Ethiop. J. Agric. Sci. 29(3)139-158 (2019)

Precision Agriculture and the Need to Introduce in Ethiopia

Getinet Alemaw[1] and Getachew Agegnehu[2]
[1] Ethiopian Agricultural Research Council Secretariat Addis Abeba, and
[2]Ethiopian Institute of Agricultural Research, Holetta Research Center

አህፅሮት

የዕቅጩ እርሻ የተለያዩ የረቀቁ የእርሻ መሳሪያዎች፣ የአይሲቲ ቴክኖሎጂዎችንና አሰራሮችን የሚያጠቃልል ሲሆን የሰብል ምርትን ሊቀንሱ የሚችሉ በማሳ ውስጥ ያሉ በተለይም የአፈር ተለያይነትን በመቀነስ ትክክለኛና ሰብሉ የሚፈልገውን የማሳ ዝግጅት፣ ዘር አዘራር፣ የመስኖ ውሀ አሰጣጥ፣ የማዳበሪያና ፀረ አረም በመጠቀም የሰብል ምርትንበማሳደግ ወጭን በመቀነስ ትርፋማነትን ማሳደግና በአካባቢ ላይ ሊደርስ የሚችል ተፅዕኖን በተለይም የአፈር ጨዋማነትንና በፀረ ተባይ የሚደርስ ጉዳትን በእጅጉ መቀነስ ነው። የዕቅጩ እርሻ በማሳ ውስጥ የሚታይና በዕፅዋት ፍላጎት ላይ የተመሰረተ ሲሆን የአፈር ካርታን ወይም በእርሻ ማሳሪያዎች ላይ የተገጠሙ የዕፅዋት ወይም አፈር የረቀቁ ሴንሰሮችን በመጠቀም ትክክለኛ ግብአትን መጠቀም ያስችላል። በአገራችን የሚታየው የአነስተኛ አርሶ አደሮች የማሳ ይዞታ የዕቅጩ እርሻን ለመተግበር ተግደሮት ቢሆንም፤ በክለክስተር የተደራጁ፤ ሰፋፊ እርሻዎች እና የስኳር ፕሮጀክቶችን ማሳን ለማስተካካልና ትክክለኛ የግብዓት መጠን በመጠቀም ምርታማነትን፣ ትርፋማትንና የምርት ጥራትን በእጅጉ ሊያሳድግ ይችላል ። ምንም እንኳ ለዕቅጩ እርሻ የሚውሉ የእርሻና የመገናኛ መሳሪያዎች ዋጋ እና የሚጠይቀው አጠቃቀቀም ዕውቀትና ክህሎት ከፍ ያለ ቢሆንም የሚሰጠው ጥቅም ከወጪው በእጅጉ እንደሚልቅ ጥናቶች አረጋግጠዋል።

Abstract

Precision Agriculture (PA) includes several techniques, technologies and management factors aimed at addressing field variation that affect crop yield by using more precise land leveling, seeding, fertilizer application, irrigation and pesticide use in order to optimize crop production, improve profitability and reduce environmental risk. PA recognizes temporal and spatial variability of production fields through information acquisition; interpretation; evaluation; and control. This can be achieved using map or management zones based on soil survey and property data or real time based for variable rate application of inputs while on the go. It has been shown that PA conserves irrigation water and power, improves profitability through correct application of fertilizers and pesticides, and reduces environmental risk. PA can be implemented in large and cluster farms as well as lowlands of Ethiopia particularly in irrigated fields. It can help to precisely level land, correct seeding, and application of the right amount of fertilizer, irrigation water, and pesticide based on the plant need. Despite its superior advantage, the high cost of machineries, software and skilled labor could scare the adoption of PA in Ethiopia. However, studies have shown that the benefits of PA out weights the cost and it can contribute to food security significantly.

Introduction

Shortage of land per household is severe and land degradation is widespread in the highlands of Ethiopia. The fertilizer rate and type used for many crops is based on blanket recommendation with limited site specific information (Agegnehu *et al*., 2015; Zeleke *et al*., 2010).

Despite large surface water resources in Ethiopia with 5.3 million hectares of land suitable for irrigation, less than a quarter of the area has been utilized using furrow and flood irrigation which waste water and exacerbate salinity and sodicity (IFPRI, 2010). In Ethiopia, since large- and small-scale farmers are using furrow and flood irrigation that resulted Ethiopia has been one of the countries affected by soil sanity in the world. The information on irrigation frequency, amount, and method of major crops at different crop growth stages on different soils is limited. Therefore, efficient irrigation technology is required for improved water and soil management.

Precision farming has been receiving more attention from researchers since the last decade. According to US House of Representatives (1997), PA is "an integrated information- and production-based farming system that is designed to increase long term, site-specific and whole farm production efficiency, productivity, and profitability while minimizing unintended impacts on the environment." The other definition is useful to narrow the PA philosophy down to its implementation in cropping systems, i.e. Site-Specific Crop Management (SSCM).

Precision farming, which provides a holistic approach, helps farmers to manage the spatial and temporal crop and soil variability within a field in order to increase profitability, optimize yield and quality, and reduce costs (Paustian and Theuvsen, 2017). Precision agriculture (PA) is considered as a paradigm shift in the management of variability within agricultural sector (Whelan and McBratney, 2000). Precision agriculture—also known as site-specific farming—is about doing the right thing, in the right place, in the right way, at the right time. Studies have shown that adopting precision farming (PF) has economic benefits for conventional crop farmers, such as yield increases, energy savings, and reduction of herbicide use. Conventional farming is the traditional form of farming, which is not certified as ecological or organic.

Following considerations of economies of scale, it was found that farm size positively impacts adoption of PF. The larger the farm, the greater is the likelihood of adoption of precision farming (Lambert et al., 2014; Reichardt and Jürgens, 2009). This can also be transferred to the size of arable land and leased land. However, owning more land exerts a greater positive influence on adoption of PF (Lambert *et al*., 2014; Roberts *et al*., 2004). Thus, large commercial farms are more likely to benefit economically from adopting PF on their farms. Large farms are not necessarily family-owned. Farms with increasing numbers of external employees are more likely to adopt PF (Reichardt and Jürgens, 2009), whereas small-scale family-owned farms with several family employees are less likely to adopt PF. On the other hand, having additional farm businesses in addition to crop farming also impacts adoption of PF. For example, livestock production negatively impacts PF adoption (Walton *et al*., 2008), whereas offering contractor services as an additional farming business often drives PF adoption (Kutter *et al*., 2011).

