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The Role of Precision Agriculture in the Promotion of Food Security

Babak Talebpour*, Ufuk Türker and Uğur Yegül

Ankara University, Department of Agricultural Machinery, Ankara, Turkey

Abstract

Population explosion and the need to provide food for humankind and to increase the quality and quantity of food products in order to ensure food security with regard to its managerial, environmental, and developmental aspects has led to the use of new agriculture methods and technologies. Today, different approaches, such as plant breeding, genetically modified foods, in vitro planting, and the spread of closed ecological systems, are applied as a solution to increase food accessibility. In addition to these methods, using modern technologies under the title of precision agriculture have been proposed as ways to achieve food security. Early intervention to prevent the occurrence of unwanted events with the ability to monitor crops in all stages of production, from tillage to post harvest, are provided by using various methods, such as remote sensing and geographic information systems. In addition to the economic and environmental impacts of precision agriculture, expanding farmers' awareness through the use of modern technologies and the integration of scattered lands to achieve sustainability are known as social impacts of precision agriculture. In this manuscript we have tried to summarize the different methods of precision agriculture that could affect food security in its multiple branches.

Keywords: *precision agriculture, food security, sustainability and traceability*

Introduction

The widely accepted definition of food security provided by the United Nations in 1996 states that "food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2012). Global food security is under pressure by several factors, such as the world population explosion, the amount of arable lands, availability of water resources, climate condition and accessibility of food, and its loss (Premanandh, 2011). According to the newly released 2006 revision of the official United Nations population estimates and projections, the world population will reach 9 billion people by 2050 (United Nation, 2012), despite the mentioned limitations (Figure 1). The worldwide call for food will increase for at least another 40 years due to the explosion in the global population (Godfray et al., 2010). Besides all the solutions to enhance food security, such as increasing the household income, promotion of the knowledge of feeding families, preparing the best food budgets, cooperation between organizations and institutes, and changes in food policy, it is essential to apply innovative methods in all stages of production, processing, and marketing of food materials.

Despite the belief that the reasons for food in-security are more complicated and that increasing agricultural performance cannot tackle worldwide poverty on its own, some believe that improving the physical performance of agriculture using a set of new technologies is the main solution (DFID, 2004). Agriculture has always had a crucial role in

* Corresponding author: btalebpour@ankara.edu.tr

the preparation of human needs for food and its development. The importance of agriculture in providing the nutritional requirements for developing populations is undeniable. Additionally, several parameters in the agricultural sector are very useful as an indicator for the expression of social identity and cultural promotion of rural communities (Borch, 2007). One of the contributing factors to food security is closing the yield gap that not only leads to increased crop production but also increases the efficiency of land use, reduces the production costs, and may result in food security (Tran, 2001). As a definition, yield gap refers to the difference between realized productivity and the best that can be achieved by using current technologies and management systems (Godfray et al., 2010). Thus, the use of current and new technologies and management systems in agriculture is one of the ways to reduce the yield gap and food insecurity.

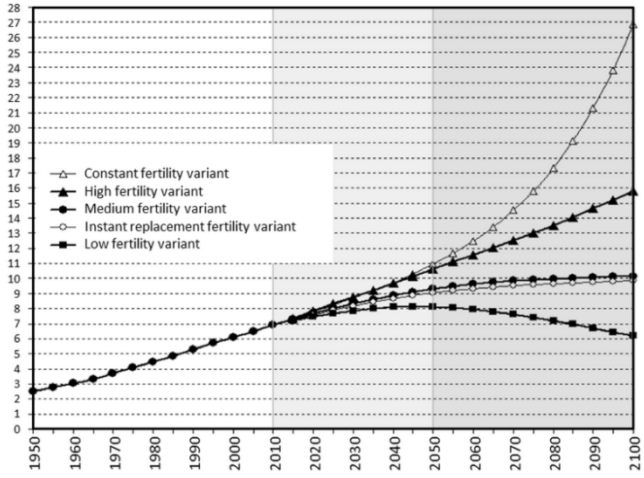


Figure 1: Estimated and projected world population according to different variants, 1950-2100 (billions). (Source: UN 2010 Revision)

Besides the numerous initiatives undertaken in recent years in agriculture, such as agricultural robots, closed ecological systems like greenhouses, genetically modified food, in vitro meat, and vertical farming, precision agriculture is one of the most important innovations to take place in past decades. During past centuries, very small field size and their losses due to natural limitations, such as water shortages and changes in soil type, required farmers to change operations manually. Despite the development of various techniques in agricultural mechanization and their application in large scales, any sort of practice within the fields based on the possible changes was not realizable without the use of new technology (Stafford, 2000). Taking the above mentioned limitations into account and attempting to tackle them has led to the use of the precision agriculture approach in past decades. Using precision agriculture, improving traditional agricultural practices, and integrating them with existing technologies by considering spatial and temporal variations is possible (Maohua, 2001).

Precision agriculture not only brings new technologies, but the use of these technologies provides a better and more accurate farm management system and information fusion. Besides increased profitability as a result of better management practices and the development of information systems in agriculture, precision agriculture can also provide the following benefits:

- Increased product quality
- Improved sustainability
- Provide a lower risk in the management system
- Food safety using product traceability
- Environment protection
- Rural development (Robert, 2002)

In this review, the role of precision agriculture in providing food security and the benefits indicated above have been evaluated. In each case, some issues were discussed in detail in association with food security and how to provide it with the use of precision agricultural technology and management system.

Product Quality

Increasing the capacity of utilization of crops with high nutritional value is one of the challenges in food security because even well-fed people may suffer from disease due to deficiency in essential nutrients. In order to prevent the spread of diseases caused by nutritional deficiency, the production of high quality crops resulting in food quality is essential. Plenty of sufficiently healthy food not only reduces hunger but also prevents many diseases caused by malnutrition (Roy et al., 2006).

The nutritional quality of crops is influenced directly or indirectly by many factors, including climate factors, the crop and its cultivar, cultural and management practices, fertilizer application, and postharvest handling (Hornick, 1992; 2010).

Presently, most of the negative effects of these factors can be reduced or eliminated by using precision agricultural technology. In fact, because of the growing concern about the importance of high products and increased crop quality without harming the surrounding environment, the need for the use of site specific management systems is dramatically increasing (Bah et al., 2012). In site specific management—based on measurements taken from the spatial and temporal variations in soil and plants—different types of sensors are used to improve yield, quality, and to reduce the cost of inputs with variable rate applications. To achieve these goals, remote sensing data acquired by several proximal sensors are combined with images obtained by sensors onboard aerial or satellite platforms and are useful tools that provide the necessary spatial variation information on the status of soil and plants (Boschetti et al., 2007).

Proximal sensors used in this management system include soil sensors, such as electrical and electromagnetic sensors, optical and radiometric sensors, mechanical sensors, acoustic sensors, pneumatic sensors, electrochemical sensors (Adamchuk et al., 2004), and crop sensors that are often used to obtain different vegetation indexes in plants. On the other hand, images from different satellite and aerial sensors, like multispectral and hyperspectral sensors, are ideal tools for quantification of crop growth in agricultural research applications (Hall et al., 2002) and are used widely in tillage for harvesting operations.

In the current manuscript we do not explain how to use each of these sensors because this issue was not the main subject of this review, but in this section and other sections we provide some examples that describe the application of precision agriculture techniques to ensure food security objectives.

1. Increasing Crop Quality Using Spatially Variable Fertilizer Management

Today, fertilizers have a very significant impact on the world's food supply. The major fertilizers used in the food production cycle contain phosphorus, nitrogen, and potassium as main nutrients on agricultural fields that are normally found in nature. The trend in fertilizer consumption in different countries of the world can be seen in Figure 2 (Anonymous, 2008).

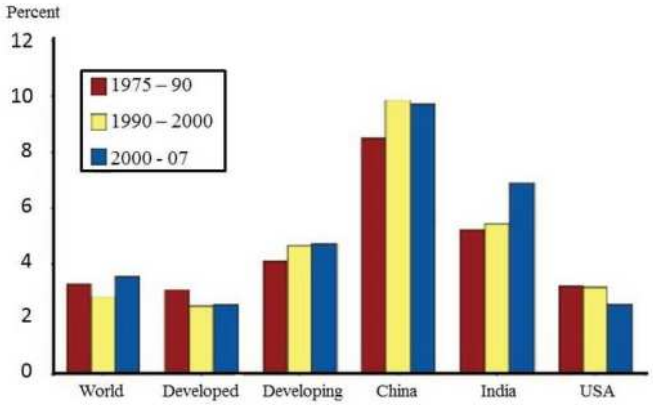


Figure 2: The trend in fertilizer consumption (Anonymous, 2008)

Besides the benefits of using fertilizer to increase crop yield in the agricultural production system, in many cases, excessive use or abuse of fertilizers has not only increased yield but caused problems, such as poor product quality.

