal scale (De Baerdemaeker, 2013). Examples of these different scales are disease symptoms on a leaf, growth, or the vegetative biomass in a field or a larger area. At those different scales, information is required for correct identification or classification of quality characteristics, of diseases, or of plants or crops. In many cases, this identification can rely on optical information taken at a high spatial resolution, but it can just as well happen that this identification is only possible through the use of high temporal frequency information. In other cases, rapid scans with low spatial resolution may indicate that uneven changes occur in the canopy or field and the cause of these may then be investigated by high spatial resolution inspection of locations of interest. Also, in case one wants to use information for statistical process control in order to detect abnormal deviations, it is required to have high temporal frequency information. There is usually a trade-off to be made between fine (or coarse) spatial resolution and low (or high) temporal frequency information since it may be impossible to have a high spatial and temporal resolution. It is a challenge to combine the data obtained at different temporal and spatial scales such that useful information is obtained (Robin et al., 2005).

Variation of crop characteristics over time can be due to normal development or also due to emerging stress conditions. Again, there may be different scales at which these changes occur. Patterns in spectra or hyperspectral image changes can be observed using time-lapse acquisition. Obtaining the information from subtle changes may require advanced image processing. For example, Wu et al. (2013) described a method to reveal temporal variation that are difficult or impossible to see with the naked eye in videos and display them in an indicative manner. The method, which they call Eulerian video magnification, takes a standard video sequence as input, and applies spatial decomposition, followed by temporal filtering to the frames. The resulting signal is then amplified to reveal hidden information.

## 9.6 CHAIN OF TRACEABILITY

After harvest, the GPS coordinates of the harvest location may be added to the shipping documents such that the origin of the product (the region, the farmer, the field, and the location in the field) can be traced and the consumer can be assured about the origin claims. It is also possible in mixed final products to state where the different components of such a mixture originated from. For retailers or stores that claim to sell locally produced food and for their clients, it offers the possibility to trace the product and verify the claims as long as the system has been made foolproof.

A crop goes through a number of operations, transactions, or shipments in the chain from the field to the customer. This is even more complicated when feed and animal production are part of the chain. At each step, there should be a possibility to trace the crop either upstream or downstream. As the chain can be relatively long, it has been suggested to implement this as a distributed system where only one step in either direction at every stage is traced instead of centralizing all data. This requires a good communication network between potential sites where the traceability data are stored, as well as access control. Cloud computing may be a way to proceed here. A benefit of accessibility of data can be that in the longer term, field variability related to weather and soil conditions can be extracted from such a database allowing farmers or their advisors to optimize production strategies. It is also a way to increase the expert knowledge or models for predicting what the outcome of a treatment this year can be, given that similar production conditions may have occurred in the past. In this way, the historical traceability information is not only valuable for consumers, but also for producers or other operators in the chain.

## 9.7 VARIABILITY MODELING AND TRACEABILITY

The advantages of having a nondestructive sensor reach far beyond the fact that it is just nondestructive. Indeed, they offer the possibility to monitor individual products during the experimental period, which in turn allows for modeling the change of quality attributes or other characteristics.

An approach based on mechanistic models further improves the interpretation of postharvest behavior (Tijskens et al., 2001). By definition, such a model will be based on a simplification of the food product and, therefore, will never be "true" as the only true model is the product itself. The aim of modeling food quality attributes is, however, not to develop true models but to develop valid models. That is, models that are consistent with the current knowledge level and that contain no known or detectable flaws of logic (Tijskens et al., 2001). Also, models should be detailed enough for the intended purpose, but at the same time simple enough to give robust manageable models. The basic strategy to develop a suitable model is to apply a systematic process of problem decomposition, dissecting the problem into its basic building blocks and then reassembling them leaving out the unnecessary detail. What is essential and what is redundant depends largely on the intended application of the model. In the end, the models are to be used to provide an appreciation of the quality of the logistic handling chain and to translate this into the impact the logistic conditions have on product quality attributes (Hertog et al., 2014).

The major challenge is to develop predictive models that assess the uncertainty of the predicted result. Given a simulation model, this problem reduces the propagation of errors from the simulation input to the simulated result. With an increasing number of random factors, it becomes practically impossible to establish the correct model response. Generally, some reduction is required by identifying the most important (combinations of) input parameters that capture most of the variability.

With the availability of nondestructive techniques, the quality of individual product items can be monitored over time, fully characterizing biological variance within a given batch. To properly analyze such data, biological variance has to be explicitly included in the (statistical) data analysis. De Ketelaere et al. (2006) proposed a novel statistical approach ("mixed models") to model such repeated quality measures and demonstrated its potential for a practical example in which the firmness change of different tomato cultivars was considered. Both types of data analysis allow quantifying different sources of variance such as variance within a tomato cultivar and within a tomato and how those sources of variance change during storage. These approaches open the door to an improved measurement, understanding, and prediction of postharvest batch behavior. As such, these approaches enable postharvest management to optimize logistics, taking into account the full range of product variation that will be encountered.

If biological variance is included in (statistical) models describing postharvest quality change, propagation of the initial biological variance at harvest throughout the entire postharvest chain can be predicted when all relevant aspects affecting postharvest fruit behavior are taken into account (Hertog et al., 2014).

Shelf life prediction is an important issue for fruit handling. As mentioned before, not only the average quality trajectory a batch follows has to be estimated, but also how much the quality is dispersed around the batch average, since we are generally interested in an estimation of the time at which, for example, 5% of the fruits reach a preset lower bound for their quality.

The implementation and validation of such a stochastic quality change model was tested in a traceability system for tomato (Hertog et al., 2008). Experimental results showed the potential benefits of integrating quality change models with traceability systems to satisfy consumer expectations. As the temperature logging radio-frequency identification (RFID) labels are too expensive to put on individual boxes, the alternative to use a single RFID label per pallet seems to be feasible given the limited effect of temperature differences within the palletized fruit. The model-based traceability systems to monitor product quality throughout the chain can then assist in identifying poor temperature control or temperature abuse at a given point in the logistic chain as the cause of unacceptable quality at the receiving point. Furthermore, such monitoring and modeling can help in identifying locations in a field or orchard where there is a large deviation in quality or shelf life. It also can help in differentiating the harvest time within a field or between fields.

These approaches enable postharvest management to optimize logistics, taking into account the full range of product variation that will be encountered.

## 9.8 MODEL-BASED STATISTICAL PROCESS CONTROL

Nowadays, agricultural production performance is usually assessed and monitored by comparing mean values of a recent measurement period (e.g., week or month) with past performances or predetermined performance standards. This is usually done without the interference of statistical analysis. However, excessive biological variation interferes with the evaluation of performance. High variability makes the performance outcome unpredictable and difficult to interpret. Therefore, understanding variability is the diagnostic key for improving process performance (Reneau and Lukas, 2006). Two concepts that are especially interesting for performing process optimization through monitoring are engineering process control (EPC) and statistical process control (SPC). EPC is the set of activities that focus on the mathematical modeling of (production) systems (del Castillo, 2002), and SPC is a collection of tools that aim at discerning between normal and abnormal process variation (Montgomery, 2005). An SPC tool that is widely used for the detection of abnormal variability is the quality control chart. The use of control charts in agricultural production, and especially in livestock production, is gaining considerable interest (de Vries and Conlin, 2003; Reneau and Lukas, 2006). The signal of the control chart can be used for early detection of problems. This synergistic concept has only recently been applied to agricultural production. Since the data of many agricultural production processes evolve over time (nonstationary) and subsequent measurements are correlated (dependent), they cannot be monitored as such with the control charts. To overcome these limitations, the concept of synergistic control was proposed (De Ketelaere et al., 2011).

In a synergistic procedure for early problem detection, the concepts of EPC and SPC are combined. For example, by using the EPC adjusted data, by means of a recursively estimated trend and ARMA model, as the input to the cusum control chart (SPC), it was shown to be possible to detect registrations that result from an out-of-control situation as a result of an emerging problem or disease. The potential of this concept was already demonstrated for monitoring laying hens (Mertens et al., 2011) and dairy cows (Huybrechts et al., 2014). This procedure can form the basis for the development of an intelligent management support tool for agricultural production systems such as dairy production, pig production, and crop production. The synergistic concept is in most cases applied for processes changing with time, but it can also be applied for assessing spatial variability or the sensitivity of, for example, varieties or treatments to spatially variable soil conditions. However, it should be noted that this approach can only be successful if reliable sensor data are available.

## 9.9 SUMMARY AND CONCLUSIONS

In PA and automation, many measurements are carried out at different spatial scales (from single plants to entire fields) and at different times during crop production. Precision farming and the use of GPS on agricultural machinery can provide location and time information of all treatments. It started with yield sensors, but at this time, tools are available for on-the-go measurement of the type and dose of treatments, for identification of crop condition, and possible infection with pests or diseases. Wireless communication can be used to transfer field data to record keeping software. Thanks to these technological developments, the control points and compliance criteria of certification systems for GAP, such as GlobalGAP or other GAP schemes, can to a large extent be automatically addressed using PA technology for automatic record keeping. PA technology can be made smart such that the requirements for environmentally friendly and sustainable production are implemented in real time in crop treatment and fertilizer equipment. This also includes the identification and registration of operations or treatments on the crop in the growing stage. At the time of harvest, the technology can help in the identification and, if possible, the measurement of the quality parameters depending on where in the field the crop was grown. Different batches can be made with labels linking to all the information. As such, PA technology can evolve to being great instruments for food safety and quality assurance.

Novel crop sensing techniques during growth or after harvest give information on crop stress, quality, diseases, pests, or weeds. Now, information is available about variability of crop or product characteristics. The repeated nondestructive measurements allow for modeling of the process evolution or the evolution of quality over time (or maybe also in space), thereby separating inherent biological variability from variations caused by external process conditions. These models and observations form the basis for SPC and informed decision making for interventions.

The frequently asked question about the economic benefits of PA is also raised about the economic effects of food safety and safety risks along the chain. In this respect, Valeeva et al. (2004) state that acceptable levels of food safety hazards need further elaboration to clarify the process of food safety improvement for producers. They also note that it is furthermore important to gain more insight into cost-effective ways of food safety improvement throughout the entire chain and that valuation of producers' benefits along the chain and their distribution are urgently needed. Perhaps, the combined economic benefits of PA and GAP for food safety and consumer confidence are underestimated at this moment.

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# 10 State of the Art and Future Requirements

*Hermann Auernhammer and Markus Demmel*

**CONTENTS**

## 10.1 INTRODUCTION

Precision agriculture (PA) means more than site-specific farming, it also deals with more than just variability. In discussions worldwide, "precision agriculture" and "precision farming" are often used interchangeably.

Agriculture is one sector in the entire land use scenario, while PA is specifically associated with precision forestry and precision fishery. "Precision (crop) farming" and "precision livestock farming" can be thought of as categories within PA. In most countries, viticulture and horticulture are seen as parts of agriculture; another way to look at these categories is as farms where operations are carried out only outdoors, on the one hand, and those where operations take place both outdoors and indoors, on the other. Of these, outdoor farming is dominant as it covers a wide range of precision farming activities (Figure 10.1).

Whichever classification is used, precision farming must be seen from the farm-level perspective. Activities of interest are farm management itself, crop management, machinery management, and labor management. In all of these areas, PA measures can be seen and may contribute to sustainability and traceability (Figure 10.2).

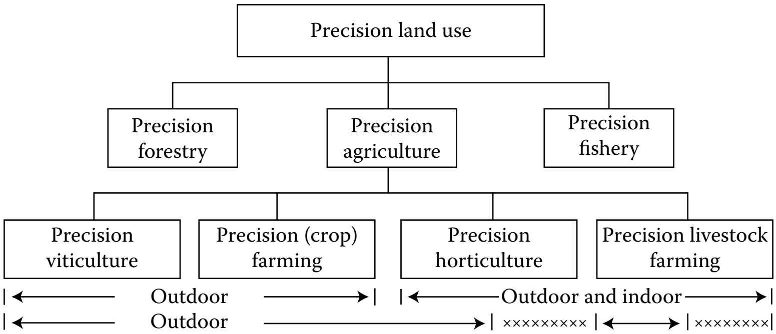


**FIGURE 10.1** Precision agriculture in precision land use broken down to outdoor and indoor systems.

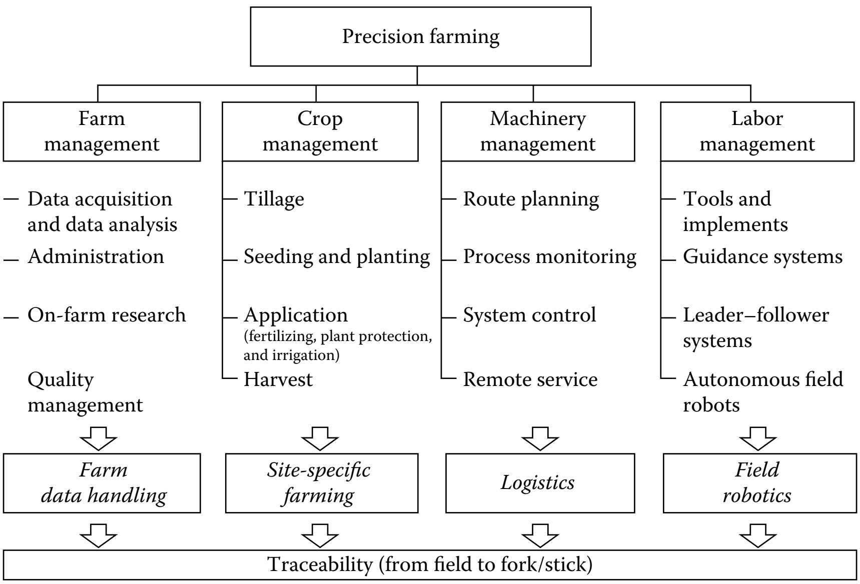


**FIGURE 10.2** Precision farming sections and items. (From Auernhammer, H. 1999. *Zeitschrift für Agrarinformatik*, 3:58–67. With permission.)