Over the past few decades, agricultural production has progressed from the machinery age to the information age with the growing use of precision agriculture (Reichardt and Jürgens, 2009). Precision Agriculture (PA), also called Precision Farming (PF) is an integrated information-and production-based farming system that is designed to increase long term, site specific and whole farm production efficiency, productivity and profitability while balancing the negative environmental impacts of agricultural activities and minimizing unintended impacts on the environment (Marino and Alvino, 2014). In this regard, various countries have shown different level of PA adoption due to various reasons. Precision farming has been practiced in many countries including in Africa. The significant factors influencing the adoption of precision agricultural technologies include socioeconomic; agro-ecological; institutional; information; farmer perception; behavioral; and technological issues (Tey and Brindal, 2012). This review provides a synthesis of the level, practice and future perspective of precision agriculture as well as the need and benefit of introducing the technology in to the Ethiopian Agriculture production system.

Literature search and review approach

A literature search was conducted through the Web of Science (apps.webofknowledge.com), Google Scholar (scholar.google.com), AGRIS (agris.fao.org), Research Gate (https://www.researchgate.net), Ethiopian Journal of Agricultural sciences, the Ethiopian Society of Soil Science (www.esss.org.et), and libraries of the Ethiopian Institute of Agricultural Research and National Soils Research Center. We searched the literature published up to 2019, using "precision agriculture", "precision farming", "smart agriculture", and "variable nutrient management" as key terms. Several publications that provide empirical evidence on precision agriculture were reviewed in this paper. The papers were grouped with respect to their research objectives and experimental types, and categorized into studies focusing on precision agriculture, smart agriculture, and precision farming.

A field survey of available farm machineries, irrigation methods, skilled personnel and etc. were made in Metehara and Wonji Sugar Estates, Melkassa and Kulumsa Agricultural Research Centers, GiZ Project at Kulumsa and Ethiopian Space Science and Technology Institute and Geospatial Information Institute. The field survey at Melkassa indicated the available skilled human resources on advanced farm machineries as well as tractor mounted spraying, Center Pivot Irrigation and sensors. The field assessment showed the production constraints that can be solved using precision farming particularly tillage and land leveling, precision seeding and, nitrogen, irrigation water and weed management. In sugarcane application of fertilizer, irrigation, herbicides, and reopeners can be easily managed using precision equipment. The field observation in the Sugar Estates, Kulumsa Agricultural Research Center led into the development of a project titled "Introducing Precision Agricultural Technologies in the Ethiopian Agriculture System" with five national and one international institute as partners. The consortium consists of Ethiopian Agricultural Research Council Secretariat, Ethiopian Institute of Agriculture Research, Geospatial Information Institute, Ethiopian Space Science and Technology Institute, Sugar Corporation and International Crop Research Institute for the Semi-Arid Tropics.

Yield Mapping

Precision agriculture includes several techniques, technologies, and management factors aimed at addressing field variation that affect crop yield. These variations can be soil type, pH and nutrient content, and water availability, weed and pest infestation. The purpose of implementing precision agriculture is to address these variations and improve efficiency and profitability of farm operations while at the same time sustaining the environment. A very important step of such management plan is yield mapping. Yield mapping is specially referred graphic representation of crop yield for a defined area and it includes acquisition, analysis, and summation of crop yield data by location within a field. Yield mapping can be viewed as an entry point and final outlet because they can be used to determine if there is enough variability to justify the use of precision agriculture and final gate because they can subsequently be used to determine if the investment in precision agriculture was worthwhile (Vellidis et al., 2013). Yield maps are created from data collected by a yield monitor – a sensor – or group of sensors – installed on harvesting equipment that dynamically measure spatial yield variability. Yield mapping requires 1/ Global positioning system (GPS), 2/ a combine mounted grain flow sensor and in case of cotton, cotton picker 3/ a sensor to measure ground speed and 4/ a data acquisition system (Birrell et al., 1996). In addition, a weigh bin mounted in the grain tank of the combine can be used to measure accumulated grain for sensor calibration. Cotton yield maps were produced for 63 acres in Oklahoma, for 58 acres in Alabama, for 300 acres in Arkansas, for 108 acres in Tennessee and for 204 acres in South Carolina to know exactly where the high and low yields were within field and confirm and justify for variable application of inputs (Vellidis et al., 2013). Based on yield maps, management factors of poor drainage in Oklahoma, variable rate seeding in Alabama and Arkansas, and variable rate nitrogen application in Tennessee were justified as precision farming management factors to enhance high yield.

Precision farming tools

Variable rates or site-specific application of inputs

Precision farming or site-specific farming is not a single technique but a range of multi-factual factors that aim to increase the precision of farm management. Many interpret this as a site-specific variation instead of a single entity within a paddock. There are a number of factors to be considered to establish a precision farming or variable rate application or site specific application of inputs particularly economic, environmental, agronomic or technological factors (Bobby et al 2011; Sugar Australia, 2017). One important technology related question is what method of variable rate application of inputs are available? The two basic technologies for variable rate application of inputs are map based and sensor based. In some cases, such as sugarcane (Sugar Australia 2017), map based control is commonly used. In this case, requirements of variable rate application systems include prescription maps to provide site-or zone specific input rates usually created using GIS, Global Navigation Satellite System (GNSS) to help the applicator interpret the prescription and variable rate capable machinery (sprayer, spreader, etc.) and a controller that uses application maps to vary the rate of input. Variable rate application of inputs require high level of data interpretation and benefits are higher when the amount of spatial variability is larger, the pattern of variability is in more coherent patches, variability patterns are stable and the cost of inputs is relatively high. Sensor based or real time based method provides the possibility to apply variable inputs without prior mapping or data involved (Bobby et al 2017). Real time sensors measures desired properties of soils or plants while on the go. Data measured with such systems are then processed and used immediately to control a variable rate application. The real time or sensor does not require the use of positioning system nor does it require extensive data analysis and interpretation.