The ill effects of the use of such fertilizers are often due to lack of attention to spatial variation in crop and soil condition. At this time, variable rate fertilizing application is offered as an important part of precision agriculture to improve fertilizer use efficiency (Raun et al., 2002). The principle of this approach applies appropriate nutrients in the required amounts at the right time and right place to meet the needs of the crops (Roberts, 2007). Managing the variability within fields is done using map-based and sensor-based technologies. With the progress made in technologies, such as GPS, remote sensing, yield monitoring, and soil sampling techniques, implementing map-based methods is easier. On the other hand, to control variable rate devices, desired parameters of soil and plants are measured using real-time sensors or sensors installed on the satellite or aerial vehicles (Zhang et al., 2002).

Cereal has always been considered one of the main ingredients in the world food supply, especially in low per capita income countries. Cereal consump-

tion accounts for a large portion of the household food budget (Regmi et al., 2001). Some statistics that depend on world cereal production, utilization, and stock are given in Figure 3.

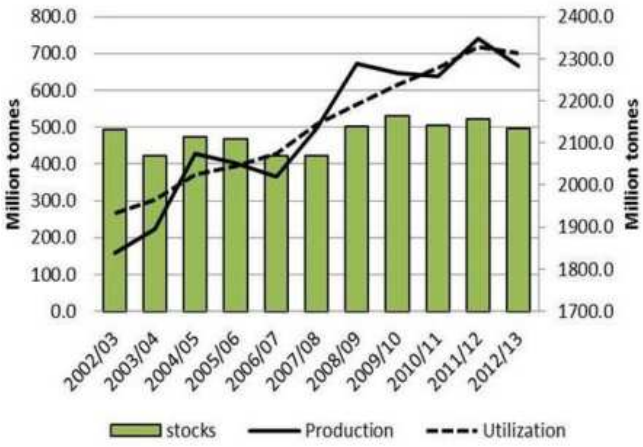


Figure 3: Cereal production, utilization and stocks

In addition to using technology to improve fertilizer use efficiency and increase crop yield in cereals, enhancement of its quality becomes one of the major issues in precision agriculture. There is substantial evidence that shows protein content in grains is one of the main indicators of the quality of grain, especially wheat. Today, protein content is used as one of the key criteria in the grain trade in international markets. Buyers are using protein content to indicate final quality parameters of parcels of wheat. In this case, wheat breading and classification of varieties plays an important role in maintaining the linkage among protein content, ultimate quality, and meeting customers' expectations. On the other hand, grain protein content depends on mineral nutrition, especially nitrogen nutrition (Zečević et al., 2005; Blakeney et al., 2009). At this time, the role of precision agriculture techniques and site specific management of nitrogen is considered a tool for better management of nitrogen and a way to supply the desired protein content.

It is now possible to determine the in-season need of nitrogen based on innovative nitrogen management strategies using precision agriculture information, such as visual assessments using calibration reference, leaf chlorophyll meter sensing, aerial and satellite remote sensing, and ground-based remote sensing (Shanahan et al., 2008). In most of these methods, the determination of the proper rate of nitrogen fertilizer can be made by calculating some vegetation indices of the plant. For this reason, the relationship between nitrogen concentration in plants with some vegetation index can be determined, and then these indices are used with final protein content to determine an appropriate rate of nitrogen fertilizer. A study about grain protein management with estimation of wheat nitrogen content is referred to as an example of using these techniques to manage protein in wheat. To indicate the effect of spectral vegetation indices such as NDVI, Green NDVI, DVI, and RVI on plant nitrogen content, all reflectance values were collected from all the remote sensing tools using satellite and airborne and ground-based reflectance (Wright et al., 2004). The result derived from all sensors in relation to some crop variables, such as preseason nitrogen, flag leaf nitrogen, yield, and protein content that are obtained in the same season, were given in Table 1.

Table 1

Coefficient of Determination (r^2) Values for remote sensing data with preseason N, plant tissue N, and protein at $p = 0.05$ (Wright et al., 2004)

	Satellite NDVI	Aerial NDVI	Spectro-radiometer NDVI	Green-Seeker NDVI
Preseason N	0,51	0,53	0,71	0,63
Flag Leaf N	0,51	0,43	0,72	0,66
Yield	0,45	0,42	0,79	0,76
Protein	0,44	0,47	0,57	0,63

After determining the relationship between the NDVI values extracted using these sensors, the relationship between plant nitrogen content with yield and protein content as a quality parameter can be determined (Figure 4). In relation to the use of nitrogen fertilizer and its effect on increasing protein content level, the fertilizing application is recommended, especially at the final leaf stage (Srinivasan, 2006).

However, it should also be noted that the increased use of nitrogen fertilizer to promote protein levels has some limitations because the extra use of nitrogen has a negative influence on other quality parameters, such as a falling number of Hagberg

and specific grain weight (Srinivasan, 2006). Therefore, more studies on site specific nitrogen management and determination of the optimum rate of nitrogen fertilizer with consideration of all limitations and factors are needed.

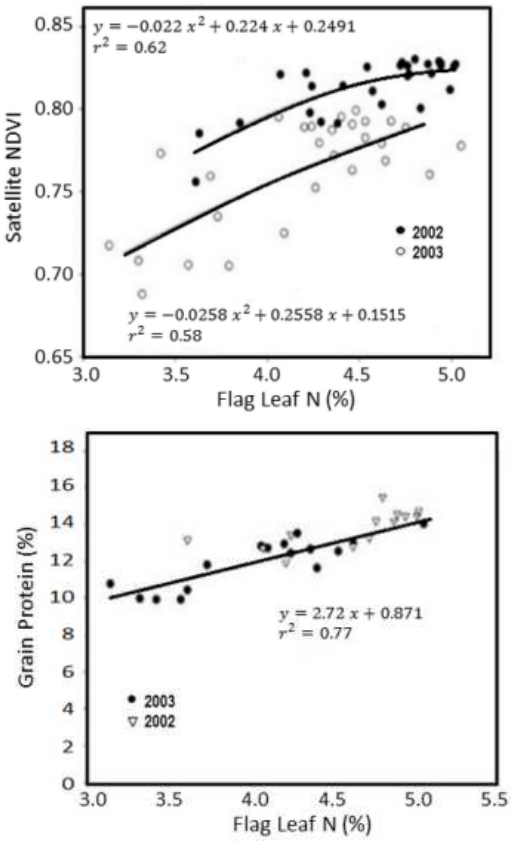


Figure 4: The relationship between satellite NDVI and flag leaf N (left) and Effect of flag leaf N on grain protein for two consecutive seasons (Wright et al., 2004)

Furthermore, measuring protein content during harvest using protein sensors installed on combines provides useful information on variability in protein content and crop yield for the entire field. Therefore, awareness of the variability in protein content can help create strategies to optimize farm return. The other benefit of monitoring protein in harvesters is the opportunity for better identification of nitrogen use within the field. Thus, the amount of nitrogen removed is a function of yield and protein content. The recommended equation related to the amount of nitrogen removed and site specific nitrogen budget are given in the following equations (Taylor et al., 2005):

N removal (Mg/ha) = Grain Yield (Mg/ha) • Grain Protein (%) • 1.75

N budget = N present + N input - N removed

2. Reducing The Impact of Climate Change

The relationship between climate change and food security and its impact on crop productivity is one of the topics under study and discussion. Climate change is one of the factors that cause stress in food systems (Gregory et al., 2005). Changes in climate can affect agriculture and food production systems in both direct and indirect ways. Influences on changes in agro-ecological and growth conditions and distribution of incomes and demand of agricultural products are some of its direct and indirect effects (Schmidhuber and Tubiello, 2007). Temperature and precipitation are two main climatic variables for which changes in their values has a significant effect on agricultural products. Figure 5 shows the trend in six of the most widely grown crops in the world (wheat, rice, maize, soybeans, barley, and sorghum) in terms of variation in yield, temperature, and rainfall data. Based on the data, many statistical and empirical models were extracted to investigate the impact of these climate trends in yield (Lobell and Field, 2007).

One of the less studied effects of climate change on agricultural products is its relationship with food quality. Apart from the overall reduction in the amount of nitrogen and protein concentration, the food quality and nutritional value of most edible products and forage crops is largely unknown. Today, temperature and CO_2 are two parameters whose effects are being investigated on quality factors. From these factors, determinations about carbohydrates, minerals, lipids, proteins, tannin and terpene content, and the quality of animal forage can be made (DaMatta et al., 2010).