## 10.2 BASIC TECHNOLOGIES

Farmers have for millennia strived to farm more precisely, first with simple hand tools such as the sickle for exact cutting of crops, and later with mechanical implements, such as the plow, with its ability to cut cleanly and to turn the soil on a large scale. Also, very early, the knowledge of given field conditions such as soil type, water availability, and topography, together with the experience gained out of previous field work and the previous harvest, were integrated into measures for the new vegetation cycle. Manure handling is a good example, where farmers distributed more material on areas with low soil fertility and less material in high-yielding zones to guarantee a higher overall yield, and to preserve and improve the soil quality by increasing organic matter content. As long as farmers cultivated only their own—and, therefore—known land, they realized site-specific farming by experience!

Unfortunately, the precision of farm work diminished with the increasing use of farm machinery on the one hand and with increasing cultivation of rented land, and therefore unknown field conditions, on the other. Additionally, an increased number of untrained workers became deployed in agriculture with either little or no interest in the quality of work.

### 10.2.1 Electronics, Sensors, and Actuators

In the early 1970s, the first electronic solutions entered agricultural technology and mechanization. Agriculture began using calculators with on/off and revolution sensors. Four major electronic developments changed agricultural mechanization:

- *Tractors:* The electronic hitch control (Heiser and Kobald, 1979) replaced the former mechanical control unit, and offered new and extended features such as down force control or integration of external depth control sensors on implements.
- *Planters:* Electronic planter monitors (Ryder and Victor, 1966) informed the driver if the singling of the seeds went wrong and therefore allowed more precise seed placement.
- *Sprayers:* Spray controllers (Göhlich, 1978) measured the actual speed of the tractor with a wheel sensor and controlled the spray output homogeneously across the whole field according to the given set point. Also, section control was part of the control loop.
- *Combine harvesters:* Loss sensors mounted on combines (Gorsek, 1983) informed the driver about unharvested kernels, aside from the sieves and/or the straw walkers. Fewer overall losses and/or improved throughput could be gained by conscientious drivers.

In the 1980s, agricultural electronics was adopted in practical farming for monitoring and control with the main focus on application implements used for seeding, planting, fertilizing, and spraying. During that period, two other major developments took place on farms:

- *On-farm data processing:* Based on personal computers (PCs), field records went from written records to digital files with enhanced capabilities in analyses and predictions.
- *Implement control:* Specified implement controllers and increasingly more multipurpose process controllers were integrated into application implements for monitoring, application control, and data acquisition related to working time, working speed, application amounts, etc. Also, first proprietary data transmission tools from the controller to the on-farm PC were developed and used.

While IBM created the worldwide accepted standard DOS for PCs, the implement controllers still followed proprietary solutions with barriers in acceptance on the one hand, and with specified and additional demand in data communication procedures on the other.

Consequently, at the end of the 1980s, the demand for standardized communication systems in agriculture were discussed in regions where farmers preferred tractors and implements from different manufacturers in order to perform field work in the best way under the given conditions, and with the available infrastructure in service and maintenance of the used technology.

### 10.2.2 Standardized Electronic Communication

Early on, electronic communication in mobile agricultural equipment was considered either as a company-specific solution by dominating market leaders or as independent solutions by a commonly accepted standard.

One of the widely utilized process controllers in Europe (dlz Spezial, 1990), with more than 50,000 sold units since 1985, could be used for implement monitoring, implement control, and for data transfer to the on-farm computer using a chip card in a proprietary way (Figure 10.3).

Farmers widely accepted electronics coming from "one hand." A single controller used year round with its simple man-to-machine (M2M) interface facilitated the interaction. Depending on the mounted implement, the connector with its specific pin allocation ensured the required control software, and the chip card allowed for data transfer in both directions to and from the management computer. Similar products were developed worldwide and thousands are still in use.

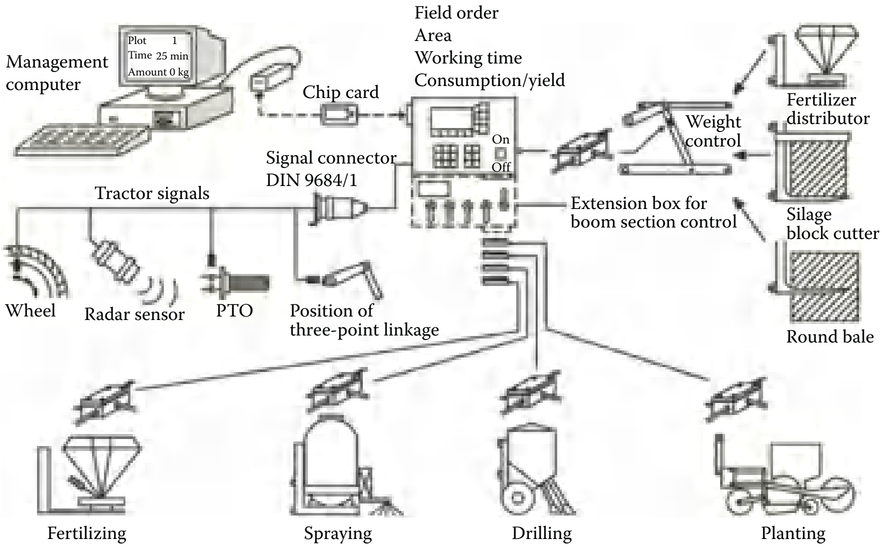


**FIGURE 10.3** Mobile multipurpose agricultural process controller MÜLLER Unicontrol.

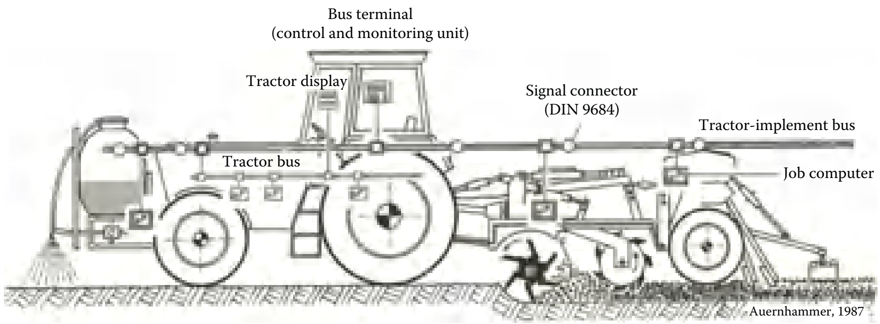


**FIGURE 10.4** Agricultural BUS-System (Landwirtschaftliches BUS-System LBS) by DIN 9684.

With all these solutions, farmers as well as manufacturers began getting strongly dependent on electronic suppliers. The small- and medium-sized implement manufacturers in Europe were especially eager to get independence as soon as possible by creating a standard for electronic tractor implement communication (Auernhammer, 1989) with an interface to the farm management computer in DIN 9684 (DIN, 1997), as seen in Figure 10.4.

In a 1987 initiative chaired by the German DIN organization, representatives from Denmark, the Netherlands, France, and Great Britain worked together. The serial bus system controller area network (CAN) (BOSCH, 1987) from BOSCH was initially selected. The main characteristics of the standard are CAN1.0A protocol with 125 kB/s, electronic control units (ECU) in the tractor and implements, with their own control algorithms and implement-specific masks for interaction, a virtual terminal with hard and soft keys, and a standardized interface to the on-farm PC. System control was defined by the task controller. The main focus of the standard addressed small-scale farming technology, where mounted implements at the rear and the front of the tractor allowed for almost self-propelling units, but also, where implement subnetworks for complex implements were integrated (Auernhammer and Frisch, 1993). Proprietary messages were not allowed, and independent system development and testing was organized in so-called Plugfests. System diagnostics were discussed but not integrated; finally, the standard was completed in 1997, after 10 years.

Moreover, at the end of the 1980s, the standardization group extended its activities and called ISO for the definition of the required specified agricultural committee structure in TC23 with SC19 and related working groups. In 1990, all members of the European standardization group joined the ISO standardization group, ISO 11783 (ISO, 2009), together with members from North America under the lead of Great Britain and, later, Canada (Figure 10.5).

In the overall scheme, ISO 11783 strictly followed the DIN 9684 design with some substantial changes and extensions. The standard follows the OSI model definition in ISO. Instead of CAN1.0A with its smaller address space, ISO 11783 changed to the extended CAN version V2B with its 29-bit address header, and in the same manner, the bus transmission rate was doubled to 250 kB/s. More attention was given to

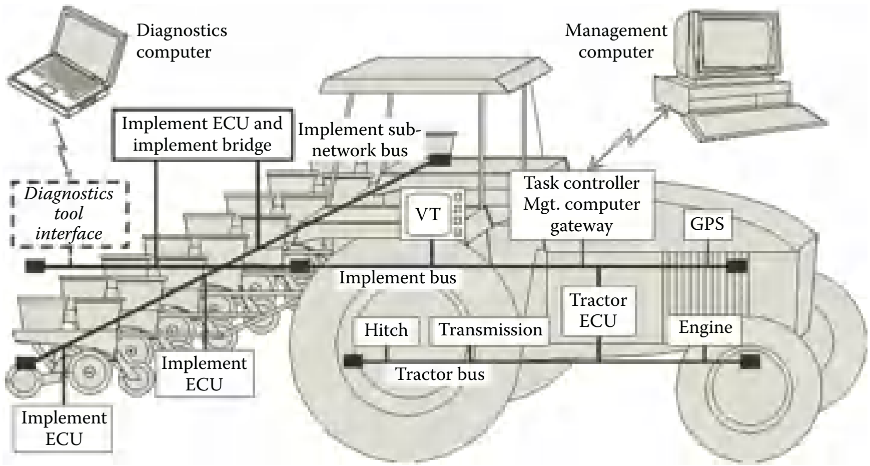


**FIGURE 10.5** Agricultural BUS-System ISO 11783. (From Stone, M.L. et al. 1999. ISO 11783: An electronic communications protocol for agricultural equipment. ASAE St. Joseph, MI, USA. Modified with "diagnostics" by Stone, M. L. 2011. ISO 11783 Part 10 Task controller and management information system data interchange. ASABE AET. http://www.shieldedpair.net/downloads/ISO%2011783%20Part%2010.pdf. With permission.)

tractor and implement combinations used in the semi-mounted or trailed mode with large working width and hydraulic power supply. Therefore, implement subnetworks are of higher importance and more well defined. Diagnostics with interface and diagnostic tools are integrated. Most importantly, today, proprietary messages are allowed and may be used by anyone within the standard to get manufacturer-specific advancement within their own tractor implement production segment.

ISO 11783 may be called a "living standard" with no foreseen finalization at this time. Additional definitions are under development and will be added as required or changed by technical enhancements.

### 10.2.3 Location Sensing

From a technical point of view, the second pillar of precision farming evolved from a military initiative, with the development of the Global Navigation Satellite System (GNSS), NAVSTAR, and, in parallel, GLONASS, offering time and positioning signals (Auernhammer, 1994). Receivers are able to determine their own position by calculating the signal transit times from at least four visible satellites.

After the launch of the first GPS test satellite in 1971 and the test of an interim system, the predominantly used system, NAVSTAR (Navigational Satellite Timing and Ranging), reached its "full operational capability" (FOC) in June 17, 1995, with civilian usability for location sensing by all, at no cost. Most important for the agriculture sector, as one of the worldwide first users, are: availability all day, usability with no restrictions of daytime and visibility, no need for additional infrastructure when basic accuracy is sufficient, and higher accuracy and lower dependency as more satellite systems are globally available, and as more signal improvement tools are used.

**TABLE 10.1**
**GNSS Systems (Own Inquiries)**

| System | Country | Satellites (Target/In Orbit) | Full Operational Capability | Satellite-Based Correction Systems |
|---|---|---|---|---|
| GPS NAVSTAR | USA | 31/31 | July 17, 1995 | WAAS |
| GLONASS | Russia | 30/24 | 2011 | SDKM |
| BEIDOU | China | 35/14 | December 27, 2011 | ? |
| QZSS | Japan | 3/1 | Unknown | MSAS |
| IRNSS | India | 7/3 | Unknown | GAGAN |
| GALILEO | Europe | 30/5 | Unknown | EGNOS |

**TABLE 10.2**
**GNSS Signal Processing Technologies**

| System | Signal Correction | Examples | Accuracy (m) |
|---|---|---|---|
| Single-frequency GNSS | No | NAVSTAR, GLONASS | 10–15 |
| Differential GNSS | Postprocessing | – | 0.5–1.0 |
| Differential GNSS | Radio communication | IALA Radio Beacon | 0.5–1.0 |
| Differential GNSS | Satellite communication | WAAS, EGNOS | 0.5–1.0 |
| Double-frequency GNSS | Second frequency | – | 2–5 |
| Differential double-frequency GNSS | Radio or satellite communication + double frequency | Starfire II, Omnistar HP | 0.1–0.2 |
| RTK GNNS | Radio communication | – | 0.02–0.05 |

Since the first tests, more than 200 satellites have been launched into orbit. Besides the two prime pioneering systems, GPS NAVSTAR and GLONASS, four more systems are under development (Table 10.1).

Advanced receivers are able to pick up signals from all visible satellites, even those from different systems, and select the best geometry for the highest possible accuracy. Additionally, different signal processing technologies (Table 10.2) can be used to achieve the required location sensing precision for navigation (± 10 m), field operations (± 1 m), vehicle guidance (± 0.10 m), and tool guidance (± 0.01 m), defined by Auernhammer and Muhr (1991).

## 10.3 FARM MANAGEMENT

Information-driven farm management needs data and algorithms to analyze, plan, and control farm processes, as well as to follow social and environmental conventions. Widespread databases guarantee any needed documentation, and allow for comprehensive analyses and predictions. At present, besides the traditional on-farm data storage and data processing, increasingly more off-farm services are offered and in use (Table 10.3).