Precision planting

Establishing optimum plant population and optimum spacing between plants minimizes interplant competition and helps to maximize seed yield. Seed rate and row spacing play important role in determining inter plant spacing, which is usually a function of planter and planter speed. Spacing anomalies, such as multiplies, skips, and misplaced seeds have varying effect on yield. Advances in planter technology varying from plate planters to finger meters, to vacuum meters have improved accuracy in plant spacing; the focus has changed to achieving perfect singulation at a higher ground speed. During plating, seeds are propelled through the seed tube at a speed of about 3.5 mph. As planter speed increases, the difference between the speed of the seed travelling out of the tube and the ground speed increases forcing the seed to bounce and roll over the furrow. However new technologies from farm machinery manufactures has enabled greater accuracy with higher ground speed. The John Deer 1725 NT Exact Emerge eight-row planter achieved good seed placement accuracy even at the speed of 20 kph with minimum gaps and doubles (Horst 2016). Adjusting seed rates based on soil condition in the field can improve overall field productivity. Maize planters with capability of varying seeding rates on the go are becoming more common (Asgrow and Dekalb, 2016). Variable rate seeding has been shown to be more practical with fields with soil variability particularly on areas with less ideal growing condition. Navigation and seed control devices can contribute accurate adjustment to seed rates.

Precision seed placement and the resulting leaf orientation have the potential to influence some of the parameters that controls productivity. Torres (2011) studied the influence of seed placement and leaf orientation on cumulative intercepted photosynthetic active radiation, radiation use efficiency, grain yield, and plant-to-plant yield inequality of maize (*Zea mays* L.). He concluded that precision planting tended to reduce plant-to-plant yield inequality, increase light interception, and promote changes in radiation use efficiency, which can result in yield improvement compared to conventionally planted seeds with random leaf orientation. Yang et al (2016) classified precision maize planters in four groups’ namely precision planters for tilled-land, minimum/no tilled-land, hilly and small land, and cold and arid land. High efficiency and accuracy for tilled-land, to clean residue from seed rows and prevent planters to be blocked for minimum/no tilled-land, light weight and small sized for hilly land and, equipped with plastic-film mulching mechanism for arid land are special features.

Site-specific weed management

Globally, the yield loss due to uncontrolled weeds reaches 43% (Christensen *et al.* 2009). In Ethiopia, uncontrolled weed infestation incurs loss of 54% on teff, 92 % in groundnut, 93% on sesame, 66% on linseed and 70% on haricot bean (Kassahun *et al.* 2009, Rezene *et al.* 2009). Weeds can be controlled manually, mechanically or using knapsack sprayers or tractor mounted sprayers. However most of the herbicide is lost to drifting, evapotranspiration, deposited on crops and ground and only a small fraction of the herbicide reaches to the target weeds. In addition to potential adverse condition to the environment and rise in concern in human health and residues on food and water their application incurs very high variable cost of production to farmers.

There is substantial evidence that weeds occur in patches and scattered across a field (Rezene *et al.,* 2009; Kassahun *et al*., 2009; Thorp and Tian, 2004). The aggregate distribution of weeds raises an opportunity to study the distribution of plants and different technologies to detect weeds spatial distribution of weeds and methods of herbicide applications. During the last two decades various rapidly growing and expanding technology for site specific and precision agriculture has been developed. Some of the hard and software includes tools for weed mapping and control that adapts spraying to sites of local weed patches (Christensen *et al.,* 2013). However automatic weed sensing is a prerequisite for site specific weed management. A wide range of weed sensing implements were developed and can be categorized into aerial based and ground based sensing using digital cameras or non-imaging technologies. The aerial imaging that uses Satellite or aircraft is important to map large fields and several farms. The ground platform using digital cameras is more promising for spatial treatment at a field with maximum resolution and greater proximity allows greater resolution of images. The first step in this method is segmentation in distinguishing between the plants and soil background and the second step is to distinguish between crops and weed plants. Hamouz *et al.* (20013) used site specific herbicide application to control weeds on 3.07 ha of winter wheat. The field was divided in to cells and blocks and weed infestation was identified manually to calculate patch index and threshold for each weed species. Four treatments blanket application along with three variable rate application of herbicides for three weed species were tested. The site specific or variable rate application of herbicides provided herbicide savings ranging from 15% to 100% depending on the herbicide and thresh hold used. The highest saving was achieved with cells with minimum infestation. The yield of winter wheat did not vary significantly among the treatments.

Huang *et al.* (2017) identified four weed remote sensing systems namely satellite that suits large scale regional studies, manned aircraft, site and time specific, UAV which is highly site and time specific with continuous three dimensional analysis and ground based. The ground based proximal remote sensing method is highly site and time specific but the observation is discrete and restricted by ground surface conditions. Ground based systems provide high spatial resolution data and are good for spot measurements and with limitations of slow movement from place to place and ground surface condition UAVs offer a unique opportunity for data acquisition and applying inputs such as herbicide. A major part of the UAVs is the pilot and the spotter and imaging sensors.

Table 1. Description and application of remote sensing systems for weed management (Huang et al., 2017)

Remote sensing system	Altitude	Swath width	Spatial resolution	Comment
Satellite	600-800 km	10-2800 km	1.25- 1000m $pixel^{-1}$	Large scale regional studies
Manned aircraft	500-1000m	1200-7150m	20-150 cm $pixel^{-1}$	Site and time specific
UAV	10-200m	20-400m	1-30 cm $pixel^{-1}$	Highly time and site specific with continuous three dimensional analysis
Ground based (proximal remote sensing)	< 5m	< 5 m	0.1-1 cm $pixel^{-1}$	Highly site and time specific but the observation is discrete and the operation is restricted by ground surface condition

In citrus various herbicides, fertilizers and pesticides are sprayed at variable rate using sensors, computers and GPs to automatically measure citrus trees along the row and make adjustment to amount of spray delivered to each tree (Zude-Sasse *et al.*, 2016). Spaces between tress and missing tress are not sprayed saving substantial amount of inputs

Site-specific nitrogen management

Agricultural intensification without adequate restoration of soil fertility may threaten the sustainability of agriculture. Appropriate management of soils could maintain soil health and agricultural sustainability, and minimize environmental risks such as soil pollution, soil acidification, loss of soil organic carbon, and soil salinization (Agegnehu and Amede, 2017; Zeleke et al., 2010). Variable fertilizer rate management can improve both fertilizer use efficiency and economic returns. Optimizing fertilizer use to obtain optimum economic yield normally has the added benefit of ensuring that deficiency of nutrients is not a limiting factor or excess fertilizer is not available for loss to the environment. Nitrogen is the most important nutrient element after water, but most research works have focused on placement, form, and timing of applied N to reduce losses from volatilization and denitrification. In contrast, less emphasis has been given to development of methods to adjust N rates in relation to the amount of N supplied by native soil resources. In order to effect variable fertilizer rate appication using sensor based methods: 1) Developing fertilizer replacement maps based on previous crop yield; 2) using biomass maps to identify in-crop nitrogen deficiency; 3) reducing the overlap to apply inputs at the desired levels; 4) targeting in-crop nitrogen to potential production can reduce crop lodging and increase yield; and 5) identifying least productive areas with yield maps to avoid from cropping and input application will be focused on productive areas.