For these reasons, precision agriculture can play a key role in climate change. To achieve this aim, the weather information that affects the product must be recorded during the growing season. Then, with regard to the prediction of climate change in a field location, the experiences of other geography similar to the weather forecast must be investigated by understanding how crops are affected by the current climate in the other region, and the future effects on production can be anticipated in the new climate.

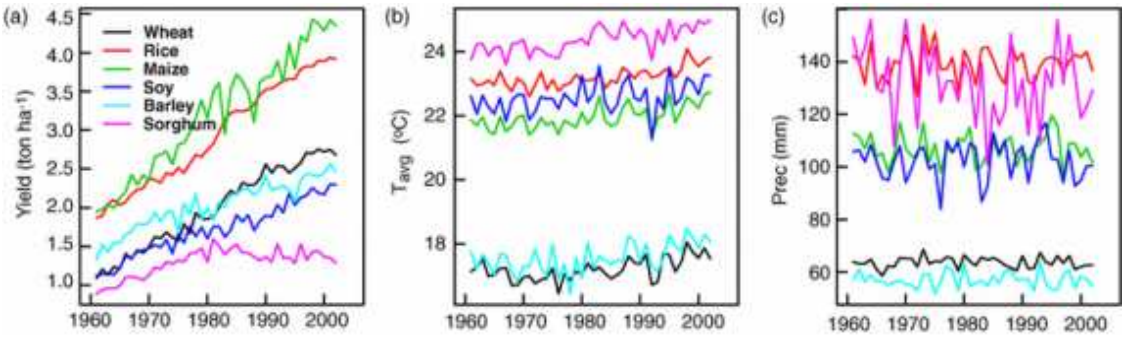


Figure 5: Time series of (a) yields, (b) growing season average monthly temperature and (c) rainfall for 6 crops, 1961–2002 (Lobell and Field, 2007)

Thus, gradual changes in management decisions, such as choosing seed, time of planting, etc., can be possible (Russo, 2012).

One of the areas that precision agriculture has an essential role in is the monitoring of greenhouse conditions. In this case, it is essential to monitor parameters such as temperature and humidity that have an impact on product quality and quantity. Making management decisions according to analysis of data and control mechanisms automatically or manually are the other stages of implementation of precision agriculture techniques in the greenhouse. Data acquisition is an essential step in the implementation of precision agriculture. Because of difficulties in manual data acquisition to achieve real-time monitoring and good production field coverage, automatic data acquisition is a better solution to collect and transmit monitored data. Today, the wireless network is widely used in greenhouses or sheds (Xia et al., 2011).

All existing temporal variabilities caused by the changing climate causes variation in crop yields from season to season at a particular point in the field (Hansen and Jones, 2000). One of the important impacts of climate variability is its impact on vegetation water stress. Water stress and decreased soil and crop water content have effects on several processes in plant physiology, such as transpiration, photosynthesis, biomass production, and nutrient absorption in direct or indirect manners (Ridolfi et al., 2000).

Nitrogen uptake is also one of the parameters that depends on soil and plant water stress. This is why nitrogen should be applied to regions with sufficient plant available water. To obtain nitrogen and plant water content, many remote sensing tools such as hyperspectral, multispectral, microwave, and thermal remote sensing methods were used as part of precision agricultural technology (Tilling et al., 2007). In the section on raising irrigation efficiency this issue will be discussed in detail and more samples of using remote sensing data will be given.

3. Control of Pests in Time

Humans constantly compete with pests to access available natural resources, and most importantly, food production. In fact, pests and diseases have always been some of the most important factors when it comes to improving crop, human, and animal health. Their significant impact on reducing the amount of food for humans and animals contributes directly to food insecurity and poverty. Therefore, plant pests, including insects, pathogens, and weeds, remain one of the major limitations in the production of food and agricultural crops in all regions of the developing world (Eze and Echezona, 2012; FAO, 2005).

Losses in agricultural crops often occur due to abiotic factors such as irradiation, water, temperature, and nutrients or biotic factors, such as weeds, pests, ands pathogens known as environmental factors. These losses usually lead—to decreases in yield efficiency and lower yield compared to attainable yield. The "site specific technical maximum" is expressed as the definition of attainable yield and depends on abiotic factors in growth conditions, which is the combination of obtaining yield and all losses that take place. As shown in Figure 6, there are two loss rates composed of potential and actual loss. The potential loss refers to losses without using any protection systems compared to yields with a

similar intensity of crop production in a no-loss scenario. Actual loss consists of losses that happened despite the use of crop production practices (Oerke, 2006).

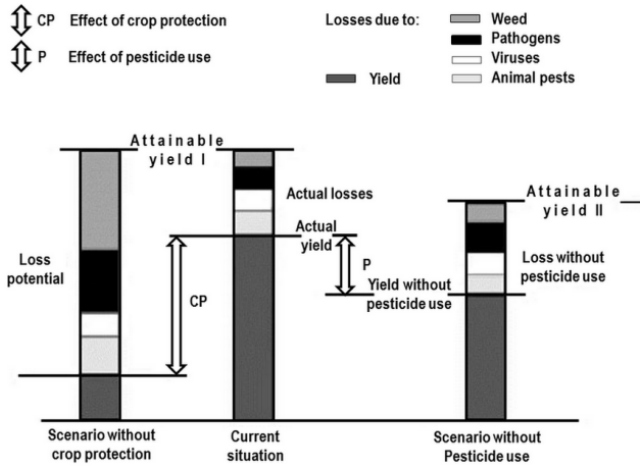


Figure 6: Crop losses and yield level (Oerke, 2006)

Besides losses in crop quantity, crop losses may be qualitative, resulting from a reduction in valuable ingredients and market quality (Oerke, 2006). For this reason, early detection of pests and diseases is necessary for growing healthy crops. Early appearance and rapid development of pests can affect vegetation of crops and reduce their growth while incidence of pests in later stages of plant development causes reduction in yield and market value (Srinivasan, 2006).

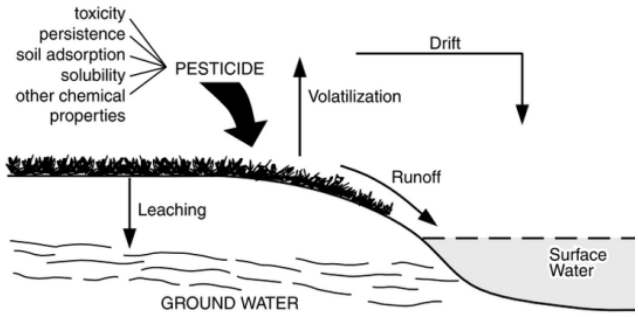


Figure 7: Disadvantage of using pesticides in ground and surface water contamination (Bauder and Pearson, 2010)

Despite all the disadvantages resulting from the use of pesticides in agricultural crops, such as a reduction of beneficial species, the drift of sprayers, residues in food, ground and surface water contamination, plant resistance, poisoning hazard, and their possible health effects on humans and wildlife, the extensive use of pesticides is common in a wide range of agricultural fields (Figure 7). However, it has been neglected that using pesticides does not always decrease the amount of losses in crops. For instance, despite a tenfold increase in pesticide use in the United State from 1945 to 2000, the overall loss in production due to insect infestation has doubled (Pimentel, 2009).

With regard to the aforementioned methods to reduce the negative impact of pesticide use and avoid the traditional applications based on average pest density, site specific pest management systems coupled with an understanding of pest population in time and space is suggested as one aspect of precision agriculture (Park et al., 2007).

Like the concept of site specific management where the application is performed based on variations in individual soil and crop factors within the field (Johnson et al., 2003), performing spatial sampling and identifying pest distribution is the first step in applying site specific pest management. The second step is to create prescription maps based on the spatial distribution with management zones. Application of control measures based on prescription maps is the last step. Required technology related to site specific pest management applications has been summarized by Park et al. (2007):

- Global positioning system
- Geostatistics to characterize spatial distribution patterns
- Create maps and database
- Remote sensing
- Application of control measures (Park et al., 2007)

In recent years, pest, insect, and weed identification using optical sensors mounted on various platforms has been proposed and used as a means of remote sensing. The wide range of sensors, from tractor-mounted sensors with a resolution less than 1 mm^2 to satellite systems with resolution of 10-

1000 m^2, are valuable tools to detect symptoms of pest attacks (Lucas, 2011). Knowing the signs of plant stress induced by pests, insects, and weeds (Hatfield and Pinter, 1993) and early symptom identification based on crop spectral signature plant characteristic (Figure 8) in reflect electro-magnetic radiations (Anonymous) is a useful way for rapid intervention to prevent the development of plant stress by using variable rate applications.