**TABLE 10.3**
**Data Handling Systems**

| System | Characteristics | Advantage | Disadvantage |
|---|---|---|---|
| On-farm | On-farm data storage<br>On-farm-specific software | Private data ownership<br>Preferred hardware<br>Specialized software | Being alone in<br>• Long-term data storage<br>• Hardware exchange<br>• Software update |
| Provider (fertilizer, plant protection, contractor, etc.) | Data storage<br>Farm-related analyses and predictions | No on-farm infrastructure<br>Analyses be demand<br>Predictions by demand<br>Specialized on-farm services | Only provider-specific predictions<br>Data ownership?<br>Data security? |
| Manufacturer | Data storage<br>Remote machine analysis and service | No on-farm infrastructure<br>Improved machinery service and repair<br>Farm data contribute to machinery improvement | Only company related provider-specific predictions<br>Data ownership?<br>Data security? |
| Cloud | Offered by software companies and others<br>Data storage<br>Access of web-based apps and services | No on-farm infrastructure<br>Great choice in required apps<br>Ongoing development of new and more beneficial apps | Data ownership?<br>Data security? |

As a very rough assessment, it may be generalized that small- and medium-sized farms still work with on-farm systems as most of them have personal field-based knowledge and experience, whereas larger farms with more employees and less field-based information prefer either contractors for fertilizing or plant protection, or rely more on the on-farm dominant machinery supplier.

### 10.3.1 Data Acquisition and Data Analysis

Automatic process data acquisition is mainly used to establish comprehensive field records and provide cost element data for bookkeeping (Steinberger, 2012). Data acquisition systems differ widely and there is still no data definition standard (Table 10.4).

Data processing is going through a change. Smaller farms often retain special software packages with data history of cultivated fields tailored to simplified usage and with more or less no specialized analytical tools. By focusing on some methods of PA, improved software packages are used with a central database and with farm-specific analytical tools (Daberkow and McBride, 2003). Very often, those systems are offered with the cooperation of tractor manufacturers and contractual partners to simplify data transfer from mobile technology to the farm database and the software tools at the farm.

Data storage in the cloud at this time is an exception, mainly owing to questions of data ownership and data security. Also, concerns related to financial data and financial information may be seen as an obstacle when using this more beneficial and more powerful data handling possibility.

**TABLE 10.4**
**Process Data Acquisition Systems**

| System | Sensor Data | Data Transmission | Standard |
|---|---|---|---|
| Specialized implement controllers | Implement, location, time, throughput (as applied) | None | No |
| Multipurpose process controllers | Implement, location, time, throughput (as applied) | Chip card, USB | No |
| Tractor terminals | Tractor, location, time, implement (if ECU) throughput (as applied) | USB, radio | No |
| ISOBUS task controllers | Tractor, location, time, implement (if ECU) throughput (as applied) | USB, radio | Partly following ISO XML |
| Controllers at self-propelled vehicles | Vehicle, location, time, throughput (gathered/as applied) | Paper print, USB, radio | No |

#### 10.3.1.1 Soil Mapping

Although they were not seen as part of precision farming in the past, very detailed soil maps were established and have been available on-farm for field-related measures for a long time. The resolution of these solely analog documents differs from region to region and from country to country, and they are increasingly being offered at no charge.

Today, soil mapping systems identify soil type and soil nutrients. The former are mainly detected on-the-go using electromagnetic or electroconductivity sensors such as EM38® or Veris®, whereas soil nutrient data are mainly gathered through soil sampling technologies and associated chemical analysis (Friedman, 2005; Ladoni et al., 2010; Sinfield et al., 2010). Often, environmental laws determine the time intervals of soil nutrient examinations.

Soil type and soil nutrient data are mainly used to establish field-specific homogeneous fertilizing strategies according to the base nutrients (once in a growing season) and nitrogen fertilization, either once or multiple times, in a growing season.

#### 10.3.1.2 Yield Mapping

The yield monitor, used in combine harvesters, was one of the first widely adopted precision farming technologies (Schueller et al. 1985; Searcy et al., 1989; Reyns et al., 2002). In yield monitors, data acquisition is carried out with specific sensors and processors. Signal processing at the combine is performed in a company-specific way. Nearly all high-performance harvesters are equipped with yield monitors using different sensor types depending on the harvested crop. In grain harvesting technologies as well as in forage harvesters, moisture sensors are also state of the art (Table 10.5).

Data transfer to the farm management system (FMS) and mapping software is part of the yield monitoring system. Mapping with GIS software mostly differentiates yields into classes of one-metric ton and can be achieved by grid mapping or contour mapping (Figure 10.6).

**TABLE 10.5**
**Yield Monitors in Harvesting Technologies**

| Harvester | Sensor Type | Moisture Sensor | Relative Accuracy (%) |
|---|---|---|---|
| Grain | Impact, light barrier | Capacitive | 5–10 |
| Cotton | Light barrier | – | 5–10 |
| Forage | Feed roller displacement | Capacitive and NIR | 5–15 |
| Root crops | Weigh cells | – | 5–10 |
| Sugarcane | Weigh cells, roller displacement | – | 5–15 |

*Source:* Demmel, M. 2007. *Landtechnik*, 62 SH: 270–271; Vellidis, G. et al. 2003. *Applied Engineering in Agriculture*, 19:259–272; Ehlert, D. 2002. *Biosystems Engineering*, 83:47–53; Demmel, M. 2013. Site-specific recording of yields. In Heege, H.J. (Ed.), *Precision in Crop Farming*. Springer, Berlin, Germany, pp. 314–329; Molin, J.P. and L.A. Menegatti. 2004. Field-testing of a sugar cane yield monitor in Brazil. ASABE St. Joseph, MI, USA, Paper No. 041099. With permission.

Grid mapping simply puts all available yield measurement values, according to their position, into a grid. Grid sizes may be a single or multiples of the working width of the combine or may be related to the working width of the application technologies, again as a single or in multiples. Yield measurement values are averaged with their standard deviation to show the mean of a grid and the variation in it. Different colors represent yield zones with different colors in different yield monitor systems.

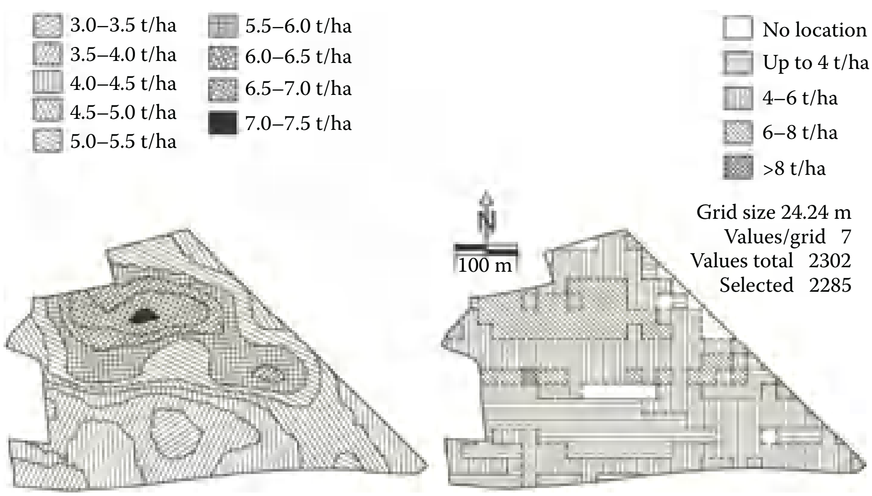


**FIGURE 10.6** Yield maps in contour shape (left) and grid shape (right).

Contour mapping is based on geostatistical data processing operations and allows for very sophisticated yield differentiation. Research is ongoing to reduce or exclude measurement errors caused by neighborhood influences (up and back harvesting design) or by variations in the working velocities or interrupts in the work flow (Lyle et al., 2014).

Nevertheless, all mapping systems deal with unavoidable measurement errors caused at the field end by filling and emptying the material flow. Consequently, yield maps of small fields (short field length) show more faulty information compared to larger fields or plots.

In an overall assessment, it can be noticed that yield mapping is widely adopted at the farm level. First of all, it makes the main target of farming, the yield, and its variety, visible within the field and, in so doing, allows a more precise reaction for future growing seasons. As a first measurement procedure, it also provides existing knowledge and experience of the given yield performance of a field.

Taking those results into consideration, for example, a generated map of a field-based nitrogen balance, will then offer more "true information" as well as a better understanding of the findings in the map (Figure 10.7).

Regarding fertilizing, the often established component, classification may be improved by differentiation related to the "mean yield" of the field. A first map may be divided into two classes with yield above and yield below the average. Most fields may better fit into a system with three yield classes, for example, ±10% around the average and classes above and below. Finally, a system with five classes, first with ±10% around the average, another two classes with 20% above and below the average class, and a further two classes above and below, may represent the in-field yield variations in an operation-oriented way. In this way, farm-specific strategies based on control and accuracy of the available fertilization technology will be able to precisely apply the required amount of nutrients in a site-specific manner.

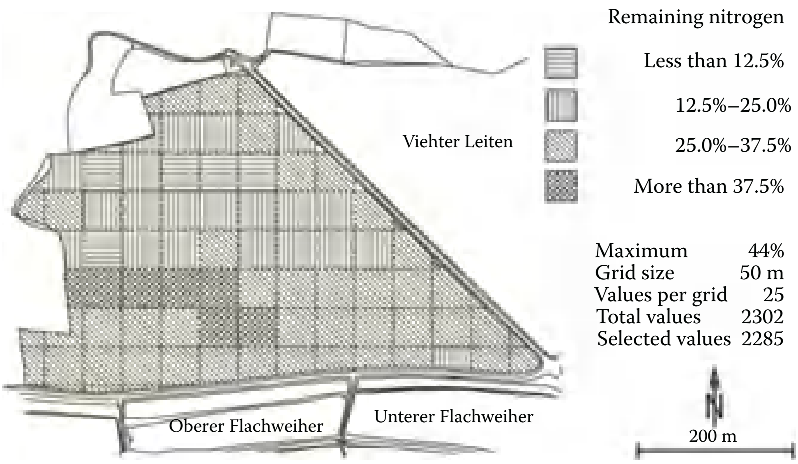


**FIGURE 10.7** Nitrogen residuals after uniform application. (From Scheyern "Flachfeld," 1991. With permission.)

There are also many concerns against repeated yield monitoring:

- Yield maps generated from yield data of different manufacturers within a field or within a growing period may not be comparable as there is no standard in data harmonizing and data processing. Yield maps in this way are often colored pictures only.
- Repeated yield measurement is influenced by different weather conditions and by different crops in a crop rotation. Even with similar crop management procedures, it is very difficult to analyze and interpret the results. Also, crops for which there is no current practical yield measurement technology available do have an important influence.
- Finally, data handling in the long term is difficult, especially on smaller farms with no specialists in data storage and retrieval.

#### 10.3.1.3 Weather Monitoring

Crop farming depends on climate conditions in regard to field measures or to produced yield of a field. In the same way, weather conditions at a farm may vary widely, especially in regard to wind speed, with implications for pest management and in rainfall, with an impact on fertilization and nutrient movements in the soil. Also, any operation scheduling depends on weather conditions and forecasts (O'Neal et al., 2004).

Larger farms as well as farms with a certain topographic differentiation of fields need more regional differentiated weather data obtained from their own weather stations. Standardized sensors with standardized signal processing algorithms allow the utilization of nearly all weather stations offered in the market. The data link can be either a wired interconnection or through radio communication to the FMS, where the first may cause problems due to lightning and thunderstorms, but offers independence through a parallel power supply.

Weather forecasting has improved during the last decades, by having the use of more powerful computers and more sophisticated models. The on-farm use of this information is often free of charge, while more detailed information needs specific contracts with suppliers or may be a free-of-cost amendment offered by other service providers or by leading agricultural machinery suppliers.

### 10.3.2 Administration

Farm management depends on or is increasingly influenced by laws and regulations formulated by legislation. Examples of restrictions in different parts of the world are

- *Nitrogen restrictions*, which allow a maximum amount per hectare documented through so-called farm-gate regimes. More diverse regulations already look to the field-gate and it might be expected that in the near future, together with improved site-specific technologies, the gate will come to the part-field.
- *Use of prohibited agents*, especially in pest protection scenarios.

- *Limited time intervals* in conjunction with applications of manure to frozen soil or during times of no plant growth, which keep lateral flow and ground water contamination in check.
- *Exclusion zones* of natural resources such as waterways, surfaces with an inclination higher than a given threshold and restricted areas of nonarable land.

In all these examples, precise data acquisition without gaps and verifiable documentation have to be guaranteed.

### 10.3.3 On-Farm Research

Plant treatments by fertilizing, pest management, and irrigation mainly follow common models and/or adviser-created recommendations. While the former suggestions are based on universal references, the latter may be more related to real farm conditions. Therefore, whenever local conditions should be integrated more intensively, on-farm research is crucial. Mainly focusing on fertilizing or pest management, different types of implementation can be chosen:

- *Untreated windows* are able to show the effect of any surrounding applications during fertilization or spraying.
- *Strips* with different application rates allow the evaluation of varying amounts or concentrations of agents.
- *Small test plots* with identical treatments and different varieties give genuine information about the performance of a particular variety.

All-in-all, on-farm research needs precise treatment as well as precise and specific data acquisition. The outcome contributes mainly to the farm management itself with the focus on increasing profit. It also contributes to more precise fieldwork in homogeneous treatments during fertilizing, pest management, and irrigation, avoiding over-applications as well as shortcomings resulting in reduced yields or in dangerous infestation.

### 10.3.4 Quality Management

Farms tend to grow and farm work often is transferred from family workers or well-trained farm workers to untrained laborers in full-time or part-time employment. Also, the transition of field work to contractors and/or machinery communities (joint ownership) is increasing, and in all these cases, monitoring will suffer.

More precise farm management, therefore, needs a well-defined work order and detailed data from any field activity, which might be included in existing field records or in quality management data pools (Kruize et al., 2013; Nawi et al., 2014).

#### 10.3.4.1 Traceability and Good Agricultural Practices

When considering the farm management activities mentioned in this subchapter, it might become clear that high-quality data acquisition, together with application of different methods, which is how PA is defined, are fundamental requirements for more precise farming.

Data storage, in the same way, is the second challenge. Agricultural data will become very valuable over time. This information requires sophisticated data management systems and long-term data storage tools with adoption of new storage devices and enhanced formats. Special attention therefore should be given to the ownership and safety of data.