Traditionally, farmers in Ethiopia apply nitrogen (N) uniformly as a blanket recommendations for field crops. However, due to large temporal and field variability in soil N supply the efficient use of N fertilizer is limited by using blanket recommendations. Sharma et al. (2010) indicated that blanket fertilizer N recommendations for large irrigated wheat areas may lead to low N-use efficiency (NUE) due to field-to-field variability in soil N supply and seasonal variability in yield. Thus, to achieve high NUE, a site-specific N management strategy using GreenSeeker™ optical sensor is recommended. Sensor-guided fertilizer N applications resulted in high yield levels and high N-use efficiency. For instance, application of 90 kg N ha^{-1} in two equal doses at planting and crown root initiation stage was the appropriate prescriptive fertilizer N management (Sharma et al., 2010). Thus, high NUE can be achieved by replacing blanket fertilizer recommendations by an optical sensor-based N management strategy consisting of applying moderate amount of fertilizer N at planting and crown root initiation stages and sensor-guided fertilizer N dose. Sensor based N-fertilizer management is especially relevant in irrigation agriculture as water is not a limiting factor for nutrient uptake and crop growth (Sharma *et al*., 2010).

Conventional agricultural practices have rarely achieved optimal efficiency in terms of yield or cost of production. Under such systems, inputs like fertilizer and pesticides are applied to prevent nutritional deficiency or losses in yield, at a uniform rate over an entire farm (Khanna et al. 1999). Such decisions are not based on information or a prescribed need, but typically made to avoid risk. More specifically, they overlook field variability. For example, over-application of fertilizers results in input losses through leaching and runoff, which cause adverse effects on resource quality (e.g. soil and water). There are, in turn, consequential impacts for plants, ecosystems, the economy, and population. Therefore, resource misallocation has serious implications for sustainability and food security (Tey and Brindal, 2012). Such realizations have focused attention on increasing the efficient use of agricultural resources. The answer to specific aspects of this problem is the adoption of precision agriculture. Precision agriculture is a production system that involves crop management according to field variability and site-specific conditions (Seelan *et al.*, 2003).

Precision agricultural technologies simultaneously enhance production efficiency and environmental stewardship. Variable rate fertilizer application addresses fertilizer use based on field and crop variability i.e., applying only what the plant needs, or soil can handle. Sensor- based nutrient management is the direct measurement of the need of plants or soil. Application of N that corresponds to the spatial variability of the N need of crops not only leads to increased N use efficiency; but also reduced fertilizer N-related environmental pollution (Khosla and Alley 1999). Surprisingly, as much as 70% of the total N leached comes from as little as 30% of the total field area (Kranz and Kanwar, 1995). In contrast, Vellidis et al. (2011) indicated that when variability in crop status is caused by factors others than N availability, the prescription of N variable rate is much more difficult. Increasing pressure for food security and sustainability as well as a need to halt environmental degradation has focused attention on increasing the efficient use of farm resources (Tey and Brindal, 2012).

Real time nitrogen adjustments

Improving N use efficiency reduces the amount of N that can potentially be lost through leaching. Nevertheless, management of N is a major challenge due to the unidentified factors related to weather such as air temperature and rainfall levels. To minimize the risk associated with the required amount of N available to the crop, various tools from handheld chlorophyll meters to multispectral sensors mounted in aircraft or on high clearance equipment have been developed by researchers. These tools can be used to help make N management decisions during the growing season and can provide in-season measures of N sufficiency. They provide the potential to fine-tune N management decisions by reacting to changing crop and weather conditions during the growing season (Minotta and Pinzauti, 1996; Hergert *et al.,* 2011).

Crops show variable response to N because of the difficulty in estimating the amount of N mineralized from soil organic matter during the development of the crop and high losses by leaching in the soil profile. According to Cantarella et al. (2007) nitrogen use efficiency (NUE) in sugarcane is less than 40%, lower than most crops cultivated in Brazil, between 50 and 70%. NUE could be increased with the use of methods that estimate the crop response in a particular situation of climate and soil N content during the season, which would allow the N variable rate application (Solari, 2006).

Leaf chlorophyll meter

Research indicates a close link between leaf chlorophyll content and leaf N content in crops, which makes sense because the majority of leaf N is contained in chlorophyll molecules. Chlorophyll meters enable agronomists to quickly and easily measure potential photosynthetic activity, which is closely linked to leaf chlorophyll content, crop N status, and leaf greenness. The chlorophyll meter records the reflection of light in the photosynthetically active waveband of plant leaves and can be used to monitor crop N status and potentially increase N use efficiency (Hergert et al., 2011). The chlorophyll meter has several advantages over other tissue testing methods. Samples don't need to be sent to a laboratory for analysis, saving time and money. The use of the chlorophyll meter is nondestructive and permits repeated measurements throughout the growing season. Plants produce as much chlorophyll as possible until something else becomes limiting. As such, luxury consumption of N does not increase leaf chlorophyll content. This causes meter readings to reach a plateau when N availability is adequate, regardless of how much extra N is taken up by the plant. Using a chlorophyll meter to monitor leaf greenness throughout the growing season can signal the approach of a potential N deficiency early enough to correct it without reducing yields. This approach makes chlorophyll meters especially useful where additional N can be applied through sprinkler irrigation systems or with high-clearance equipment such as a sprayer (Raun *et al*., 2002; Ferguson et al., 2011; Hergert *et al.*, 2011).