Research conducted by Franke and Menz (2007) provides an example of using remote sensing to monitor the heterogeneity of crop vigor. In their study, in order to evaluate the diagnostic accuracy of contaminated areas using remote sensing imagery related to ground truth sample points, the infection rate of wheat by a kind of fungal disease has been studied using multi-spectral satellite imagery and hyper-spectral aerial imagery. The experimental field is divided into three plots with fungicide treatment done between imaging times according to the development of infection in different stage of growing (Figure 9).

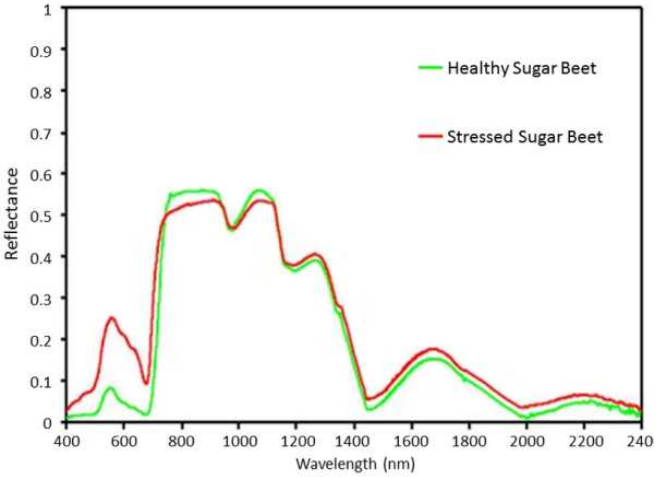


Figure 8: Spectral signatures of healthy and stressed sugar beets (Nowatzki et al., 2004)

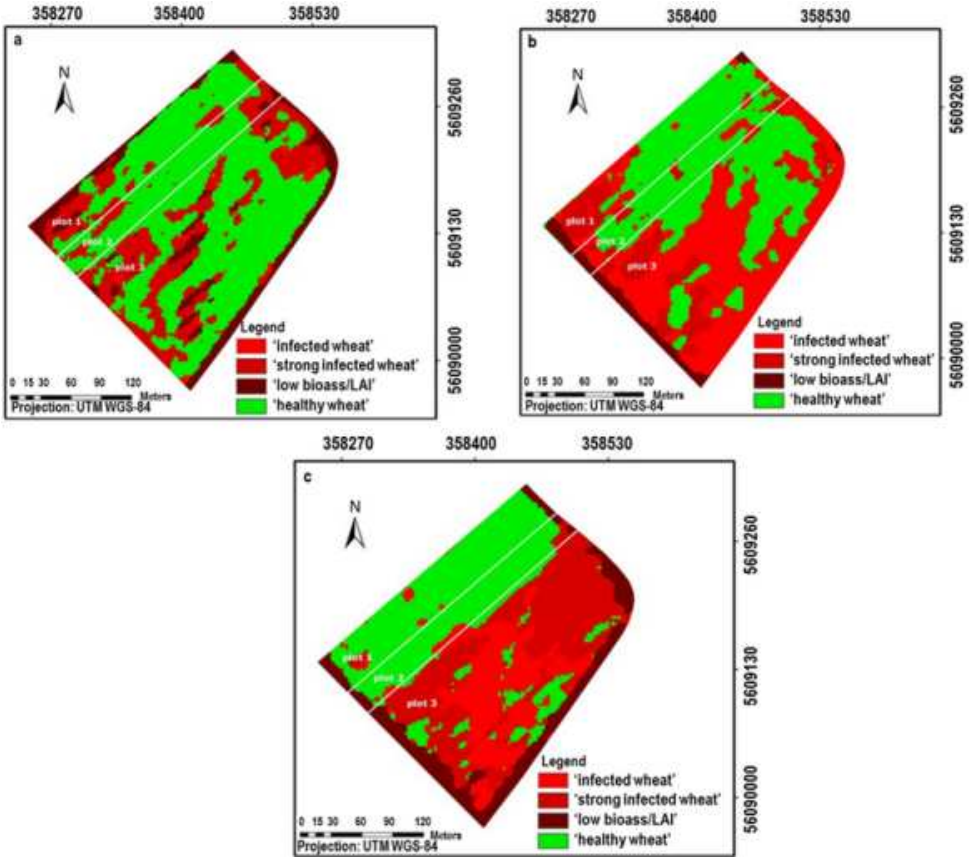


Figure 9: Image classification result of a) 22 April b) 28 May and c) 20 June in three sub-areas of various fungicide applications with four classes of different infection rate (Franke and Menz, 2007)

The results demonstrated that the use of multi-spectral images at later growth stages or at higher contamination rates have more positive results and that using hyper-spectral remote sensing data can improve recognition rates due to higher spectral resolution (Franke and Menz, 2007).

4. Raising Irrigation Efficiency When Water Resources Are Low

Slight growth in crop production efficiency would lead to higher prices and worse malnutrition around the world. Since food production depends on the amount of water used, expansion of irrigated area and improved irrigation efficiency are essential in increasing food production. Hence, the demand for irrigation water can be considered a derived demand for food (Carruthers et al., 1997). On the other hand, because of the use of the common supply of water between agricultural and non-agricultural sectors, such as urban areas and industries, and according to increasing demand as well as environmental considerations in these sectors, the importance of demand in agriculture and its impact on threatened food security has been drawing more attention. Thus, improving the efficiency of water use has a key role in tackling the issues of water scarcity and food security, especially in small holder agricultural systems (Hanjra and Qureshi, 2010).

The concept of precision irrigation systems refers to all precise activities, including the accurate determination of the crop water requirements and application of determining volume at precise locations and times (Smith et al., 2010). Inappropriate irrigation scheduling and inadequate water applications are common factors limiting agricultural production in many arid and semi-arid regions. Precision irrigation as a part of a precision agricultural system provides many approaches to determine when and how much to irrigate by monitoring plant and soil water status, measuring the evapotranspiration rate, and calculating crop coefficients (Pinter et al., 2003).

Among all the direct and indirect methods to estimate plant water status, using remote sensing techniques as a tool of precision agriculture has been widely developed due to its advantages, such as its capacity to integrate over large scales (Jones, 2007). Remote sensing can provide multiple data, allowing for estimating plant water content and close monitoring of processes that occur within a small period of time. Nowadays, using spectral signatures based on hyperspectral spectrums and numerous indexes related to vegetation and plant water derived by using different electromagnetic bands and obtained from satellite and airborne platforms provide useful data to diagnose water stress in large fields. Figure 10 illustrates three spectral signature with different canopy water content (CWC) that shows the effects of canopy water content on the reflectance of near-infrared (NIR) and shortwave-infrared (SWIR) spectrums (Clevers et al., 2010).

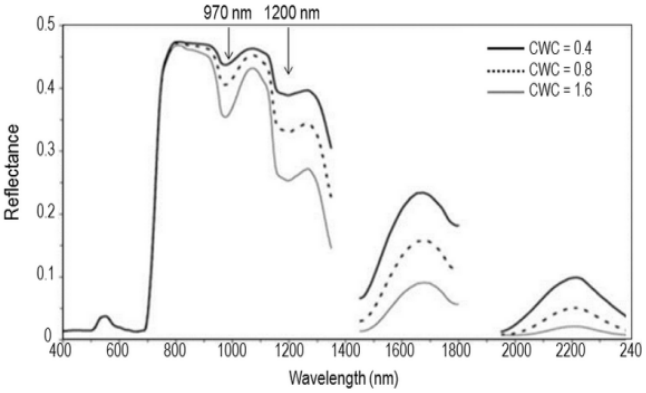


Figure 10: Three canopy spectral signatures different CWC values (in $kg.m^{-2}$) (Clevers et al., 2010)

An example of using remote sensing techniques to reduce water use without any significant impact on crop yield is shown in Figure 11. In this figure, a thermal image of a cotton canopy that was acquired with a thermal scanner on board a helicopter was used to distinguish the variability of water concentration within each field. Yellow and orange pixels in the image below represent higher temperatures than blue and green. So with regard to the relationship between plant water concentration and canopy temperature, it can be concluded that blue and green represent higher water concentration than yellow and orange. These changes result from the variable ability of the soil in different parts of the field to absorb water and supply for plant consumption. In such conditions, if irrigation was done uniformly, different areas of the field would not receive water in their actual needs. Therefore, variable irrigation rates across the field could improve water use efficiency in spatially variable water concentration areas (Anonymous, 2001).