Large gaps, however, remain in the documentation storage scenario. These are mainly related to nonsensor-based or nonautomated data acquisition processes:

- *Worker identification* in common and especially in regard to hazardous agents or implements
- *Implements without electronics* in tractor–implement combinations following the ISOBUS
- *Agents* for seeding, planting, fertilizing, and plant protection
- *Yield sensors* in all of the used harvesting technologies
- *Soil stress and soil compaction* caused by field work under suboptimal conditions or created by improper tires or tire inflation pressure or by too high axle loads (Demmel et al., 2008; Hemmat and Adamchuk, 2008)

Consequently, the data where failures will occur are generally manually acquired, as humans are never perfect:

- *Forgotten* in times of heavy workload or at the end of a long working day
- *Wrong figures* either as wrong or unclear reception or willfully done to hide the right ones
- *No perception*, regarding certain items such as soil damage or soil crouching
- *Others*

Finally, thorough data records document attempts to perform farm work more precisely, to fulfill community laws and regulations, to achieve the required quality items in field operations, and to trace products back to the field and plot, if required (see Chapter 9 of this book).

## 10.4 CROP MANAGEMENT

Advanced agricultural technology, new sensors, data processing, and powerful software systems may be seen as the key elements of site-specific crop production and crop management (Auernhammer and Schueller, 1999; Schueller, 2002). These elements were first driven by profit maximization, mainly focusing on yield and fertilization; today, environmental issues gain higher importance (Bongiovanni and Lowenberg-Deboer, 2004). In this way, the ideas and possibilities of this concept are provided to conventional as well as organic farming systems, even though in the latter precision farming is still not the mainstream and many constraints can be observed.

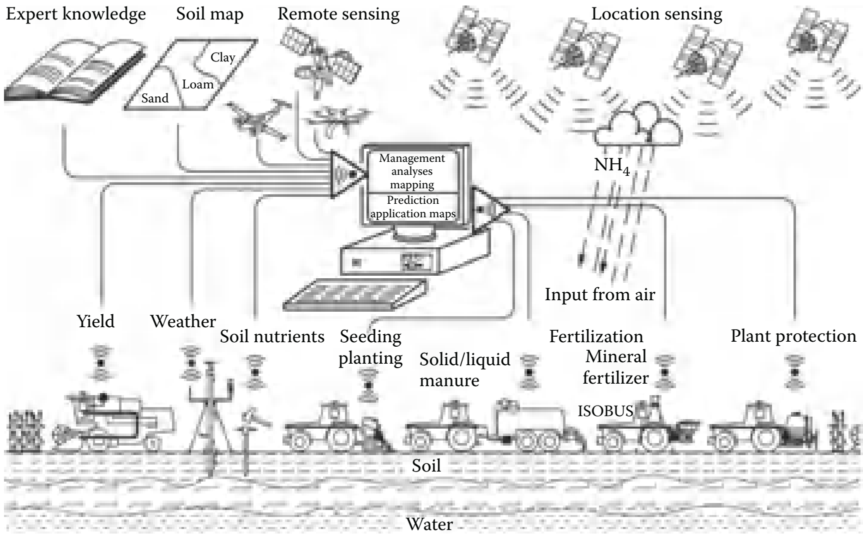


**FIGURE 10.8** Site-specific crop management in precision agriculture. (Adapted from Sommer, C. and H.-H. Voßhenrich. 2004. *Managementsystem für den ortsspezifischen Pflanzenbau. Verbundprojekt pre agro*, Darmstadt, Germany, Chap. 4: 121–150, CD-ROM 43013, http://www.preagro.de/Veroeff/Liste.php3.)

Crop management covers the whole plant growing season with tillage at the beginning, and seeding or planting, followed by application measures of fertilization, plant protection and irrigation, and, finally, with the harvesting of grown plants (Figure 10.8).

However, the use of precision farming technologies today differs widely in crop management activities.

### 10.4.1 Tillage

Although tillage has not been long in the focus of precision farming applications, a number of utilities have been applied to tillage measures, and spatial variable tillage (by intensity and depth) has been investigated and discussed.

GNSS-based automated guidance of tractors has the strongest influence on the optimization of tillage. Its main goal is to avoid overlapping or gaps. Different investigations have shown that overlapping can be reduced by 5%–10%, and the relative figures increase with smaller working widths. Further, changed turning regimes—wide U-turns with skipping passes instead of swallow tail turns—will reduce turning times by one-third. This increases the field efficiency on short fields and with small working width (small-scale farming). The possibility of combining automatic steering with headland automation of tractors increases these effects and reduces the workload.

Some investigations have tried to evaluate the effects of site-specific primary tillage, varying the tillage depth according to soil type and soil moisture (Figure 10.9). While soil type does not change over time, soil moisture is a variable and, today,

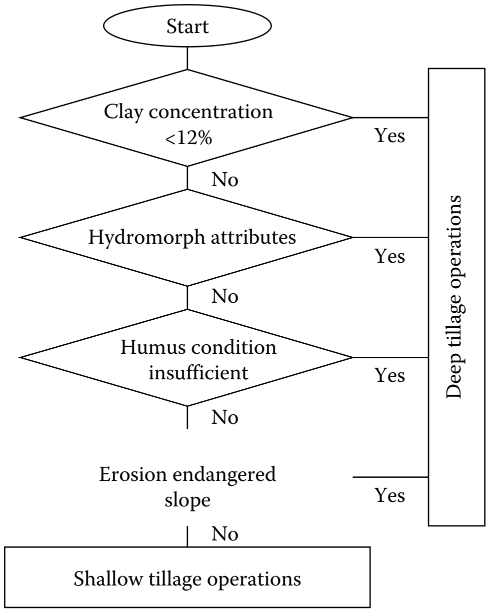


**FIGURE 10.9** Algorithms of site-specific primary tillage. (Modified from Sommer, C. and H.-H. Voßhenrich. 2004. Soil cultivation and sowing. In KTBL (Ed.), *Managementsystem für den ortsspezifischen Pflanzenbau. Verbundprojekt pre agro*, Darmstadt, Germany, Chapter 4: 121–150, CD-ROM 43013, http://www.preagro.de/Veroeff/Liste.php3.)

hard to measure on-the-go. Therefore, the adoption of site-specific tillage first needs reliable soil moisture sensors.

The rise of controlled traffic farming, a farming strategy concentrating all field traffic on permanent tracks and for the first time discussed in the 1980s, was facilitated by minimum till and no-till technology and the availability of automatic guidance systems for agricultural machinery. Although it is an entire system, it will be mentioned here (Demmel et al., 2012a,b).

### 10.4.2 Seeding and Planting

From the very beginning, seeding and planting have been the processes with the highest requirement for precision. They constitute the fundamentals of a crop stand. Traditionally, markers have been used to accurately align passes while travelling the field. In advanced plant production systems, during seeding, track lines laid out by multiplying seeding implementation widths are established, matching the working width of the application technology. In manually guided seeding, those track lines show, in the average, overly narrow distances up to 8% of working width, and also show the higher overlapping caused by increasing slope.

Besides tillage, seeding and planting are increasingly being carried out with the assistance of GNSS guidance systems. This makes sense, with the increased working width of seeders and planters in both the rear-mounted and the trailed tractor implement configuration. Parallel passes with this technology will come to a precision of ±0.02–0.05 m in flat areas and under nonslippery soil conditions. Pass connection errors are usually smaller with rear-mounted equipment, as the position of the location sensor is still close to the implement and might also be reduced in the tractor implement geometry stored in the ISOBUS controller.

With trailed seeding and planting combinations, the seeding/planting tools are a long distance from the tractor-mounted location sensor. Consequently, under unfavorable conditions, the pass-to-pass errors increase. An additional location sensor at the implement can optimize the guidance of the tractor to overcome this problem. Another possibility is a second active steering system with a GNSS receiver at the implement.

GNSS-based position location also allows for section control of seed drills or planters, a function that automatically switches the whole metering unit, or sections or single rows of a planter, on or off at the headland to avoid overlapping. This function not only reduces seed costs, it also improves plant growing in critical areas at the headlands and makes harvesting easier at the end of the season.

Based on soil type and topographic (three-dimensional) maps, farmers tend to vary plant density, especially during planting. Electronically controlled electric drives of the metering units of modern planters and seed drills make the adaptation of the seed rate to changing conditions in the field possible, either manually by the driver or based on maps. These technologies also allow for equal-distance planting in areas with a triangular or rectangular geography. In the future, weeding and even pest control may simply be taken over by small autonomous field robots working across the field or following weed spots. Even single plant husbandry would become possible in this planting design.

### 10.4.3 Application in Fertilization

Following local yield measurements in combine harvesters and georeferenced soil sampling, site-specific fertilization was a very quickly adopted implementation (Auernhammer et al., 1999). From a systematic point of view, there are three different approaches to master this new challenge and possibility (Auernhammer et al., 1999), as shown in Figure 10.10.

#### 10.4.3.1 Fertilizing by Balance

Based on local yield measurement from the previous harvest combined with soil nutrient sampling and analyses at the beginning of the vegetation, a highly reliable estimation of needed nutrients related to a nutrient balance can be achieved. It may be called "farming by balance" or, nowadays, "prescription farming." Additionally, long-term information from the historic data of a field can be taken into estimation. But whatever decisions are taken, this concept mainly focuses on "one-treatment only" applications, as any changes within the growing season cannot, or can only be included with low reliability, into the final determination. This approach is dealing with basic nutrients (P, K, Ca, etc.), one application of nitrogen only, the choice of the mostly beneficial crop variety, and the adjacent needed/preferred chemicals. Fertilizing operations then are based on application maps and appropriate application implements.

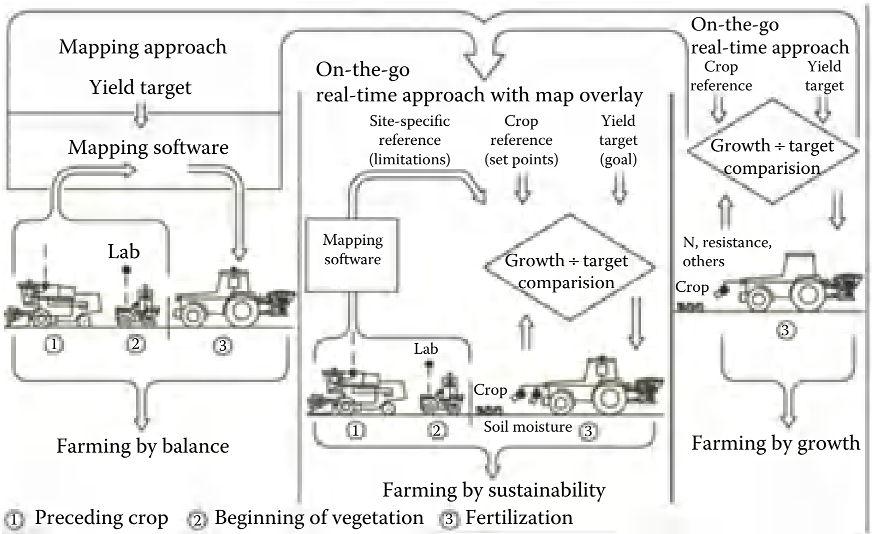


**FIGURE 10.10** Theoretical approaches of site-specific fertilization.

Application maps are typically grid-based. The grid size is limited by either the working width of the spreader (it makes no sense if narrower) or by the section width when section control is available. Application maps may follow definitions in an ISOBUS system or might be in a proprietary format related to the used spreader controller. Application implements may be either spin spreaders or air spreaders, while spin spreaders usually have no section control units or a maximum of two section control units, and can deliver only one fertilizer type, either a single or a mixed nutrient agent, according to the required nutrient application. Control of the required distribution amount strictly follows the map and causes more rapid rather than smooth adjustments. Highly precise dosing is possible when the controller takes care of the time of flight in relation to the distributed material, adjusting the required amount of output prior to the map-based boundary. Nonuniform driving speeds cause less precision.

Air spreaders support section control but still follow the above-stated principles in distribution. Additionally, there is an extra influence from curved application tracks. This curve may be integrated into the control algorithms if path planning information is available to the application map. Otherwise, under- or over-application at the boom ends is unavoidable. Moreover, on-the-go nutrient mixing is an option available through a multibin design of the spreader (Peisl, 1993), shown in Figure 10.11.

### 10.4.3.2 Fertilizing by Growth

Whenever multiple applications deliver benefits, for example, avoiding overfertilization and allowing a reaction to unforeseen weather conditions, the growth factor has to be included in application management. This is the case in nitrogen fertilizing and especially under humid conditions with unpredictable rainfall. Under these conditions, the needed amount of fertilizer at a certain time results from the difference between the aspired growth target and the on-site growth situation.

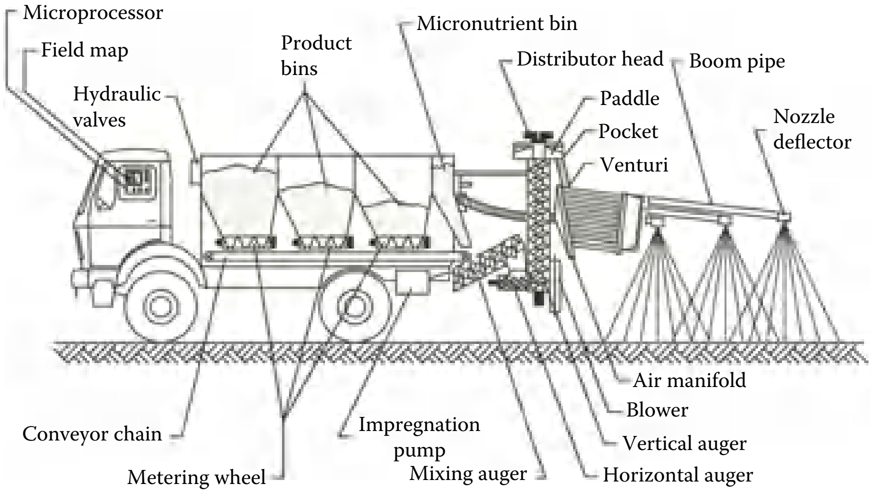


**FIGURE 10.11** Design of a truck-mounted multibin fertilizer air spreader.

It is well known that the greenness of crops is an indication of the amount of chlorophyll and it is also well known that there is a very close correlation between chlorophyll content and nitrogen uptake, as chlorophyll mainly consists of nitrogen. Therefore, a greenness or chlorophyll sensor could give the needed information to determine the required amount of nitrogen derived from a standardized growth development curve of a specific variety with respect to the expected yield.