As indicated in Figure 1, the study of Agegnehu et al. (2016) indicated that chlorophyll content of barley leaf increased. Leaf chlorophyll was also positively and significantly correlated with plant N concentration and grain yield of barley. The use of the chlorophyll meter is nondestructive and permits repeated measurements throughout the growing season.

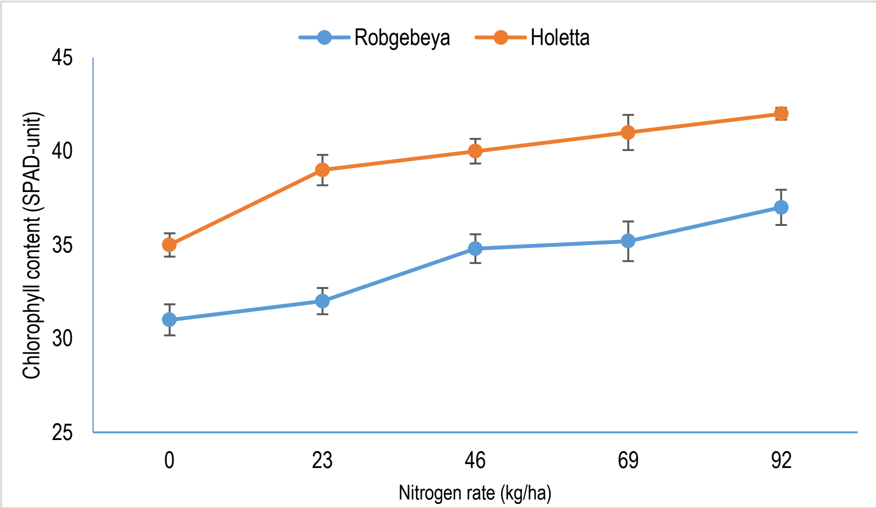

Figure 1. Mean chlorophyll content of barley leaf as influenced by N application N rates. Error bars represent ±1SE. Data synthesized from Agegnehu et al. (2016).

Crop canopy sensors/ground-based remote sensors

Recent advances in PA technology have led to the development of ground-based remote sensors or crop canopy sensors. One of these alternative methods is the use of ground-based active crop canopy sensors, a technology widely studied in crops highly domesticated such as wheat (Berntsen et al., 2006) and corn (Kitchen *et al.*, 2010). These sensors essentially measure the amount of light reflected from the crop canopy. Active sensors have their own source of light energy and allow for the determination of reflectance measurements at specific times and locations throughout the growing season (Hergert *et al.*, 2011). This kind of sensor has been effective for N fertilization in these and other crops (Ferguson et al., 2011; Vellidis *et al.*, 2011).

However, in crops such as sugarcane, with relatively few research findings of its physiology and nutrition, the use of this technique for N recommendation is still a challenge. Researches with canopy sensors on sugarcane have been conducted in Brazil. Amaral and Molin (2011) tested the canopy sensors GreenSeeker and CropCircle ACS-210 on sugarcane and found significant regressions between N rates and their NDVI values. Portz et al. (2012) reported that N-Sensor ALS was able to identify the variability of biomass and N uptake on sugarcane. According to Amaral and Molin (2011), there are good possibilities of N recommendation for sugarcane based on canopy sensors. However, they emphasize the necessity to prove its effectiveness, both in terms of economic return and non-occurrence of longevity reduction of sugarcane ratoons due to the application of low N rates.

Crop canopy sensors are used much in the same way as the chlorophyll meters. However, the crop canopy sensors do not need to be directly attached to the leaf. They are placed about 0.60 m above the canopy and collect data as the sensor moves through the maize crop, which are usually attached to a high clearance tractor (Fig. 2). This allows the crop canopy sensors to cover a lot of ground in a short period, thus recommendations for supplemental N fertilizer can be made on a field scale. A strong relationship exists between leaf chlorophyll concentration and leaf nitrogen (N) concentration (Hergert et al., 2011; Agegnehu *et al.*, 2016). Hence, greater leaf area and green plant biomass levels result in higher reflectance and higher subsequent sensor readings as these variables are directly related to the N content of the plant, higher values relate with higher plant N content. These properties allow sensors to be a valuable tool in determining the relative plant N status by comparing the plants with sufficient N to plants with an N deficiency.

Fig. 2. Plant chlorophyll sensors used to adjust nitrogen fertilizer application.
Source: Hergert et al. (2011)

Site-specific irrigation management

Precision irrigation refers to the management of irrigation amount and frequency based on the crop need. The amount of water applied to the crop is based on measurement of soil, crop, and weather variables that refers to the status of the plant. The major goal of precision irrigation is raise in water efficiency, the reduction of energy consumption and maximization of crop productivity using the technology such as wireless sensors networks, mobile devices, remote sensing, and real time control and information system (Lozoya *et al* 2016). The components of VRI consist of pivot control panel, VRI control panel, Solenoid vales, control nodes, GPS system, variable frequency drive and remote control system (Payero *et al* 2017). The pivot control panel controls the start/stop of the pivot and the travelling speed. The VRI control panel controls operations specific to the VRI system including irrigation application rates in response to the irrigation management map. Solenoid valves are used to control flow to the sprinkler heads. Mohammed et al (2011) compared Sprinkler irrigation (SP), surface drip (DI) and Subsurface drip (SDI) for alfalfa production in Saudi Arabia. Water irrigation module was used to fully control the irrigation methods. In this method, the water requirement of the growing plants is calculated based on the available soil moisture of the root zone area. According to Mohammed (2011 growth parameters of the alfalfa was better for SDI than SP and DI with the least water supply and highest irrigation water use efficiency. The increase in dry yield was 45 % higher for SDI as compared with SP.

Sui *et al* (2015) in Mississippi USA studied yield response of maize to variable rate irrigation (VRI) for two years. The VRI systems were equipped with five VRI zone control units, a global positioning system (GPS) receiver, and computer software. Each zone control unit controlled the duty cycle of the sprinklers in the zone to realize variable rate water application across the pivot laterals. The GPS system determined the pivot position for identification of control zones in the real time. There was no significant yield difference between five irrigation rates except the irrigation efficiency and water productivity. Sui (2015) compared variable rate irrigation with uniform irrigation in soybean and maize in Stoneville, Mississippi. A center pivot VRI system was employed for delivering irrigation water and soil electrical conductivity was used to delineate management zones and create VRI prescriptions. Irrigation was scheduled using soil moisture content measured by soil moisture content. There was no significant difference in terms of seed yield but VRI saves 25% irrigation water in soybean and 21% in maize as compared to URI. Irrigation water productivity of VRI was 32.2% and 27.1 % higher than the URI in soybean and maize. Jobbagy et al (2011) employed precision irrigation for potato production in Slovak Republic on 22 ha field.