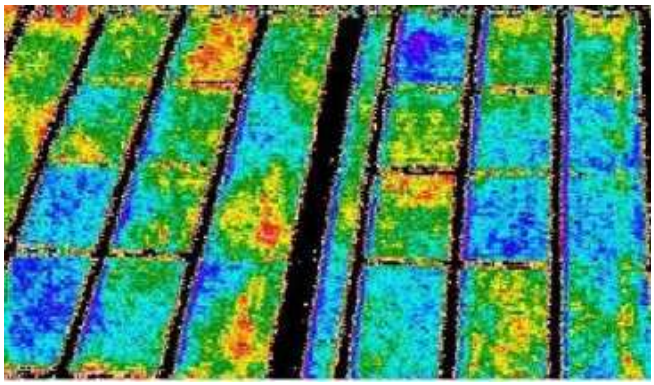


Figure 11: Water content of crop fields with thermal imaging (Anonymous, 2001)

5. Maintaining Crop Quality With Precision Post Harvesting Application

One of the major factors influencing food insecurity and development of malnutrition, especially in developing countries, is high post-harvest loss. High losses in food production and supply chain in terms of quality and quantity are experienced. Development of engineering and managing systems related to the reduction of losses in the post-harvest stage, with proper understanding of basic science in order to maintain product quality and quantity and wholesomeness of foods, is essential.

Post harvest process management is a part of precision agriculture technology (Roberson, 2000). With the development of numerous technologies to measure multiple parameters related to crop quality and the use of precision agriculture technology, producers are able to classify their crops at the harvest level. The existence of different sensors for measuring moisture during crop harvesting is an important factor in the maintenance of the product quality in cereals as well as parameters such as proteins and oil. A storage facility was provided on the basis of the measured parameters. Insects, mold, and other bio-gents are the main reasons for losses in grain and dry food post harvest that include 10% - 40% of losses. Mycotoxins and harmful microorganisms can develop under unsuitable storage conditions, which can pose a serious hazard to human and animal health and reduce the nutritional value of stored crops (Anonymous, 2013). Therefore, it is essential to monitor crop status during production as part of precision agriculture in order to identify pest attacks or disease-stricken areas to prevent mixing crops of these areas with healthy crops. This is an important factor in reducing losses in the post harvest stage.

Because of the undeniable role of fruits and vegetables in human nutrition, especially as a source of vitamins, minerals, dietary fiber, and antioxidants, adoption of precision post-harvest management is indispensable. Horticultural crop losses occur between harvest and consumption in both quantitative and qualitative forms. Loss in edibility, nutritional quality, caloric value, and consumer acceptability of fresh produce as qualitative losses are much more difficult to assess than quantitative losses. Differences between countries and cultures in terms of quality standards, consumer preferences, and purchasing power influence marketability and the magnitude of post-harvest losses. Reduction of post-harvest losses in this area can increase food availability to the growing world population, decrease the area needed for production, and conserve natural resources (Kader and Rolle, 2004).

Enhancing market quality standards by minimizing fruit and vegetable bruising during post harvest applications is considered an important issue. This issue led to the development of some equipment for measuring parameters, such as temperature, humidity, moisture, and pressure, to monitor conditions in treatment and storage in order to achieve optimum parameters and preserve quality. With continuous control of these parameters in the handling and storage process and analyzing related data in real time, automatic regulation of temperature, humidity, and fresh air delivery can be made to preserve or enhance quality (Cox, 2002; Roberson, 2000).

Sustainability and Rural Development

Sustainable agriculture is a sort of agriculture that allows for optimal production based on providing ecological, economic, and social opportunities for the present and future generation's profits (Dumanski 1998). Generally it can be said that sustainable agriculture is a search for the best use of natural resources and services while maintaining these resources (Pretty et al., 2003). Poverty reduction, increased food security, and good environmental stewardship may possibly happen

on a global level with a proper implementation of sustainable agriculture (Anonymous, 2012). Incorporating natural processes into food production processes, minimizing the use of non-renewable inputs that are harmful for the environment and human health, making beneficial use of farmers' ability to take the place of human capital for excessive inputs, and leveraging advantages of people working together to get rid of problems, such as, pest, irrigation, watershed, forest, and input management, are the main aims of application of sustainable agriculture (Pretty et al., 2003).

All existing data about the effects of fertilizer application, agricultural machinery, irrigated area, and agricultural land area on world food production prove that the growing use of these factors has a significant impact on increasing food production in a linear relationship. However, the answer to the question whether all relationships between these factors and world food production will remain linear or not is difficult. The hopeful scheme of this assumption of linearity might be used for estimating the rate of input usage, but not accurately, for predicting the growth rate of food production (Tilman, 1999). There is an argument about the use of low external input technology to achieve sustainable agriculture development (Tripp, 2009). Despite obvious relationships between the above mentioned factors and total world food production, inexpert use of some inputs has caused significant environmental damage. A large amount of nitrogen intake contributes to surface water and atmosphere contamination as well as increasing occurrence of certain disease symptoms. Inefficient use of water causes water-logging, and salinization and agricultural machinery increases the consumption of fossil fuels (Pretty, 2008). Therefore, it is essential to take into account parameters such as farm management systems, soil and plant biodiversity, soil structure, and efficient use of water resources and nutrients in agroecosystems in order to to achieve sustainable agriculture (Figure 12) (Brussaard et al., 2007).

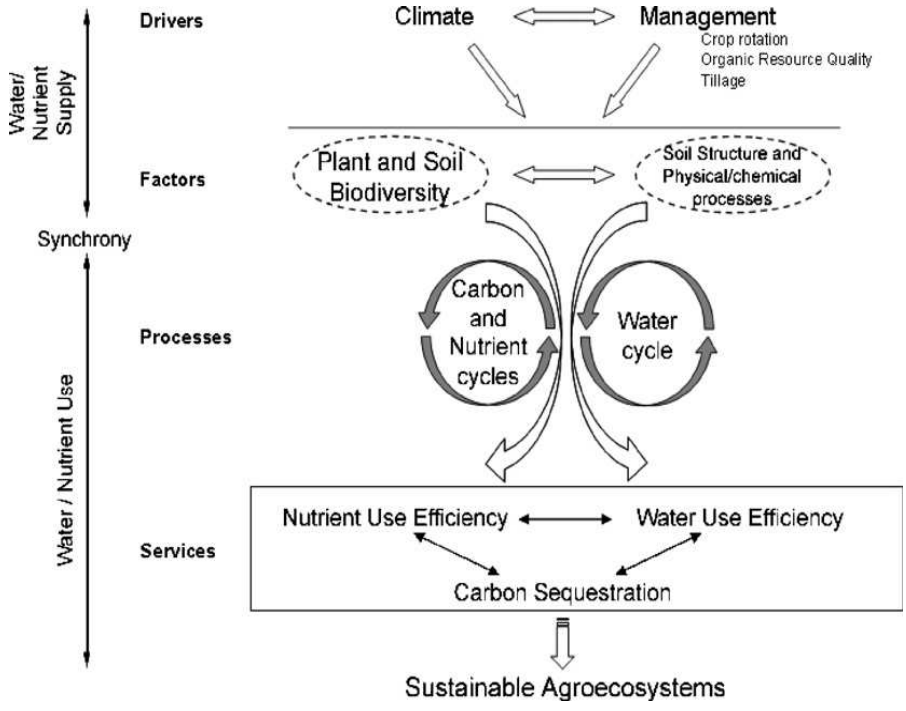


Figure 12: Conceptual diagram of sustainable agroecosystems (Brussaard et al., 2007)

Precision agriculture is one of the ways to reduce the adverse and harmful effects of using inputs in agriculture. For this reason, the concept of precision agriculture and sustainability are inseparably linked (Bongiovanni and Lowenberg-DeBoer, 2004). The importance of precision agriculture using site specific management and variable rate application was discussed previously. We are also aware that sustainability is associated with economic, environmental, and sociological impacts (Figure 13) (Bongiovanni and Lowenberg-DeBoer, 2004), so to avoid repetition in this section, further examples concerning the effects of these technologies on reducing the environmental impact and increasing the profitability and social effects were presented.