This type of precision fertilization is well adopted (Table 10.6), especially in Europe, with split nitrogen fertilizing strategies in three to four applications.

There are more than 1000 systems in operation in Europe (as of 2014) with an average field capacity per system of around 4,000 ha/year. The standard control procedure adds more nitrogen to those parts of the fields with lower biomass; this is often changed to the opposite for the last dressing. The majority of the systems take

**TABLE 10.6**
**Crop Growth Sensors in Nitrogen Fertilizing Systems**

| Sensor Type | Principle | Vegetation Index | Wavelength | Algorithm | Fertilizing System |
|---|---|---|---|---|---|
| Yara N-Sensor | Passive | S1, S2 | Confidential | Yes | Online |
| Yara ALS | Active | S1 | 730, 760 | Yes | Online |
| CropCircle 430 | Active | NDVI, WDVI | 630, 730, 780 | No | Online |
| GreenSeeker | Active | NDVI | 656, 774 | No | Online |
| Isaria | Active | IRMI | Confidential | Yes | Online with map overlay |

*Source:* Adapted from Maidl, F.-X., A. Spicker, and K.-J. Hülsbergen. 2014. *LfL-Schriftenreihe Heft 7, Neue Techniken im Ackerbau,* Hrsg.: G. Wendl. Bayerische Landesanstalt für Landwirtschaft, Freising, Germany, pp. 63–74 (ISSN 1611–4159).

control of rear-mounted spin spreaders through proprietary data link interfaces. The sensors are typically mounted at the cabin roof of the tractor in a fixed position through the growing season with simplified cabling, and normally there is no location sensor.

A more detailed assessment of the aims using those online systems delivers four different strategies (Leithold, 2014):

- Yield maximization in more than 50% of use with the risk and the acceptance of overfertilization and also with extended fertilizer costs.
- Quality optimization in about 30% improving the protein content.
- Crop harmonization in about 10% to get higher harvesting performance.
- Manual overcontrol in about 5% when soil properties are known or visible on-the-go.

Today, manufacturer-specific control algorithms cover the main cereal crops, including maize and rapeseed, and long-term investigations into their use with potatoes and other root crops have also started.

Wireless data transmission, integration into the ISOBUS standard, and the use of the ISOBUS user terminals (UT), follow the efforts using standardized electronic communication systems and allow a simple sensor movement to other tractor–spreader combinations. Location sensing can be used with the ISOBUS to allow the generation of "as-applied maps" via the task controller (TC).

#### 10.4.3.3 Fertilizing by Sustainability

Compared to manually controlled nitrogen application, any growth sensor replaces the "eye of a farmer" only where all his field experience and knowledge is sidelined. In a sustainable system, therefore, the "farmer's brain" must be included into the set-point definitions together with long-term spatial field data such as soil type, topography, local yields, soil resistance, rain fall, and others. This requires a sensor with a map-overlay system, which is able to make an adjustment of the growth sensor signals either given as a function of statistically well-confirmed dependencies or by well-established agronomical rules of interactions (Figure 10.12).

The final set point of the required local application can be derived through sensor fusion. When integrated into the ISOBUS standard, this technology could widely be used in mineral fertilizing as well as in organic fertilizing, pest management, and in seeding and planting (Ostermeier, 2013).

#### 10.4.3.4 Organic Fertilization

Besides mineral fertilizing where farmers always try to make the most precise application, organic fertilization remains in the background. This might be acceptable in manure spreading as this type of organic fertilizer may be seen as a soil agent improving the organic matter in the soil and contributing to the stabilizing of humus. But in conjunction with slurry, known as a rapid effective nitrogen fertilizer, it is inadmissible. Besides, the indispensable requirement of highly precise pass-to-pass operation using two different solutions can be seen at this time:

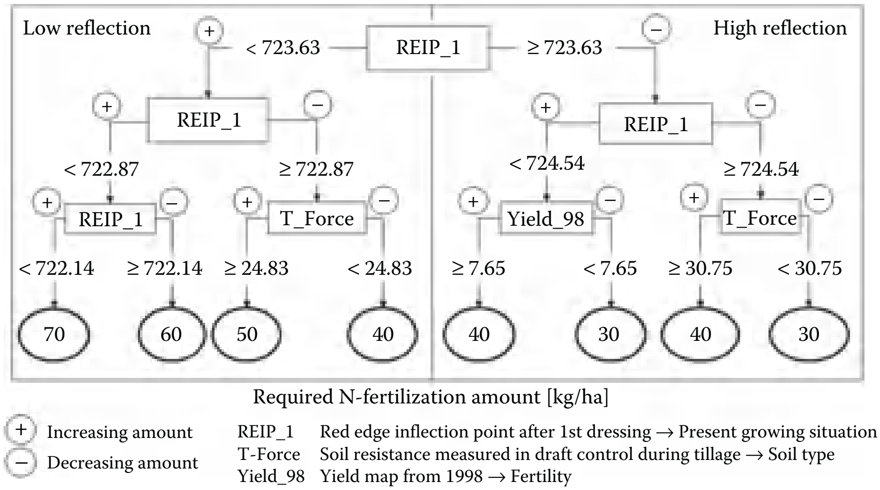


**FIGURE 10.12** Decision tree formulating site-specific nitrogen requirement through data mining. (From Weigert, G. 2006. Data Mining und Wissensentdeckung im Precision Farming-Entwicklung von ökonomisch optimierten Entscheidungsregeln zur kleinräumigen Stickstoff-Ausbringung. Dissertation: Technische Universität München, Professur für Unternehmensforschung und Informationsmanagement, Freising-Weihenstephan, Germany, http://mediatum.ub.tum.de/?id=603736. With permission.)

- Uniform or even site-specific spreading of manure may be based on wagon platforms with weight sensors together with a variable hydraulic drive to feed the manure to the spreading unit according to the planned application rate. Either homogeneous or site-specific application may be addressed in this way.
- In slurry application, on-the-go measurement of the flow rate and the nitrogen content is essential. NIR sensors show good results (Reeves III and Van Kessel, 2000) and allow precise nitrogen application in the field, as is followed in the management of mineral nitrogen fertilizer. Also, P and K contents may be introduced into a more precise slurry application.

Again, also in organic fertilizing, location sensing is a must to be able to create "as-applied" maps for long-term improved field management.

#### 10.4.3.5 All-in-All

Fertilization, especially site-specific nitrogen fertilization, can be seen as the most advanced precision farming technology at the field level today. Depending on given situations and related to nutrient requirements, "well predicted one application only" or "growth adjusted multiple" operations can respond precisely in a site-specific manner to avoid overfertilization with leaching, as well as to avoid underapplication, which causes yield losses. Nevertheless, some problems at the farm level can still be seen:

- Prediction of fertilizer amounts often follows simple balance attempts where historical field data are neglected, or due to data handling, are not available.

- In multiple application strategies, growth sensors offer a high potential through real-time crop state measurement but are still restricted to cereals. Application algorithms cover selected plant varieties only and in most cases a calibration at the field is required.
- Application implements are able to guarantee highly precise dosing with section control. Precise pass-to-pass operation prevents overlapping, but in nonlinear field structures, under and over supply takes place when no pass planning information or true look-ahead direction sensor is part of the system.
- Application control based on application maps normally generates stepwise set-point adjustments with no smooth and therefore no natural transitions.
- Sensor fusion with historic field data in systems with growth sensors are still an exception.
- Data communication in tractor–spreader combinations often is proprietary and forces the farmer to stay with the established system, having no choice to replace either the tractor or the spreader without new problems and open questions.

### 10.4.4 Application in Plant Protection

Contrary to fertilization with a wide range of specific strategies to rate the necessary amount of nutrients in relation to an established yield target, non-GMO plant protection measures can hardly be determined in advance. Treatments regularly take charge when monitoring shows an infestation greater than a defined threshold, or when spot-wise critical expansions of weeds, insects, or fungi are observed. In other words, plant protection either means monitoring in the first stage, or neglecting the given situation and following well-established recommendations with homogeneous whole-field treatments.

#### 10.4.4.1 Monitoring

When farm and field sizes grow larger, thorough and accurate monitoring requires an exponentially increasing time when no dedicated aids or tools are available. Thus, comprehensive research activities have been carried out worldwide to close this gap, by looking for sensors and on-the-go weed detection methods on tractor–sprayer combinations or on autonomous vehicles or unmanned aerial vehicles (UAVs) (Thorp and Tian, 2004; Sankaran et al., 2010; Zhang and Kovacs, 2012; Pérez-Ruiz et al., 2015). At the field level, however, few of these solutions can be found.

Besides governmental organized or extension-based plant monitoring activities covering all major crops and all important plant infestations, on-farm monitoring with sensors in combination with the sprayer is starting to be adopted:

- Tractor mounted or spray boom-located NIR-based growth sensors are used to detect local biomass and apply more agents in dense crop standings and in the opposite way during whole-field treatments.
- Also, tractor-front-mounted plant-density sensors are used to react in a similar way.

#### 10.4.4.2 Application

Owing to the development of powerful herbicides, fungicides, and insecticides, chemical plant protection has played and continues to play a key role in the development of modern agricultural plant production. Application technology has followed this trend. Its performance was increased by wider spraying booms, larger solution tanks, and faster working speeds. Application rates have been dramatically reduced, increasing the requirements on a precise allocation. Electronics became the most appropriate technology and today they are integrated in nearly all sprayers in "developed" plant production regions.

Electric three-way or by-pass valves regulate the liquid flow in a closed-loop control system according to the required spray pressure with regard to nozzle type and application rate. Radar velocity sensors or speed data from GNSS receivers provide slip-free true ground speed information. Position data from GNSS receivers also allow for electronic section control based on application maps. Boom control requires more attention with wider spraying booms in rough and hilly fields as well as when working at higher speeds. In this case, high-performance sprayers include distance sensors in the boom sections to facilitate active hydraulic or electrical boom distance control, and active boom suspension.

With trailed sprayers and nonlinear field structures, sprayer wheels might destroy additional plants when no action is taken to guide the sprayer within the tractor path. Precision sprayer track-guidance measures tractor steering and actuates with adjusted guidance activities in the sprayer drawbar. But nevertheless, even with sprayer track control, curved passes result in under- and over-application at both boom ends if the pass direction is not integrated into the control algorithms and/or driving speed is too high in relation to control time delay and nozzle adjustment time. An example is shown in Luck et al. (2011), where during spraying with a single nozzle control in irregular field shapes of a total of 185 ha, nearly 20 ha received less than 90% and nearly 13 ha more than 110% of the target rate.

And finally, as described above, NIR-based single nozzle control can become a part of the site-specific treatment that controls the output volume in accordance with the locally sensed crop biomass. Or the sensor signal can be used to create local overcontrol in accordance with predefined site-specific application set points.

#### 10.4.4.3 Mechanical Weeding

In cereals, nearly half of the chemicals are used for weed control. From an environment-friendly standpoint, most of the pesticides could be replaced by mechanical weeding. On the one hand, vision-based implement guidance is available and mainly used in row crops or in cereals with wide row distances; typically, organic farmers use this technology more often than the conventional ones. On the other hand, GNSS-based RTK implement guidance is available. Both technologies allow for interrow weeding whereas in-row weeding still suffers.

#### 10.4.4.4 All-in-All

In general, all of these electronic and sensor-based control prospects offer highest precision during application of chemicals at the field level. But in the future, these treatments have to be improved by more localized information. Ongoing development of in-field monitoring therefore is the key to environmentally sound plant protection measures with the following challenges:

- Any manual monitoring is time consuming and requires very special knowledge.
- Adapted sensor technologies related to a fast and clear identification of weeds, fungi, and insects are still not available.
- Autonomous air-based or land-based platforms for such sensors are not available or have problems in use at the farm level.
- Also, monitoring systems with cognitive capabilities to identify and maintain spots with different propagations in the right way may not be available today.

Further improvements in spray technology are required, such as

- Spray booms with a steady adjustment to the crop surface with no lateral and horizontal deviations even at higher driving speeds, on rough or hilly surfaces and also under nonlinear field conditions.
- Direct injection systems (Peisl et al., 1992) with infestation-specific treatment.
- Integration into the monitoring equipment with site-specific or plant-specific handling of microagents and newly developed physical or electrical treatment possibilities.

And finally, more attention should be given to mechanical weeding in newly designed field cropping systems (Demmel et al., 1999) together with autonomous vehicles in interrow, in-row, and also at single plant surroundings (Slaughter et al., 2008).

When taking all these different aspects into account, it might be concluded that, contrary to precision fertilization, future environmentally-friendly, sound, precise, site-specific or even plant-specific, plant protection is a long way off. And also, GMO crop farming in monocultures with specialized monoculture agents will not be able to overcome foreseeable problems.

### 10.4.5 Application in Irrigation

While just 15% of all arable land in the world is irrigated, this land generates nearly half of the value of all crops sold (UNESCO, 2007a). Worldwide agriculture (and horticulture) accounts for over 85% of water consumption (UNESCO, 2007b). It is expected that irrigated areas and water consumption will increase by 20% by 2025.

Irrigation systems can be divided into gravity-based (flooding furrows or entire fields) and pressure systems (sprinkler systems and drip irrigation). Worldwide, about 94% of irrigated land is under gravity irrigation. In the United States, about 50% of the irrigated land is under gravity irrigation; the other 50% is irrigated by pressure systems. Owing to the fact that agricultural irrigation accounts for the largest part of water consumption worldwide, different attempts have been made to increase water efficiency (Demmel et al., 2014). Based on the development and adoption of precision farming technologies in crop farming, ideas of precision irrigation and site-specific irrigation have also been discussed and investigated. Unfortunately, their application is limited to pressure irrigation systems. Two steps or levels can be distinguished, improved and automated irrigation control and site-specific irrigation.