The basic hydrological data particularly wilting point and the field capacity were measured on 19 points and the soil moisture factor was decisive for irrigation rate measured across the points. As compared to the conventional uniform application of irrigation, precision irrigation saved 478.56 m^3/ha of water, electric power of 249.68 kW/ha with overall cost reduction of 23.8%. Jobbagy et al. (2011) concluded that, although the initial cost of software and technology is significant, precision irrigation is very effective farming practice. Rumiao et al (2015) studied the influence of URI and VRI on growth and yield of winter wheat in the alluvial flood plain at the experimental station of China Agricultural University in Zhuozhou, Hebei Province. The experiment was conducted using center pivot on 1.64 ha divided in to four blocks and two sub blocks for URI and VRI. TDR probes at different locations and depths in both VRI and URI treatments were used to trigger an irrigation event measured real time soil water contents. There was no difference in mean plant height, leaf area index, and yield between plots treated under URI and VRI. The study concluded that AWC could be used as a representative parameter to determine management zones.

Global adoption in precision agriculture

In Australia, interest in Precision Agriculture (PA) has increased rapidly within the grain growing regions over recent years (David et al., 2007). Many farmers have invested in machinery guidance systems and yield monitors, but few are using the technology to manage spatial variability across farming zones. An economic analysis showed the cost of a basic PA system to achieve Site Specific Crop Management with a yield monitor, 2 cm auto-steer machinery guidance, variable rate sowing equipment and computer software could add about 8% or AU$ 20/ha/year to average input costs over 5–10 years where 1000 ha are cropped annually. The justification of this extra cost will depend on the situation, particularly the amount of variation present, efficiency gains, yield increases, and/or the value individual farmers place on factors like reduced operator fatigue, extended working hours, and certain environmental benefits. PA technology has decreased in cost since its introduction and if this trend continues, adoption is likely to increase in the future and this will be supported by the ongoing collection of soil, yield, and field data. Adoption is likely to be enhanced by farmer, manufacturer, and researcher collaboration to demonstrate the benefits of this technology on a commercial scale. Before investing heavily in PA tools, interested farmers can evaluate the technology, whilst estimating the degree of variation present in fields and the potential benefits of PA by engaging contractors and consultants with the appropriate tools.

In Argentina farmers in the province of Cordoba, Pampas and Bones Aires, often equip their combine harvesters with yield monitors (Bongiovanni and Lowenberg, 2005). Differential Global Positioning System (DGPS) is available from private companies for broadcasting information. Guidance systems for agricultural chemical applicators are the fastest growing PA Technologies as they are easy to use and lead into immediate benefit. In addition, Variable Rate Technologies are used for seeding and fertilizer application. Studies have shown that large farms with relatively high capital per worker and highly educated and professional farm managers are likely to adopt precision agriculture. Factors that affect adoption of PA in Argentina include high investment cost, knowledge, and skill to manage the technology. In Africa PA is being used in Kenya, Zimbabwe, Sudan, and South Africa. In South Africa, farmers have reported that the costs saved while using variable rate fertilizer and irrigation are the major factors in adopting precision agriculture (Jacobs *et al.*, 2018). Ncube *et al*. (2018) suggested that African farmers could benefit from PA in terms of increase in water and nutrient efficiency and timely carrying activities such as weeding. Benefit from precision agriculture include soil preparation, fertilization, irrigation, and weed management. In Africa, the benefits of precision agriculture include improved food security through increases in water and nutrient use efficiency, and timely management of activities such as weed control. Precision agriculture has saved costs of inputs in both commercial and smallholder farming in Africa. Pollution control of ground and surface water sources has slowed down where fertilizer and agrochemical applications are now more efficient. The Chameleon and Wetting Front Detector Sensors have enabled small-scale farmers in Mozambique, Tanzania, and Zimbabwe to cut down irrigation frequency fifty times and double productivity. It is clear that precision agriculture has played a major role in improving food security in Africa through the efficient use of inputs such as fertilizer and water, while also reducing environmental pollution and degradation.

In general, it appears that countries such as USA, Australia, Canada, and Argentina are likely to use wide spread use of precision agriculture due to financial, farm size and education level. In the US, PA has been the most significant innovation introduced into the agricultural system during the 1980s but adoption has not meet expectations for 10-15 years. The major reasons were attitude and willingness or adopters did not realize that there are problems that can be solved by the technology. During the last decade of the 20th century, there was accelerated adoption of precision farming among producers and commercial businesses. The major reason was certain technologies of precision farming were tested and proven to enhance efficiency, productivity and profitability in environmentally responsible manner; positive change in commodity prices that increased many fold; introduction of new precision farming technologies such as auto guidance system that help to work longer hours; and availability of skilled labor to use the technology.