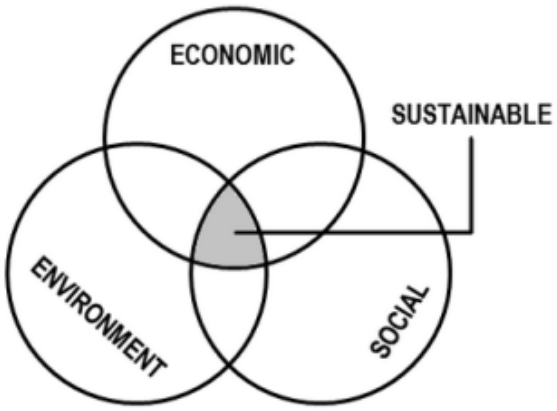


Figure 13: Sustainability associated with three disciplines: ecology, economics and sociology (Wood, 2012)

The concept of precision agriculture is based on detection of variation in the field, and the application of each input is performed on the basis of these variations (Robert, 2002). As an alternative to non-selective application of inputs at equal rates on large scales, precision agriculture provides useful information to apply some external physical inputs to appropriate target treatments, which positively affects farm application on ideal environmental balance (Bongiovanni and Lowenberg-DeBoer, 2004). For instance, neutral soil pH is an important factor in fertilizer and pesticide applications that made them more effective in the soil. In order to raise this factor in the soil and avoid profligacy, applying lime based on soil pH variation can reduce the amount of lime using variable rate applications. Therefore, the result of this approach includes uniform soil pH, more efficient use of inputs, and improved environmental conditions (Kahabka et al., 2000). It can be stated that using precision agriculture application maximizes both food production and resource efficiency without waste or harm to the environment. The same applies to excessive fertilizer or pesticide applications (Oliver et al., 2013).

Profitability of precision agriculture is the most interesting area for farmers, supply providers, and researchers. Sometimes the only way to persuade farmers to use this technology is to provide answers to questions such as how costly and how beneficial the technology is (Olson, 1998). Several studies related to economic feasibility of precision agriculture based on utilizing site specific management and variable rate application indicate its profitability more than conventional application of inputs in uniform patterns and introduce as potential strategy to increase overall farm profitability (Koch et al., 2004; Inman et al., 2007; Biermacher et al., 2009).

For an example of studies on economic feasibility in precision agriculture, the profitability of variable rate irrigation in corn production can be referenced. In this study, experiments were designed to compare variable rate treatments with conventional treatments to investigate the rate of return conversion in corn. In order to measure profitability, net return was used as a result of deducting the total variable cost of total returns. The result showed that the net return in variable rate irrigation yielded larger than conventional application. Despite the use of additional equipment and control in variable rate application, the benefit of using less irrigation water costs and appended yield compensated for the extra charges associated with variable rate irrigation (Lu et al., 2005).

Several studies investigating economic benefit of site specific management have found that increased variability in farm resource (soil fertility, for example) or problem (pest or weed infestation, for example) provides a higher return to precision agriculture (Olson, 1998).

Accepting the fact that sustainable agriculture is a social construct has led to the acceptance of the undeniable role of sociology in order to obtain agricultural sustainability. Due to the fact that agriculture is a comprehensive issue involving econo-

mics, technology, politics, international relations and trade, and biological and environmental problems, the social features of agriculture can be deduced (Karami and Keshavarz, 2010). According to the definitions of precision agriculture and understanding that the purposes of the issue coincide with the goals of sustainable agriculture, the social impact of utilizing precision agriculture technology cannot be ignored.

Like any other technology, adoption of precision agriculture is affected by a number of factors such as profitability levels compared to current farm practice, adaptability, ease of use, testing capability, ability to identify risks, and social conditions that can improve farmers social competency and provide a chance for participating in the experience (Robertson et al., 2007). It can also be expressed that adopting precision agriculture is not so irrelevant to social issues. Perceived ease of use, perceived usefulness, confidence, perceived net benefit, and educational level are among factors that influence intention to adopt precision agriculture (Figure 14) (Adrian et al., 2005).

Apart from the expression of the impact of social factors on adopting precision agriculture, the interactive impact of precision agriculture on social issues has not been neglected. The impact of sustainability on rural and social development is one of the issues that has been discussed for many years (Brinkerhoff et al., 1990; Anonymous, 2003).

Today precision agriculture is known as one of the advanced e-agriculture applications that supplies profitability, sustainability, and environmental protection using Information and Communication Technology (ICT) and other technologies. On the other hand, with regard to the role of e-agriculture and ICT in achieving rural development, it can be generalized to explain the role of precision agriculture in rural development. Despite the challenges in adopting precision agriculture, such as low level of literacy among farmers in general—which enables only a small percentage of them to use electronic devices and software— small size of fields, information asymmetry between farmers and regions, low labor employment opportunities, high costs of implementation, and lack of proper communication infrastructures, the opportunities for adopting precision agriculture in rural development can be stated as follows:

- Develops specialist consultant sectors that provide educational opportunities for farmers
- Offers opportunities to uplift the livelihood of the rural residents
- Capitalize on local knowledge to increase levels of knowledge for appropriate management
- Achieve more revenue through better management practices and managing risk
- Create opportunities for more participation in rural development projects
- Create awareness about the importance of land integration for better management
- Improve livelihoods through the responsible use and management of fragile ecosystems using the features of environment protection (Chandra and Malaya, 2011; Chapman and Slaymaker, 2009)

Traceability

According to EU law, "traceability means the ability to track any food, feed, food-producing animal or substance that will be used for consumption, through all stages of production, processing, and distribution" (Anonymous, 2007). The concept of traceability in agriculture simply refers to all stages of collection, classification, conservation, and application of data related to all necessary processes in the food supply chain in order to provide assurance concerning the origin, location, and product history for consumers and other stakeholders, as well as use in crisis management in case of problems in food quality and safety. Thus, traceability is the ability to detect the farm where the product has grown and inputs have been consumed. It also provides the ability to review records to determine the accurate location and product history in the food supply chain (Opara, 2003).

Regarding the definition of traceability in the field of food security and safety, it can be stated that traceability is the ability to document all relevant elements needed to determine a product's life history, such as movements, processes, and controls. Thus, traceability is as a tool for better and more effective management for food manufacturers, farmers, and end-users in terms of quality of the food product.

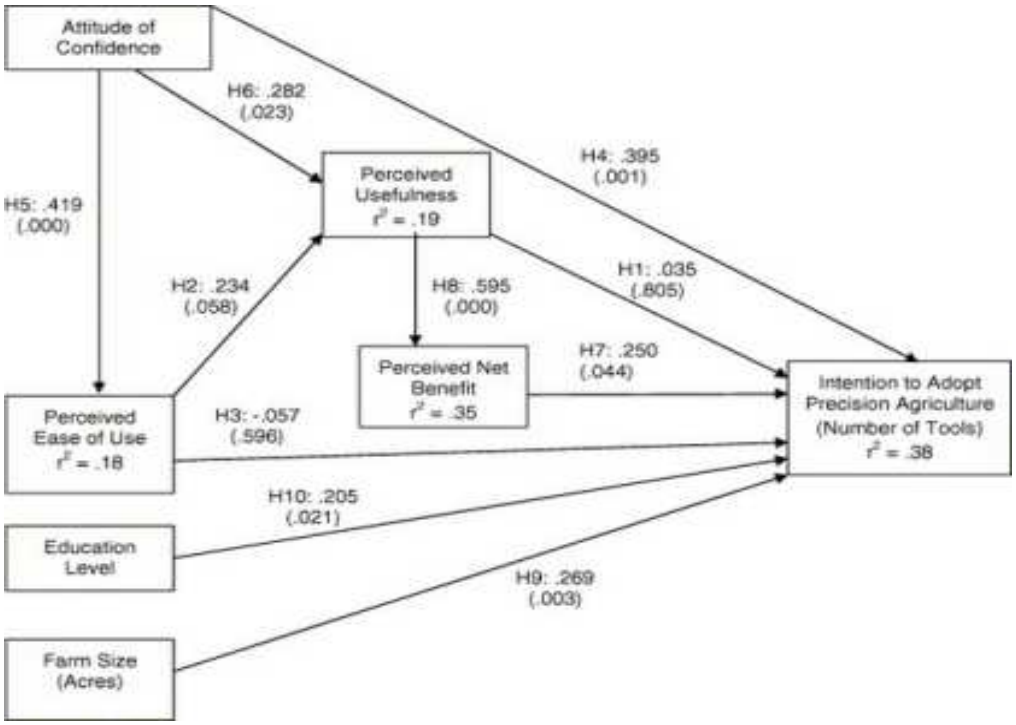


Figure 14: Proposed structural model and path analysis.(Adrian et al., 2005)

In addition to its effects on the promotion of food safety, detecting the source of possible contamination, facilitating the product recall procedure, and controlling risks related to public health arising from product consumption are among other goals of traceability to obtain food security (Raspor, 2005).