#### 10.4.5.1 Irrigation Monitoring and Control

In many cases, irrigation is controlled manually based on the experience of the farmer. Often, the applied amount of water is controlled only by the time the equipment (pump and sprinklers) is running. In a first attempt, the installation and use of a water meter significantly improves the accuracy and efficiency of irrigation. Furthermore, systems have been developed, investigated, and evaluated that increase water efficiency by using simulation models based on the Penman–Monteith equation (extended by local weather data from small electronic on-farm weather stations) or soil moisture sensors (Noborio, 2001), or a combination of both (Figure 10.13).

The development of fast-reacting, low-maintenance, and low-cost soil moisture sensors is still in process due to the fact that it is difficult to combine all three features. Besides, wireless networks are needed to cover the whole irrigation area with soil moisture sensors. In larger center-pivot or linear-move irrigation systems, these models are combined with ECUs for the pump, the valves, and the automation drive.

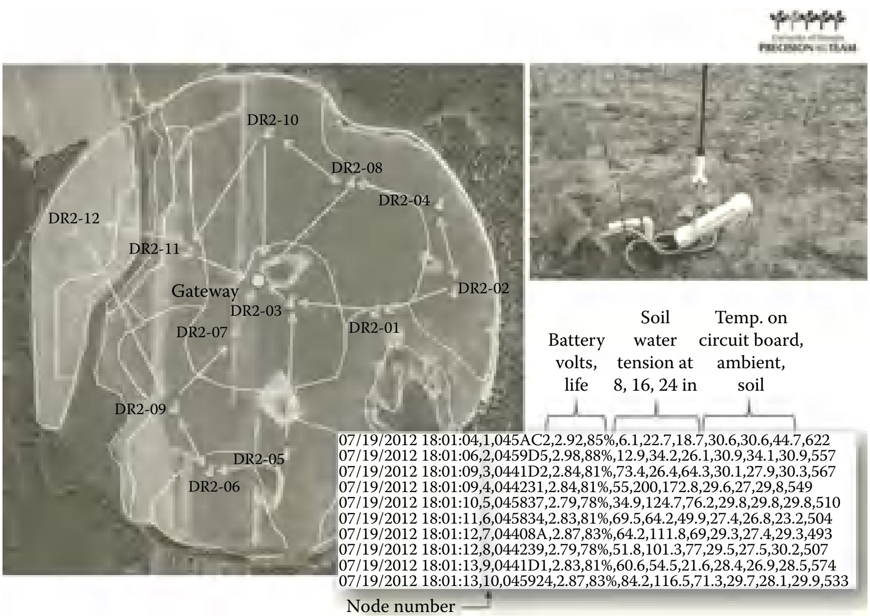


**FIGURE 10.13** (**See color insert**.) Irrigation soil sensor network. (From Vellidis, G. 2015. Irrigation sensor network. Personal communication on teaching material, January 14, 2015. With permission.)

These control units include comprehensive monitoring and visualization functions that give the user instant information about the system, and the applied amount of water on the farm PC, or a smart phone, and also send an alarm if a malfunction is detected. The automation of center-pivot and large linear-move irrigation systems is characterized by continuous and intensive development.

#### 10.4.5.2 Site-Specific Irrigation

Owing to the fact that soil heterogeneity also influences soil water balance and creates the need for irrigation, the observation of high soil heterogeneity within a center-pivot circle with a diameter of 400–500 m has been carried out and systems for spatial variable irrigation have been developed and investigated (Evans et al., 2013). This technology, called “site-specific variable rate irrigation” (SS-VRI) has been commercially available for center-pivots for several years, but its adoption by producers has been on a very low level. It is expected that higher costs for irrigation water, water scarcity, and the implementation of economic incentives for compliance with environmental or other regulations, will potentially provide the necessary incentives for much greater adoption of various advanced irrigation technologies.

### 10.4.6 Harvesting

All actions the farmer takes during the growing season are aimed at contributing to high yields, attaining the required quality, and delivering the outcome with marginal losses at the right time and at the lowest cost. To increase efficiency and to reduce costs, harvesting technology is increasing in size, tends to be very specific to the harvested crop, and becomes highly complex. To realize this progress in the field, there must be either higher qualified operators or more electronics and well-designed control capabilities with a high degree of automation. The increase in size and performance, and extended control and automation can best be implemented with self-propelled machinery concepts.

#### 10.4.6.1 Guidance

Large harvesters enable highest performance when driven within the genuine working width or very precisely along given rows to avoid cutting losses or overlapping. Operators are challenged by this the whole day and sometimes even during the night, with no decrease in concentration.

Especially in row crops such as corn, silage maize, or sugar beet, mechanical row guidance sensors became standard equipment and are used more than 80% of the operation time. More recently, with the increasing header width of self-propelled combine harvesters, edge detectors were adopted to guide these machines along the edge of the standing crop with accuracy better than 10 cm. Similarly to row sensors, these sensors are also part of today’s harvesting technology and need no calibration and no additional infrastructure in the field (Figure 10.14).

Today, high-accuracy GNSS-based guidance systems (RTK) are used on harvesting equipment as well. These guidance controls are not influenced by laying crops and also allow for skipping passes with reduced turning times and less soil compaction at headlands.

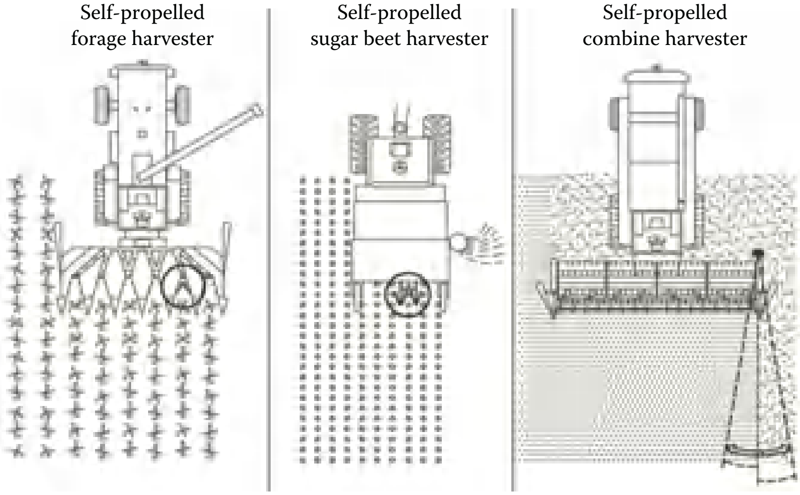


**FIGURE 10.14** Row and edge guidance sensors in self-propelled harvesting machinery.

More precise work recently became possible by utilizing guidance systems in transport vehicles in silage maize harvest operations (Europe) and with grain carts unloaded on-the-go. Precise parallel speed adjustments of both vehicles in this case avoid material loss. Together with additional optical sensors measuring the filling situation an adjustment of the loading device (spout) always allows perfect loading of the transport unit.

#### 10.4.6.2 Operation Control

Large-capacity harvesting machinery allows maximum performance and precise work with low losses only when internal process units are well adjusted (Schueller et al., 1986) and in harmony with their neighbors. Preprogrammed adjustment tools, mainly in combine harvesters, enable manually activated employment of the harvester related to the coming crop. Site-specific control improvements can then be stored over a period of time and used for future operations. More recently, these field-specific control adjustments have also been transferred in real time to combines from the same manufacturer and of the same type (members of a group or swarm in a leader–follower concept) through wireless communication.

Besides guidance systems that give more freedom to the driver and allow more time for machinery observation and control, constant material throughput with less variation is realized by so-called cruise control systems optimizing all separation and cleaning processes. This advancement can be seen as an important and helpful supplementary feature, either following a control strategy to get maximum throughput under time restrictions, to optimize the output quality, or to minimize losses.

#### 10.4.6.3 All-in-All

Never before has such huge and mainly self-propelled harvesting machinery done as comparable a job as it has done today. A wide range of different sensors, high-performance control algorithms, and fast and finely adjustable actuators allow for this, and will also be able to improve further:

- In-machine unit optimization relating to previously collected site-specific preinformation from parallel tracks. Site-specific information may even come from spatial soil data or from inclination maps (Bishop and McBratney, 2002). This information may be used to optimize cleaning at the sieves in combine harvesters or to empower soil separation from root crops more intensively or more smoothly.
- Besides locally diverse variations in crop quality and even with an increasing working width, the quality of the harvested crops may differ more widely. Therefore, because of product as well as of cost reasons, selective harvesting and on-the-go division of low- and high-quality composition such as protein or starch would be an option.
- When harvesting under wet conditions, soil compaction is a major issue in environment protection. Optimized tires or rubber belt undercarriages are a first option.
- However, one limitation may be that overcollection of material in the hopper or tank in relation to an on-the-go operation measured by soil moisture value may be seen.
- Also, the continuing growth of harvesting technology might be questioned. Unmanned followers—all in smaller size—are able to increase the overall performance of an operator and may even be easily adapted to different operating conditions such as field size, field shape, topography, and others, but will still be under manual control.

## 10.5 MACHINERY MANAGEMENT

Cost-efficient utilization of farm machinery requires time-critical logistics to guarantee that any needed equipment with an appropriate performance will be at the right location at the right time with no breakdown. While this requirement has lower importance on family farms with widely seen overcapacities, it is a "knock-out criterion" in large-scale farming as well as in a contractor work organization.

### 10.5.1 Route Planning

Specialized very high-priced machinery tends to be increasingly used in cooperation as well as in so-called machinery rings or in most cases worldwide, by contractors. But independent from the organization, the main target is "to fulfill the required task in the right time," which is very difficult in areas with identical or very similar conditions.

A good example of this may be "planting of sugar beet," as planting has to be done as early as possible to achieve a long growing period. Also, beet will gain highest yields only in the best soils, which are typically found in a narrow area. Furthermore, there is no point of ripeness, which means beets should be in the soil as long as possible. From a farmer's business point of view, beet should grow as long as there is no frost, but from the sugar mill point of view, the request is to start as early as possible with processing to arrive at a long processing time with lowest costs per sugar unit. In other words, in a certain region, planting should be completed on one day and consequently all operations during the growing season will fit the same requirement, whereas any delay in any operation will lead to a decrease in profit and/or quality.

In similar operations, only very detailed route planning in agreement with all the involved farmers, including different pricing, will be successful (Figure 10.15).

Any mission depends on

- Available georeferenced field data with additional field metadata according to the required process or, if "unknown," specific GNNS-based field inventory and recording of field metadata. In both cases, the field traffic situation with road condition and restrictions is additionally required.
- Job schedule or flow diagram based on farmer's time preference, field sizes, in-field conditions, field-to-field distances, road conditions, working time per day, and many others.
- Single or multiple job execution, including either groups of similar machinery or the machine executing the leading task together with required transport units and associated facilities.

Several systems are available and used for optimization with highest possible precision in two different ways:

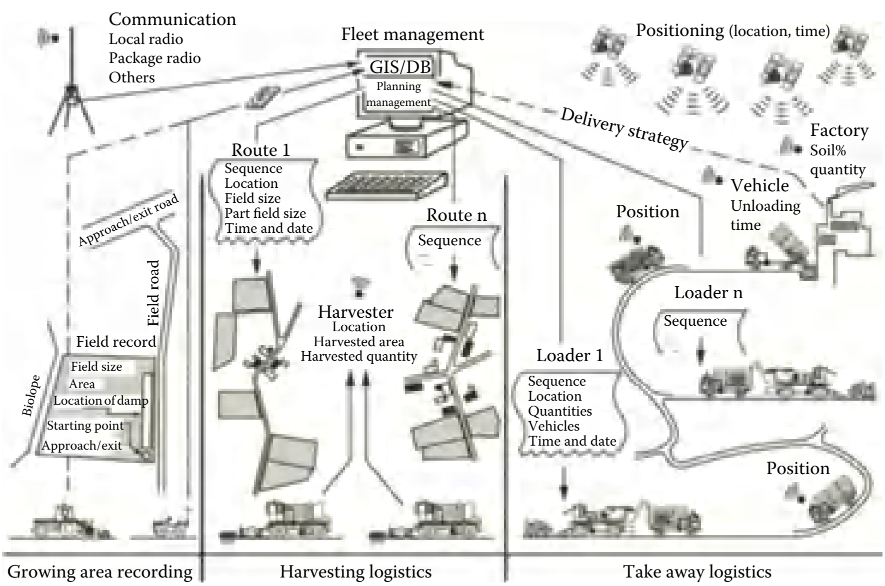


**FIGURE 10.15** Route planning in sugar beet production.

- Operator-driven systems (contractor, cooperation, and large-scale farm) focusing on the optimized utilization of the available equipment to fulfill all required field tasks in a limited time with as little as possible idle time and minimized timeliness costs.
- Processing industry driven to keep the plant running, for example, in sugar beet, sugarcane, vegetables, starch potatoes, and others.

Also, route planning systems for combinable crops are of great importance following the maturing of small grains on strictly planned routes from south to north first and repeating this way for corn harvesting later in the northern hemisphere or vice versa in the southern one. Great attention has to be given to the end of the period as, often, weather conditions become insecure and fast changing.

### 10.5.2 Process Monitoring

Existing sensors in the machinery with GNSS receivers and telecommunication equipment together with GIS and on-screen software allow for centralized or decentralized real-time monitoring of any mechanized field work. Thus, at any time, machinery settings as well as the work progress can be observed. With well-adapted actions it will be possible to

- Confirm the instantaneous work situation being in a good fit with its machinery performance to the required field task and with the workflow in comparison with the previous established work schedule.
- Discover possible/necessary improvements in the machinery settings to gain more work progress and possibly compensate for a certain work flow delay.
- Be aware of an earlier fulfillment of the ongoing field operation with consequences to the work schedule of the day, the worker, or the engaged machinery.
- Detect and document any misuse or wrong use by time and location especially when untrained or less trustworthy workers are engaged.

Related to transportation tasks on rough field roads and/or heavy loaded public roads, the monitoring of multiple transportation units mainly during harvest of a huge amount of biomass (e.g., silage, sugarcane, and sugar beet) provide benefits as

- Transport capacity in number of units can be easily adapted to the required task.
- Unexpected traffic situations can be compensated for by altered navigation or to extended transportation units.
- Any idle time of the harvesting unit(s) may be eliminated to fulfill the field task within the scheduled time.