Implications of precision farming for Ethiopia

The Ethiopian land holding is less than one hectare in the highlands and a bit more in Afar, Gambella, and Somali Regions. Hence, adoption of precision farming may be difficult, as the technology requires large farms of at least 60 hectares. However, the current system of cluster-based farming for a single commodity (several hundred farmers clustered to grow a single crop variety) may open the possibility of adoption for site-specific input application. The high cost of initial investment on machineries, soft wares and the skilled labor that can use it may scare adoption of precision farming. However studies (David et al. 2007, Hamouz et al. 2013, Jenson 2012) have shown that the benefit out weights the investment cost. On the other hand, there is vast fertile land suitable for irrigation in Awash, Omo, Wabe Shebelle, and Dawa Genale Valleys (Table 2, Fig 3.). These valleys are suitable for irrigated wheat, rice, maize, pulses, and horticultural crops production. Ethiopia is importing 30% of wheat, 70% of sugar and rice, and 85% of the vegetable oil annual demand from abroad. This has brought a huge burden for the economy which otherwise would have been used for development. Hence the government of Ethiopia has a project to intensify the productivity of wheat in the highlands and increase the area of wheat production in the lowlands of Afar, Wabe Shebelle and Omo valleys using irrigation. In Afar region, the temperature is mild and suitable for cereals and horticultural crop production during the months of October to January while the Omo valley does not have a cool season. Heat tolerant wheat verities developed at Werer Agricultural Research Center gave a mean seed yield of 42 q/ha at four locations in Awash Valley (Berhanu Megersa personal communication 20119) and up to 50 q/ha at Omorate and Woito in Omo Valley (Table 3). However, Irrigation water amount and frequency, fertilizer type and amount, and weeding practices are not studied. Hence, site-specific input application can assist tremendously in irrigation water, herbicide, and fertilizer applications. The current method of furrow irrigation promotes salt affected soils which can only be minimized using sprinkler irrigation particularly center pivot and site-specific irrigation management. In addition to the productivity and profitability, the advantages of site specific irrigation management includes to conserve water (based on the crop need only), minimize herbicide damage by applying the chemical on the weed only and applying fertilizer at the right amount, time or crop stage on specific site. Hence, the farmer minimizes production cost, utilize inputs efficiently with minimum harm to the environment.

Table 2. Irrigation potential in the river basins (Sileshi, 2010)

River basin	Catchment (km^2)	Irrigation Potential in ha and size			
		Small	Medium	Large	Sum
Abay	198,890.7	45,856	130,395	639,330	815,581
Tekeze	83,475.94	N/A	N/A	83,368	83,368
Baro-Akobo	76,203.12	N/A	N/A	1,019,523	1,019,523
Omo-Gibe	79,000	N/A	10,028	57,900	67,928
Rift Valley	52,739	N/A	4,000	45,700	139,300
Awash	110,439.3	30,556	24,500	79,065	134,121
Genale-Dawa	172,133	1,805	28,415	1,044,500	1,074,720
Wabi-Shebele	202,219.5	10,755	55,950	171,200	237,905
Danakil	63,852.97	2,309	45,656	110,811	158,776
Ogaden	77,121				
Ayisha	2,000				
Total	1,118,074.53	3,731,222	Total	1,118,074.53	3,731,222

Precision farming technology can be introduced in large farms such as Sugar Estates, cotton, and cereals farms in the low lands and fits well with the cluster approach of farming in the high and mid altitudes. The technology enables correct tillage, land levelling and seeding resulting in uniform crop stand establishment and maturity that maximizes product quality and minimizes loss. Precision farming saves irrigation water, energy, reduces the cost of herbicides, and assists the correct application of fertilizer. Ethiopia has vast fertile lands suitable for irrigation, however, the current method of furrow irrigation promotes salt affected soils, wastes water (Figure 4) and energy, hence precision irrigation using center pivots can sustain soil health and saves water and energy. The newly established sugar projects such as Tendaho, Beles, Kuraz, Kesem, Arjo-Dedessa and Welkite and planned ones at Gode and Borena covers large acreage of irrigated land. Nevertheless, sugarcane is large plant and requires unmanned Arial Vehicle to apply herbicides and ripeners. The cost of the technology such as hard and soft wares, unmanned Arial Vehicles, and sensors is getting cheaper by the day.

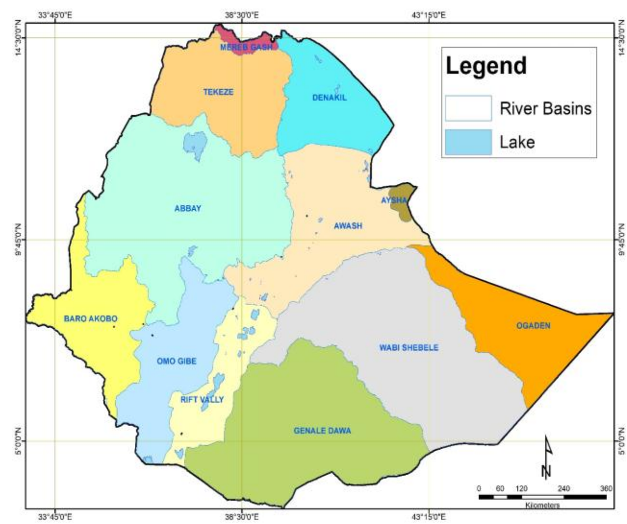

Figure. 3 River Basins in Ethiopia (after Seleshi, 2010).

Figure 4. Furrow irrigation on wheat and on maize at Omorate (Photo Getinet Alemaw 2019).

Table 3. `Mean Grain Yield of nine bread wheat varieties grown in South Omo during 2018 at two locations (Getinet et. al., 2019).

Genotype	Location mean (t/ha)	
	Omorate	Weito
Gambo	3.1	2.3
Fentale-1	2.7	3.1
Fentale-2	2.5	2.2
Amibara-2	4.3	4.1
Amibara-1	3.6	2.3
Werer-2	4.0	3.5
Pavon-76	3.2	2.0
Denda	3.9	2.3
Lucy	4.9	4.6
Mean	3.5	2.9

Note. Altitude 371 at Omorate and 560 at Weito m

References

Agegnehu G, B Lakew, and PN Nelson. 2014. Cropping sequence and nitrogen fertilizer effects on the productivity and quality of malting barley and soil fertility in the Ethiopian highlands. Archives of Agronomy and Soil Science 60: 1261-1275.

Agegnehu G, PN Nelson, MI Bird, and C van-Beek. 2015. Phosphorus response and fertilizer recommendations for wheat grown on nitisols in the Central Ethiopian highlands. Communications in Soil Science and Plant Analysis 46: 2411–2424.

Agegnehu G, PN Nelson, and MI Bird. 2016. Crop yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. Soil and Tillage Research 160: 1-13.

Agegnehu G and T Amede. 2017. Integrated soil fertility and plant nutrient management in tropical agro-ecosystems: A review. Pedosphere 27(4): 662-680.

Amaral LR and JP Molin. 2011. Optical sensor to support nitrogen fertilization recommendation for sugarcane crops. (In Portuguese, with English abstract.) Pesqui. Agropecu. Bras. 16: 1633-1642.

Asgrow and DEKALB. 2016. Population and variable rate seeding for corn, Asgrow and DEKALB, USA.