Besides the ability of traceability to track or recall products quickly and easily during a crisis, there are reports on the benefits of utilizing traceability that are mentioned below:

- Improves production efficiency
- Decreases labor requirements
- Decreases costs
- Improves inventory control
- Verifies product claims
- Improves food safety
- Other benefits (Ontario Report, 2012)

Despite the problems of implementing, maintaining, and operating traceability systems related to staff, customers, suppliers, consultants, and software, the benefits of using these systems are more than the mentioned problems and costs, which can be a suitable reason for the development of traceability systems (Sparling et al., 2006).

Precision agriculture can provide opportunities to track the products through a system. These opportunities include the process that describes all the practices that have been done to produce the final product. Consequently, the ability of product tracking and traceability becomes one of the main issues in precision agriculture research, especially tracking on-farm operations (McBratney et al., 2005). Using a geographic information system (GIS) as a tool of precision agriculture can provide facilities to improve traceability information by linking them with agro-environmental situations, such as soil condition, local properties, and catchment areas. Therefore, geotraceability can be defined as the ability to identify the characteristics of the direct and indirect environment of the field in order to document the history of the events happening in the production area that may affect the crops from planting to harvest (Oger et al., 2010).

One of the applications related to traceability in precision agriculture is using radio frequency identification (RFID) technology. In recent years, using RFID tags were developed in many areas of

agriculture such as livestock, horticulture, and cold chain application as well as precision agriculture. Expanded use of RFID in precision agriculture makes it possible to increase the efficiency, productivity, and profitability of farming systems while avoiding unwanted effects on the environment. Obtaining real-time information enables farmers to adjust strategies at any time by providing a solid base to recognize differences and alter management action accordingly. Because of easier installation of RFID compared to other wired systems, sensors can be widely used to obtain local information in details. Use of RFID in precision agriculture can include the following items:

- Measurement of soil temperature using wireless sensors
- Greenhouse temperature, relative humidity, and lighting conditions
- Matching bins of harvested fruits with corresponding trees during harvesting in orchards
- Off-road vehicles to helping fleet management
- Attachment to the products (seeds, fertilizers, pesticides, etc.) and the readers hat are installed in the machine, detecting what is put into the implement's hopper or tank (Ruiz-Garcia and Lunadei, 2011)

As an example of research using RFID, we can refer to an article by Peets et al. (2009) that was done to identify what data should be stored in an automatic recording system in order to track the application of agrochemicals. In this research, a prototype system was developed to identify and verify agrochemicals in traceability systems and reference existing national pesticide databases using RFID tags by employing a database for the record of detailed data (Figure 15). Country of registration, chemical type (e.g., herbicides, fungicides, and adjuvants), registration number (main identifier), container size, specific gravity, unit of measure (g, kg, ml, l), and a digital signature are among the essential information that can be stored in RFID labels. The results demonstrated its feasibility as a suitable route to store this information. Therefore, the ability to use these labels provides possibilities for identifying key parameters of pesticides and their location using an RFID reader while reducing the size of the database held on farms (Peets et al., 2009).

Nowadays, assuming the amount of information recorded and needed by farmers using universal protocols to establish communication between machines, tractors, and computers is increasingly expanded. The International Standard Organization Binary Unit System (ISOBUS) is one of these protocols in agriculture that is used to implement control and create a data communications network that allows farmers to control all equipment from different manufacturers (Figure 16). With the help of this system it is possible to collect the information automatically.

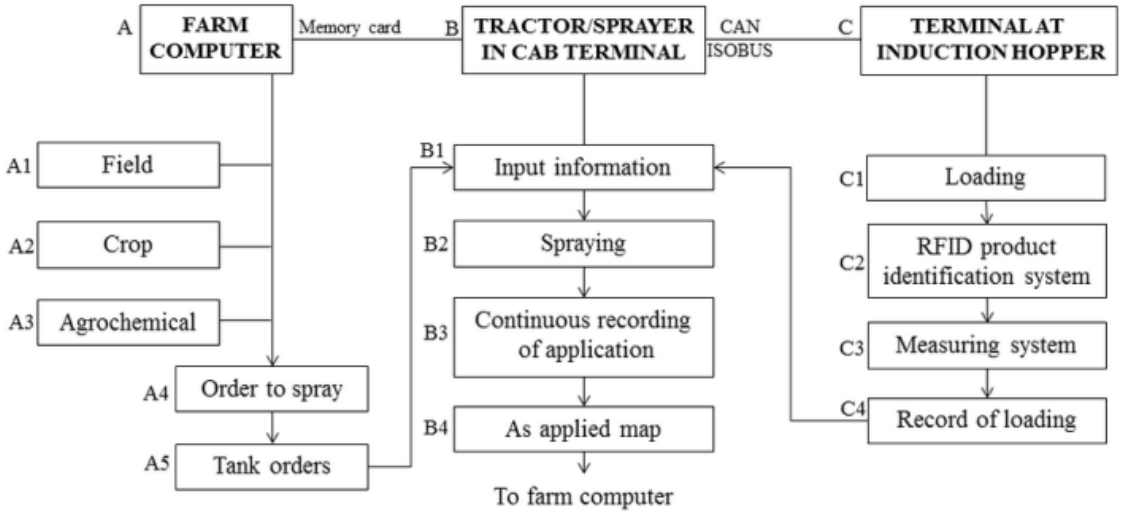


Figure 15: The outline of a data flow chart of a farm traceability system (Peets et al., 2009)

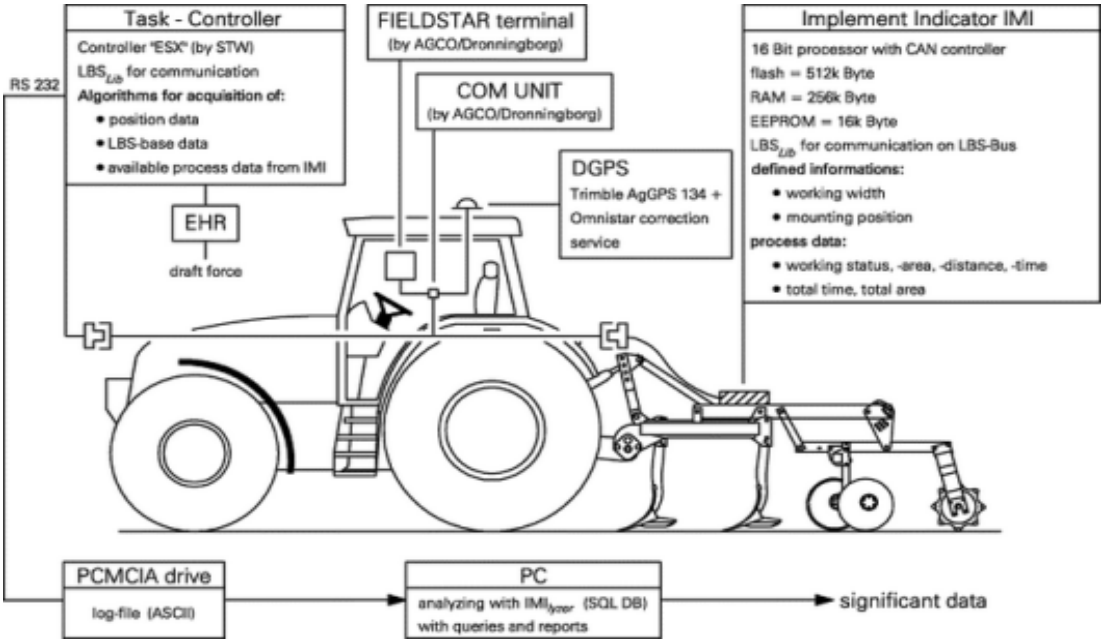


Figure 16: The process of data acquisition system using ISOBUS (Steinberger et al., 2009)

Then, by combining them with the time and location data, it will be possible to document the production process. Thus, a complete and comprehensive documentation of products and processes, including all changes in field processes is provided in precision agriculture, and this is what is needed in traceability.

In addition to using communication protocol, an information exchange protocol is also needed to track food from the farm to market. Using these protocols, such as AgroXML that is called Extensible Markup Language (XML), provides data interchange between farmers and those who are involved to get the product to the final recipient and consequently, the possibility of tracing back the food production in a farmer's field (Gebbers and Adamchuk, 2010).

Risk Management

Besides the impact of climate change on agricultural production, like what happened to farmers in Kenya and Zimbabwe who suffered from livestock loss and other losses in the droughts of the 1980s (Figure 17 illustrate food security risk index in 2013), a rise in production costs caused by crop and livestock diseases has a significant effect on reducing food abundance (Von Braun, 2009). It is necessary to make the decision on risk management, in spite of practical methods to increase production and biodiversity by genetic engineering.