In summary, process monitoring of machinery used in a single task, or associated to clusters of similar machinery, or in combination with transport units, gains benefit through reduced idle time in the whole process as well as in any of the connected units. Also, unexpected situations can be easily seen, action can be immediately taken, and the total work can be undertaken in conformity with the work target and work schedule.

### 10.5.3 System Control

While route planning and process monitoring focus on "what should be done" and "what happens," system control focuses on "how it should be done." System control mainly concentrates on harvesting with a (large) fleet of harvesters, grain carts in the field, and a fleet of transport units. The most critical challenges occur while changing from one field or one harvest area to another. While the harvest has to be finished in a way so as not to run the whole fleet to an abrupt stop, the movement of the equipment has to be initiated and the harvesting of new fields has to be prepared and started in a way that the nonproductive time of all the equipment is minimized.

Still, this type of fleet management rests upon well-experienced human skills, but increasingly fundamental research and simulation is on-the-go and will soon come to the field level.

### 10.5.4 Remote Service

This section looks mainly at the machinery itself. Machinery manufacturers in particular show a very high interest in any solutions to problems or feedback with regard to their products. This can be achieved, first, by gathering field-level data according to a certain technology for further improvement and development, and second, by providing maintenance proactive services and repair, to avoid breakdown and idle time. The system approach is based on permanent or intermittent machinery data acquisition and transmission to a centralized database with access for manufacturers, dealers, service providers, and also contractors and/or farmers (Figure 10.16).

A system such as that described above is required by advanced engineering at the manufacturer's level as well as by service providers, as comprehensive and realistic field use data have not been available to

- Discover weak structure or design points in machines
- Provide the settings under different conditions
- Monitor different loads at specific in-machinery locations
- Analyze running time and load spectra
- Create more advanced maintenance information material and service instructions
- Develop improved and field-level designed replacement technology

On the other hand, farmers have some constraints when it comes to offering their process data to manufacturers, gaining no individual benefit and also considering data security concerns. Even when this system seems to be rewarding to all engaged parties, it is very difficult to bring it to the farm level with the required broad acceptance. There may be two steps to going forward.

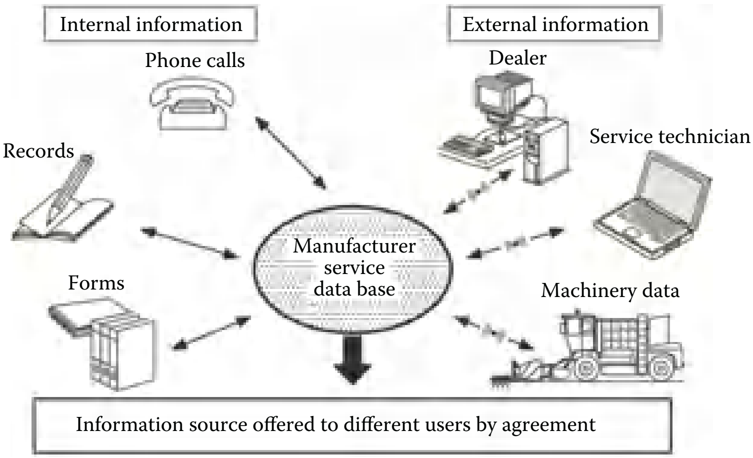


**FIGURE 10.16** Remote service system with manufacturer service database. (Largely modified from Ahrends, O. 2003. Das Serviceformular—Ganzheitliche Umsetzung im Unternehmen. In: Eine gesamtheitliche Teleservice-Lösung für die Landmaschinenbranche, Kapitel 4: 39–53, CD-ROM, ISBN 3-00-011832-2. With permission.)

#### 10.5.4.1 Service Hiring

If users are utilizing the machinery permanently at its maximum performance and are sure to have immediate service and/or repair after a breakdown, they may go into a special service lease contract. In this case, data are part of the contract and have to be transferred to the database without any restrictions. The disposition of the data will also be defined in the contract.

#### 10.5.4.2 Machinery Hiring

Contractors may hire machinery mainly to get the most advanced technology and to avoid unexpected breakdowns through aging or wearing out. In the fulfillment of a contracted guaranteed operational readiness, data become part of the contract and can be obtained by the manufacturer or service provider to the extent and density required.

#### 10.5.4.3 All-in-All

Only optimized machinery management guarantees the fulfillment of any task within time limits and with the required precision. As farmers predominantly tend to avoid risk, they often have overcapacities together with long years of experience in organization and utilization of the owned machinery. In contrast, contractors aim to get maximum performance out of their technology and normally operate with fleets of machines or integrated machinery systems. Besides long-term contracted clients, new clients with no historic information have to be served. Well-engineered management tools are able to support, at the field level:

- Route planning with included optimization algorithms to fulfill any required task at the right place and right time with the required performance. More

specialized tools either assist contractors or concentrate more on the processing industry, for example, in sugarcane processing, to keep the plant running.
- Real-time process monitoring to be well informed about ongoing tasks, to look into the machinery with adjusted settings, to be able to activate improvements through different communication systems.

Additional tools may be seen in research and testing related to optimized system control in interconnected tasks, for example, with harvesting and transport vehicles. Different targets from minimized idle times, maximized task performance, and reduced soil compaction through cost minimization in virtual land consolidation systems (transborder farming) can be observed. Those activities will gain more attention in emerging autonomous field operation systems.

Also, remote service systems can be seen in this context. Mainly driven by manufacturers, less breakdown time might be expected with faster and improved service and repair. Furthermore, field-level experience will lead to improved machinery design to better adjust next-generation developments to the needs of the farmer.

Machinery management was often not identified as an important section within precision farming. But as farm sizes, machinery sizes, and machinery performance grow, requirements in this area are increasing.

## 10.6 LABOR MANAGEMENT

Whatever is accomplished or will be accomplished in precision farming is related to labor, which means human beings. But human beings have different abilities, education, and knowledge; they differ in age; they have different motivations; and whatever work they are doing, in time they get tired. On the other hand, precision farming means doing everything more precisely, even with the differences in human beings and even when human beings get tired. Precise work therefore calls for improved tools and more automation.

### 10.6.1 Tools and Implements

Worldwide, farms of less than 1 ha account for 72% and larger farms between 1 and 2 ha account for 12% of all agricultural operations. Together, these 84% of all farms control only 12% of all agricultural land (Big Picture Agriculture, 2014) and cultivate the land mainly by hand and/or using animals. As in highly mechanized regions with highly sophisticated implements for precise work, better adapted tools could lead to more precise work under these conditions as well. The following examples may focus on tasks for plant production:

- A wheel-guided plow allows for precise working depth in comparison to plow draw bars carried on animal shoulders.
- Seeding with wheel-driven metering devices guarantees uniformly distributed seeds compared to hand spread seeding.

- Fertilizing with any equipment driven by a wheel with material-adjusted dosing facilities minimizes fertilizer input with uniform distribution.
- Plant protection with hand-operated backpack sprayers will apply chemicals more precisely than hand-powdering.
- Finger knife mowers cut laterally more precisely than reaping hooks.
- Rotating mechanical threshing devices achieve better grain separation than flails.

Besides more precise work, all of these examples offer higher performance and often reduce failures, losses, and workload.

### 10.6.2 Guidance Systems

Modern agriculture is dominated by self-propelled machines such as tractors with implements, combine harvesters, and sprayers. All of them allow higher speeds, increased working width, and higher performance with more engine power. But they all have to be guided by drivers, often through long days as well as at night, in dust, fog, and often in very slippery soil surface conditions. So, any type of automation in guidance is very welcome to lighten the load for human beings and to allow a constant output of steering accuracy through a full working day. Available systems used on the farm level depend on the working situation (Table 10.7).

#### 10.6.2.1 Mechanical Systems

Furrow guidance evolved first. Besides unsuccessful work with plows to increase working speed, the main focus was given to tractor rear-mounted interrow cultivators

**TABLE 10.7**
**Guidance Systems**

| Sensing Type | System | Machinery | Acceptance at Field Level |
|---|---|---|---|
| Mechanical sensors | Furrow guidance | Plow<br>Interrow cultivator | No |
| | Row guidance | Maize choppers<br>Sugar beet harvesters | More than 80% |
| Optical sensors | Camera row guidance | Tractor<br>Interrow cultivator | Less, mainly in special crops and in horticulture |
| | Laser edge guidance | Combine harvester | More than 80% of large harvesters |
| GNSS systems | Parallel swathing | Tractor–implement combination | Add-on |
| | Steering assistance | Tractor–implement combination<br>Self-propelled harvesters | Add-on |
| | Auto-steering | Tractor–implement combination<br>Self-propelled harvesters | High |
| | Auto-steering and headland management | Tractor with mounted (front, rear) or trailed implements | Low |

to dispense with the cultivator guide. During planting, a v-shaped plate or a mole-blade established, in a simple way, the guidance furrow; a guidance plate at the inter-row cultivator followed and did a good job if there was no disturbance of the guiding furrow by rain, soil movement, etc. As no high-quality guidance was possible at all and upcoming tool carriers with interaxle-mounted cultivators could be used by the driver alone, furrow guidance systems never gained acceptance at the field level.

While in-field established furrows never guarantee robust conditions, strong-stem plants such as maize can do this. So, with a well-adjusted sensor, application guidance of harvesters along the rows became possible and offered freedom to the driver for either more supervision of the technique, for improving the work quality or to allow more accurate control of the material delivery into a parallel transport unit. A very high acceptance of this guidance system describes the benefit of both, the precise work with the higher performance of the harvester and the optimized loading of transport units.

#### 10.6.2.2 Optical Systems

Camera-based systems still suffer as highly precise guidance is difficult in creating a robust centerline from one or more parallel crop rows independent from wind disturbances in higher crops, by differences in the growth habitat, or by deficiencies in one or all the rows. Furthermore, changing illumination caused by the altitude of the sun as well as shadows, dust, and fog may create problems.

Laser-based edge guidance in combine harvesters is well accepted on the field level. The main reasons from a labor point of view may be seen in fast and simple oversteering in special situations or in laying crops, and in more freedom for accurate control of the increasing complexity and increase in size of modern combine harvesters.

#### 10.6.2.3 Satellite Systems

Today, GNNS-based guidance systems show a fast rising adoption rate due to their high accuracy independent from field conditions, time of day, and other influences. Besides direct integration into new machinery, many retrofitting systems are available and well accepted mainly in tractors. In-field usage is focused on parallel tracking following an A–B line in a linear or nonlinear shape. The overall usage in the field can be seen in three different types:

- Driver-assisted use refers to parallel tracking along linear A–B lines whereas unshaped areas as well as headlands are manually guided.
- Auto-steering means parallel tracking all over the field but not at the headlands.
- Extended auto-steering integrates headland management systems. Until now it is restricted to U-turns but can include down (up) shift, hitch, and hydraulic functions and power-take-off (PTO) engagement, and disengagement.

#### 10.6.2.4 Overall Assessment

Today, the utilization of guidance systems is the most applied precision farming technology worldwide. Also, it might be expected that this trend will continue, very soon covering all larger tractors and all self-propelled agricultural machinery. Also, the trend to GNNS-based systems will continue.

From a labor point of view, all available systems offer secure handling with simple actuation and manual oversteering. Huge benefits may be seen in a formidable reduction of workload and a corresponding increase in comfort.

But headland management systems in small- and medium-scale farming systems with tractor–implement combinations are still challenging. More simplified systems should be used whenever possible to reduce the risk of accidents and damage when turning. However, manual management might be welcome in the field to break the monotony of auto-steering in long fields with less variations and low monitor and control requests.

### 10.6.3 Leader–Follower Systems

Auto-steering opens the door to driverless vehicles, at least inside fields, if a certain kind of observation and fast time intervention is possible. In a first and simple solution, this can be realized in a system where a manned leading vehicle is either followed by or following an unmanned one (Figure 10.17).

There may be two different solutions:

- The follower is of the same type. Through wireless communication, it takes over all settings from the leader. It may also be monitored in the reverse way by the leading driver who would also be able to immediately stop the follower in the event something went wrong.
- The follower is of a different type with a different duty such as a chaser bin working together with the combine and the transport unit. In this case, it is simple to call the follower to the best position, overloading in parallel pass. Later, the follower may go autonomously to the storage unit to unload and

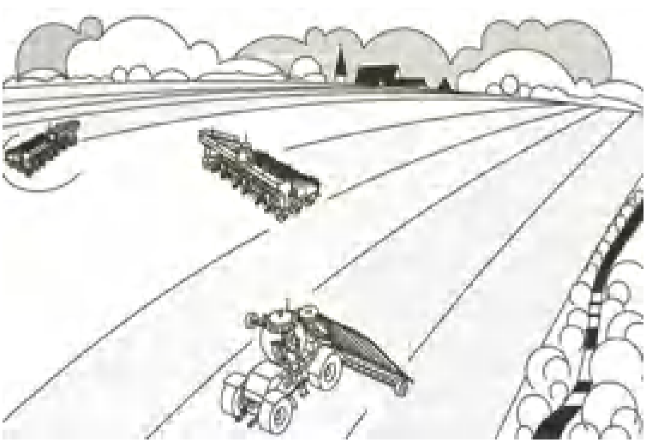

**FIGURE 10.17** Visionary leader–follower system for consecutive tillage and seeding where the leader carries out the most challenging task.

be waiting for the next call. Again, the leading driver takes care of the follower, but as distances will be larger, unexpected disturbances may occur with unforeseeable situations.

In comparison, a leader–follower system of identical type might be simpler, but has not been realized so far as

- Moving vehicles must have a driver on-board by the Vienna Agreement Law from 1948.
- Secure communication links do not exist (spies, hackers, etc.).
- Typical agricultural machinery is of high mass and of high power, so any uncontrollable situations would be hazardous especially when close to public roads or urban locations.
- Instead of less trained drivers on auto-steered vehicles, well-trained high-cost specialists would be required.

### 10.6.4 Field Robots

Leader–follower systems would be able to reduce the labor requirement at the field level by about 50% for one follower and more for multiple followers. The use of field robots could reduce the labor requirement to 10%–20% of the nonrobotic situation depending on the required service and field monitoring tasks and the number of robots. But nevertheless, field robots are moving vehicles and may not be allowed by law. Even if laws and regulations change, two more questions will arise:

- Who wants to take over the overall responsibility of running large and massive autonomous vehicles at the field level with more or less no human attendants?
- What might be the most appropriate target when only small autonomous vehicles are the solution for the mechanization of tomorrow?