Adopting precision agriculture to make decisions on risk management is used to get more and better information and improve control of crop growing conditions. The aim of this approach to risk management is site specific treatment of problem areas to decrease the probability of low yields and returns according to temporal variability in yields and net returns from season to season while also taking into account spatial variability. Despite high risks of using precision agriculture, such as not eliminating the probability of crop failure, financial risk due to investment in bad crop season, and human and technological risks, early estimation of yield using remote sensing data leads to improvement in farmers' confidence in early marketing. It also makes contracting easier by pushing agriculture closer to "producing to specification." This means that if farmers have more control over input application and yield quality, buyers are more willing to contract prematurely to ensure their return (Lowenberg-DeBoer, 1999).

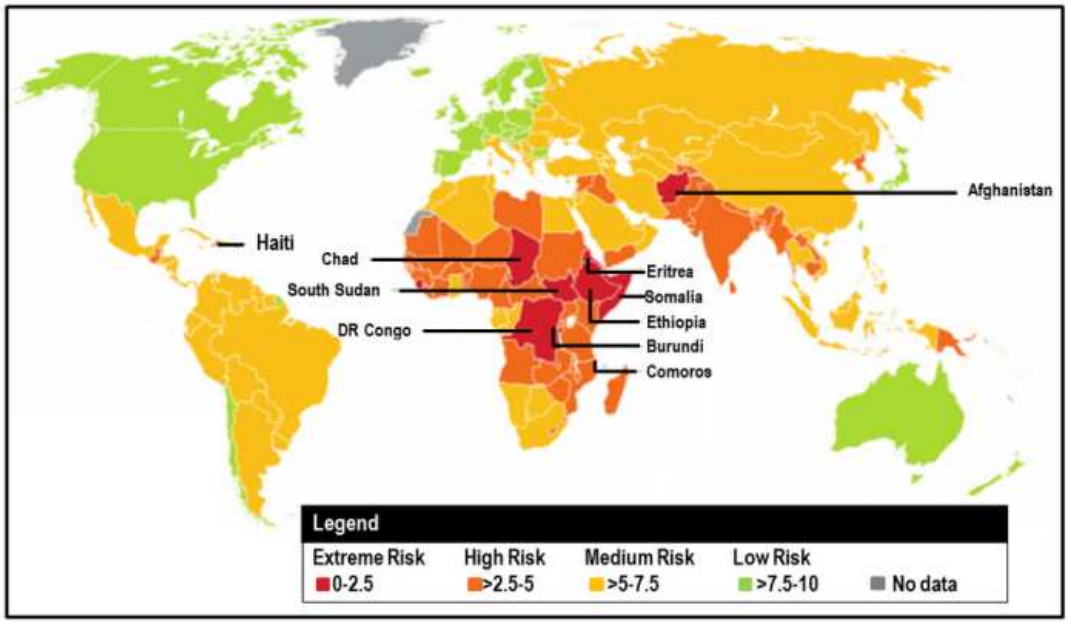


Figure 17: Food security risk index 2013 (Anonymous)

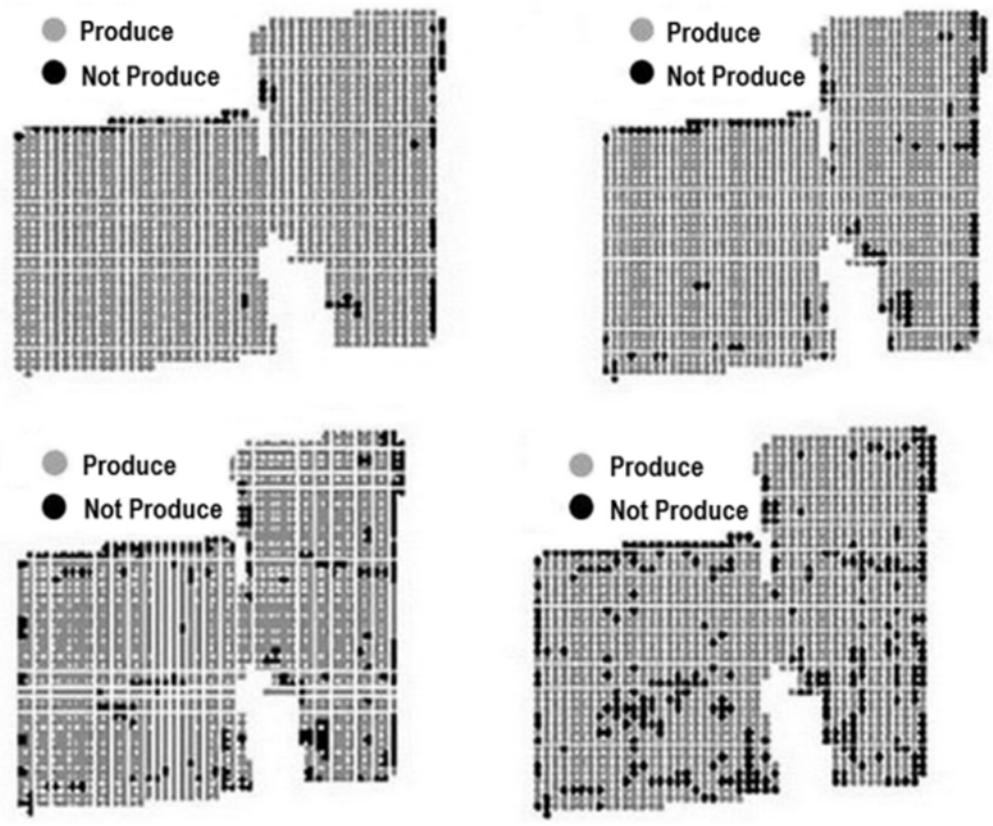


Figure 18: E-V risk maps of net return using 20 years average, decision not to produce. a) risk neutral, b) low risk averse, 3) medium risk averse, and d) high risk averse (Power et al., 2003)

Precision agriculture technologies provide some opportunities to collect and analyze information on a spatial basis for farmers. The collected information allows farmers to improve their decision making abilities on a spatial basis by calculating different levels of risk on their entire field. Few decision supports, such as risk assessment tools, have been suggested to help precision agriculture users to make decisions based on collecting data. To implement such a risk management system, performing the following procedures has been suggested: 1) measure risk by determining key statistics that are representative of changes in temporal risk, 2) integrate yield monitoring data with geographic information system (GIS) in order to visualize this temporal risk spatially throughout a field, and 3) analyze the resulting maps to present practical solutions. In order to map the risk, a break-even probability, a coefficient of variation (CV), and a mean-variance (E-V) has been introduced as appropriate risk statistics to create risk maps. Using these maps enables farmers to address the underlying issues creating this spatial risk (Powers et al., 2003).

As an example of using risk maps, a series of E-V maps of net return considering the non-production decision is illustrated in Figure 18. The dark areas on these maps show the areas that a farmer may choose not to produce on because of certain risk aversion levels given their break-even requirements. Because of high risk aversion, being aware of the existence of some risks in agricultural crop systems will be of a great help in removing more risky lands (Dillon et al., 2007).

Conclusion

While the discussion about future energy supply and use of clean and renewable energy sources are one of the vital challenges of recent centuries, the world population increase to 9 billion people over the next forty years and the issue of food security for this growing population has turned into one of today's primary concerns. In addition to providing sufficient food, a safe and nutritious food supply are the main parameters defined by food security. The use of various methods to increase the quality and quantity of agricultural products, such as using genetics to breed high quality and high yielding varieties, increasing the use of modern and spacious machinery to exploit more agricultural lands, employing other technologies, like robotics, in agriculture, and adopting suitable cropping patterns are among the solutions that are used to increase productivity.

However, the implementation of management practices to transition from traditional agriculture to modern agriculture has been addressed as one of the solutions to meet food security. In order to achieve this goal, the use of precision agriculture has been developed in recent decades. Precision agriculture, or site specific management systems, is an agricultural concept based on variabilities throughout the entire field that causes increasing productivity while decreasing costs and minimizing environmental impacts. Different types of technologies used in precision agriculture, from various remote sensing sensors to geographic information systems, are all tools that can help perform numerous applications, such as yield mapping, weed mapping, salinity mapping, and variable rate applications. These are used to improve farm management. Food security can be improved directly or indirectly by using each of these operations with their positive impact on product quality and quantity, sustainability, environmental protection, and product traceability.

With growing demands on the world's food supply and all the challenges related to the environment and energy resources, it's crucial to maximize agriculture resources in a sustainable manner. It seems that despite doubts about the economic feasibility of implementation of precision agriculture, the next generation will inevitably appeal to such practices.

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