From this point of view, a very clear answer can only focus on the circumstances related to the required operations in different fields (Tables 10.8 and 10.9).

Assuming that all of the most important pros and cons are considered, a threefold answer or prospect may be derived:

- There is no expectation to use large and massive autonomous field robots in the near future mainly owing to safety and responsibility reasons.
- Small autonomous field robots do not fit the high power requirements and also cannot carry large amounts.
- Small autonomous field robots equipped with specialized sensor applications or with very specific application tools requiring only easy-to-transport enhancements may be the first accepted solution at the field level.

#### 10.6.4.1 All-in-All

Labor management is one of the most important activities in any business, including agriculture. Besides reduction in time consumption and in workload, more precise

**TABLE 10.8**
**Large Autonomous Field Robots with Pros and Cons to the Required Tasks**

| Task | Pros | Cons |
|---|---|---|
| Tillage | Increased working time 24 h/day<br>Immediately preparing field conditions to directly following seeding or planting<br>No timeliness costs and minimized weather influences | Potential hazardous incidents<br>Reduced site-specific interactions<br>Relatively high soil compaction<br>Large headland for trouble-free turnings<br>Possible high timeliness costs through rainfall-stopped prepreparation |
| Seeding and planting | Increased working time 24 h/day | Potential hazardous incidents<br>Reduced site-specific interactions<br>Auto-refilling is challenging |
| Application of fertilizers and chemicals | Extended working time related to best wind and humidity conditions<br>No exposure of operator to chemical agents | Potential hazardous incidents by vehicle or by agents<br>Reduced site-specific interactions<br>Auto-refilling is challenging |
| Harvesting | Extended working time related to crop and soil conditions | Potential hazardous incidents<br>Reduced site-specific interactions in laying crops<br>Auto-unload is challenging |

**TABLE 10.9**
**Small Autonomous Field Robots with Pros and Cons to the Required Tasks**

| Task | Pros | Cons |
|---|---|---|
| Tillage | Reduced soil compaction<br>Most site-specific adaption in variable tillage effects<br>Minimized headland need<br>Minimized timeliness costs by prepreparation | Required power increases mass of the vehicle<br>Less overall capacity<br>Management and maintenance of "herds" asks for highly qualified people |
| Seeding and planting | Enlarged working time 24 h/day<br>Minimized headland need<br>Less payload required<br>No auto-refilling in small fields required | Less overall capacity<br>Management and maintenance of "herds" asks for highly qualified people<br>"Herd supply" in refilling is challenging |
| Application of fertilizers and chemicals | Enlarged working time 24 h/day<br>Minimized headland need<br>No auto-refilling in small fields required | Less overall capacity<br>Management and maintenance of "herds" asks for highly qualified people<br>"Herd supply" in refilling is challenging |
| Harvesting | Extended working time related to crop and soil conditions<br>Minimized headland need<br>Possible selective harvesting in low-mass row crops | Less overall capacity<br>Management and maintenance of "herds" asks for highly qualified people<br>Auto-unload is challenging |

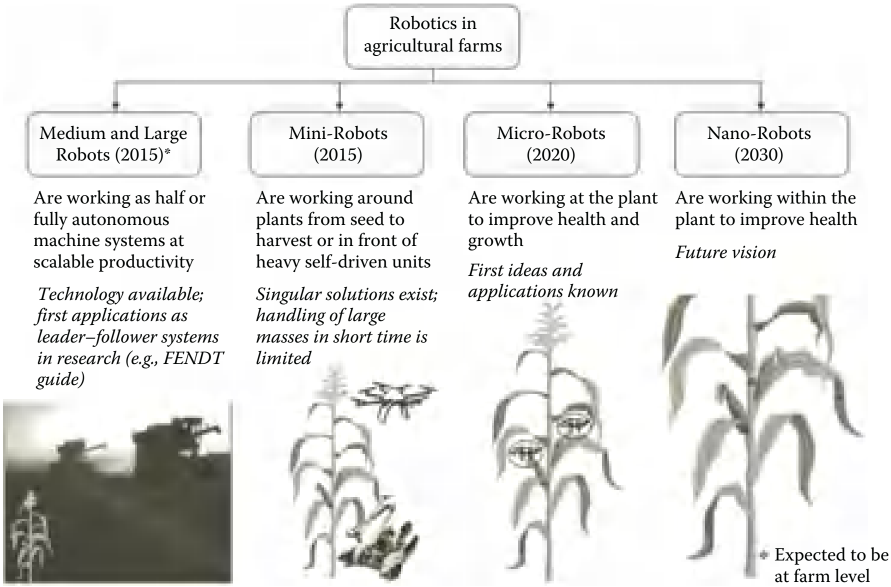


**FIGURE 10.18** Expected field-robot development and usage in agriculture. (Adapted from Auernhammer, H. 2011. Twenty years of precision agriculture—More questions than answers? In *ACPA2011, The 4th Asian Conference on Precision Agriculture*, July 4–7, 2011, Tokachi Plaza, Obihiro, Hokkaido, Japan, CD-ROM, Keynote No. 4: 1–6.)

task fulfillment at the field level is challenging for sustainable land use in future. In this way:

- Auto-guidance in whatever shape is the most promising technology in labor management and will increase in numbers with nearly no restrictions.
- An increase in productivity may be seen in the use of leader–follower systems enabling agricultural equipment of smaller size.
- Small autonomous field robots may first come to the field level in field scouting, monitoring, and in conducting very specific treatments at the plant level.

In the future, miniaturization will continue and bring field robots to flowering plants and finally to larger-stem-sized plants (Figure 10.18).

## 10.7 FUTURE REQUIREMENTS

After more than 20 years of precision farming, the utilization at the farm level is still small compared to the huge potential in today's information-based land use (Auernhammer, 2011). While larger farms and farms with partial or major usage of contractor work progress, smaller and mid-sized farms are having problems in the switchover from familiar mechanical machinery to electronics-controlled equipment owing to the need for additional investments and specific knowledge, plus a certain mistrust of data acquisition, data storage, information management, and communication (Tey and Brindal, 2012).

Another reason may be in the transition of precision farming to the farm level. From both the research and the advisory angle, fertilization in site-specific farming only gained dominance with the expectation of making everything simpler, easier, and more profitable. As this happened when basic nutrients were addressed, it opened more questions than answers in nitrogen application measures. In this case, no answer or sometimes too many answers were available with regard to the best nutrition management:

- How should the most beneficial yield maps be established?
- How should management zones be defined?
- Should more nitrogen be used at the more fertile zones or should the opposite occur?
- Should on-the-go growth sensors and straightforward online control of the spreader follow integrated algorithms only?
- Do yield map-based measures influence plant protection?
- What is the overall value of year-by-year yield mapping?

There are many other open questions with no reliable, unreliable, or more philosophical answers. In other words, farmers, and in particular pioneering farmers, still stand alone and lose interest, motivation, and enthusiasm.

### 10.7.1 Big Data Challenge

Any type of site-specific farming means "information-driven farming." Farming in this context means data generation, data exploration, data modeling, and, finally, data-based operation control (Nash et al., 2009). In other words, precision farming approaches the big data challenge, and earlier precision farming models as seen in Figure 10.8 together with the above-defined situation "farmer left alone" approach the model of tomorrow (Figure 10.19).

Data of field operations will soon go to the cloud. Web services will then need to ensure that required data explorations or data modeling always use the newest, most advanced, and well-tested scientific algorithms. Farm management itself will evolve to the use of apps with twofold aims:

- Any financial data will still reside at the farm management system remaining as safe and limited-accessibility information.
- Field operation measures derived from big data will go in a timely manner from the cloud to in-field precision farming technology, and in parallel for safe documentation to the farm management system.

But all this will only become a reality in the future if big data in the cloud may be stored and handled in a highly secure way with farm-given access permission and with contractual and financial agreements to any data user.

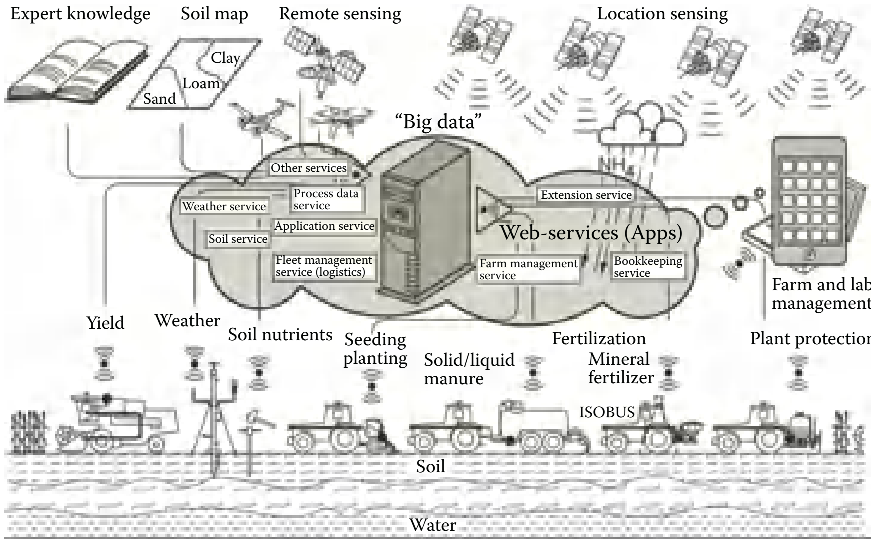


**FIGURE 10.19** Cloud-based big data in precision cloud farming.

### 10.7.2 Models

In today's precision farming practice, existing models are mainly used, evaluated, and approved under homogeneous conditions in conventional farming systems. In the future, there is a big need for well-adapted new models related to the inhomogeneities of different farming types, given farm situations, farm-related rules and laws, and other factors (Table 10.10).

All these models may also be more detailed and subdivided into very specific farming systems. Feedback of any information on human overcontrol during operations or other influences or unexpected occasions into the cloud is essential. This allows for learning processes with more and better adjustments to the real world.

### 10.7.3 Automation

While site-specific farming suffers at small- and mid-sized farms in contrast to the overwhelming acceptance of guidance systems also in these farm types, farmers demonstrate a preference for more and higher automation. In future, auto-steering will be an internal application in tractors and self-propelled machines, and automation will integrate the whole tractor–implement combination. Control will move from the tractor to the implement in tractor implement management (TIM), as implements do the job, know the best conditions, and tell the tractor to react in a well-adapted manner. This will become possible if

- Communication between tractor and implement follows well-accepted standards open to any manufacturer, and specifically to small- and medium-sized producers. Safety control is a must; in this case to clearly avoid inappropriate breakdowns and also to allow dedicated maintenance and repair.

**TABLE 10.10**
**Models in a Big Data Environment**

| Model | Related to | Main Influences |
|---|---|---|
| Nutrient balance | Application in only one operation | Yield map, soil map, soil nutrient map, cultivated variety, expected rainfall, etc. |
| Nutrient optimization | Multiapplication in multiple operations | Yield map, soil map, soil nutrient map, cultivated variety, expected rainfall, economic evaluation, etc. |
| Irrigation | Dry land farming | Soil type, inclination, cultivated variety, crop status, weather data, etc. |
| Soil fertility | Humus | Crop rotation, soil type, climate parameters, topography, tillage regime, working depth and working intensity, humus enrichment target, etc. |
| Soil compaction | Large-scale machinery usage | Type of machinery, soil moisture, tires and tire inflation, path planning, yields, yield moisture, etc. |
| Task quality | Contractor work and nonfamily workers | Task order, task documentation, settings, on-the-go measured task parameters, worker identification, etc. |
| Field size optimization | Transborder farming | Crop rotation, soil map, soil nutrient map, topography, yield targets, roads and logistics, etc. |
| Organic farming | Organic farming | Crop rotation, humus content, infiltration, distance to conventional field plots, etc. |
| Hillside farming | Upland farming | Topography, plot length, tillage system, crop rotation, residual coverage |
| Consumer-focused farming | Good agricultural practice | Data availability and compatibility along the food chain |

- Communication between tractor and implement relays in the response of a so-called full-liner, where both machines come from the same manufacturer. Safety and responsibility in this solution will be clearly defined.

Tractor and implement(s) may then be seen as an integrated self-propelled unit. Adjusted settings given from implements to the tractor will be stop and go, left–right steering, forward speed adoption, PTO-revolution adjustment, hitch position changing, and flow control at auxiliary hydraulic valves.

Automation may also spread across field machinery, including cloud settings into the loop either related to a task operation or in real time during job execution. Automation in this case will evolve to the Internet of agricultural utilities.

### 10.7.4 Sustainability

As precision farming in whatever shape, type, and application is used at the farm level, it is always interacting with land and nature. But more often, it is primarily used to increase profit, accepting negative or even harmful and long-lasting impacts on nature, such as overfertilization with increased leaching, wasting of scarcely available water, and reducing number of crops in the rotation; or, far worse, going into monoculture crops.

For tomorrow, whatever term will be used instead of the well-known term of today, precision farming should be more than profit driven; it should move to sustainable agriculture in the right manner. Therefore, besides the dominating economic prospects and expectations, the ecological and the social implications should also be integrated targets:

- First of all, site-specific data in detail as well as from history should be part of any model and field operation.
- Major attention should also be given to crop rotation, including cover crops and their positive effects on soil fertility, plant growth and reduction, and suppression of weeds, plant diseases, and insects.
- Under more arid climate conditions, irrigation should focus on minimum consumption of water together with the most adapted plant varieties, whereas under more humid conditions, the reduction of soil compaction and soil erosion should be the dominant target.
- In all plant protection systems, the use of chemicals should be reduced or even eliminated, creating systems with physical weed control and with spatial or single plant-related highly specified plant protection measures or organic agents.
- Finally, most crop production will go in some way or another to the consumer. Traceability creates trust in the produce and allows secure seek-backs when problems occur.

With all these facets, it is clear that PA means more than site-specific application. PA means sustainable agriculture with no equivalent alternative in either conventional or in organic farming systems.

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