Berntsen J, A Thomsen, K Schelde, OM Hansen, L Knudsen, N Broge, H Hougaard, and R. Hørfarter. 2006. Algorithms for sensor-based redistribution of nitrogen fertilizer in winter wheat. Precis. Agric. 7: 65-83.

Birrell Stuart J, AS Kenneth, CB Steven. 1996. Comparison of sensors and techniques for crop yield mapping, Computers and Electronics in Agriculture 14: 215-233

Bobby R, M Alley, W Thompson, and D Holshouser. 2011. Precision Farming tools; Variable rate application, Virginia Cooperative Extension, publication no.442-505.

Bongiovanni R and J Lowenberg-DeBoer. 2005. Precision Agriculture in Argentina 3° Simpósio Internacional de Agricultura de Precisão, EMBRAPA Brazil.

Cantarella H, PCO Trivelin, and AC Vitti. 2007. Nitrogen and sulfur in sugarcane crop (p. 355-412). I*n:* T Yamada, SRS Abdalla, and GC Vitti (eds.), Nitrogen and sulfur in Brazilian agriculture. IPNI Brasil, Piracicaba, SP.

Christensen S, HT Sogaard, P kudsk, M Norremark, L Lund, ES Nadim, and R Jorgensen. 2009. Site specific weed control technologies, Weed Research, 49:-233-241.

David CJ, JN Bernard, GW Nicholas, MN Robert. 2007. The adoption of precision agriculture in an Australian broad acre cropping system Challenges and opportunities. Field Crops Research 104: 68–76

Duvick DN. 2005. The contribution of breeding to yield advances in maize (*Zea mays* l.). Advances in agronomy 86: 83-145.

Ferguson R, J Shanahan, D Roberts, J Schepers, F Solari, V Adamchuk, and L Shiratsuchi. 2011. In-season nitrogen management of irrigated maize using a crop canopy sensor. In: J.V. Stafford, editor, Precision agriculture. Proceedings of the 8th Conference European on Precision Agriculture. Czech Republic, Prague: ECPA. p. 503-513.

Getinet Alemaw. Anteneh Tadesse, Kaleb Kelemu, Awoke Tadesse, Agdew Bekele, Mehiretu Amanuel, Tesfaye Haregewoyen, and Berhanu Megerssa 2019. Report on Adaptability of Heat Tolerant Wheat Varieties under Irrigation in South Omo Zone During 2018, (Unpublished).

Hamouz P, K Hamouzova, J Holec, and L Tyser. 2013. Impact of site specific weed management on herbicide savings and winter wheat yield, Plant Soil Envirn.59:101-107.

Hergert GW, R Ferguson, C Wortmann, C Shapiro, and T Shaver. 2011. Enhanced efficiency fertilizers: Will they enhance my fertilizer efficiency? In: Crop Production Clinics Proceedings. pp. 145-148.

Horst Georg 2016. High Speed precision planting, John Deer, USA.

Huang Yanbo, NR Krisdhna, SF Reginald, and P Dean. 2017. UAV Low altitude remote sensing for precision weed management, Weed Technology 1-6.

IFPRI. 2010. Irrigation potential in Ethiopia: Constraints and opportunities for enhancing the system. International Food Policy Research Institute (IFPRI), Addis Ababa, Ethiopia.

Jacobs AJ, JJ Van Tol, and CC Du Preez. 2018. Farmer's perception of precision agriculture and the role agricultural extension: A case study of crop farming in the Schweizer-reneke Region South Africa. S. Afr. J. Agric. Ext. 46 (2): 107 – 118.

Jensen HG, LB Jacobsen, SM Pedersen, and E Tavella. 2012. Socioeconomic impact of widespread adoption of precision farming and controlled traffic systems in Denmark. Precision Agriculture 13(6): 661-677.

Jobbagy J, J Simonik, and P Findura. 2011. Evaluation of efficiency of precision irrigation for potatoes. Res. Agr. Eng. 57: 514-523.

Kassahun Zewdie, Tadelle Amede and Weldeyesus Sinebo. 2009. Review of weeds research in oil crops in Ethiopia. pp. 339-354. In: Abraham Tadesse, (Eds.). Increasing crop production through improved plant protection Vol. II, Plant Protection Society of Ethiopia (PPSE), PPSE, Addis Abeba Ethiopia.

Khanna M and D Zilberman. 1997. Incentives, precision technology and environmental protection. Ecological Economics, 23, 25–43.

Khosla R and MM Alley. 1999. Soil-specific nitrogen management on mid-Atlantic coastal plain soils. Better Crops 83: 6–7.

Kitchen NR, KA Sudduth, ST Drummond, PC Scharf, HL Palm, DF Roberts, and ED Vories. 2010. Ground-Based Canopy Reflectance Sensing for Variable-Rate Nitrogen Corn Fertilization. Agron. J. 102: 71-84.

Kutter T, S Tiemann, R Siebert, and S Fountas. 2011. The role of communication and co-operation in the adoption of precision farming. Precision Agriculture 12(1): 2-17.

Lambert DM, BC English, DC Harper, SL Larkin, JA Larson, DF Mooney, RK Roberts, M Velandia, and JM Reeves. 2014. Adoption and frequency of precision soil testing in cotton production. Journal of Agricultural and Resource Economics: 106-123.

Lozoya CM, A Aguilar, A Roman, and R Castello. 2016. Sensor-based model driven control strategy for precision irrigation, Journal of Sensors 1-12.

Marino S and A Alvino. 2014. Proximal sensing and vegetation indices for site-specific evaluation on an irrigated crop tomato. European Journal of Remote Sensing 47(1): 271-283.

Minotta G and S Pinzauti. 1996. Effects of light and soil fertility on growth, leaf chlorophyll content and nutrient use efficiency of beech (Fagus sylvatica L.) seedlings. For. Ecol. Manag. 86, 61–71.

Mohammed HA and MI Saleh. 2011. Effect of precision irrigation on productivity and water use efficiency of alfa alfa under different irrigation methods in arid climates. Journal of Applied Science Research 7: 299-308.

Nucuba B, W Mupangwa, and A French. 2018. Precision agriculture and food security in Africa in System analysis and global challenges. Springer International Publishing AG Austria PP 159-178.

Paustian M and L Theuvsen. 2017. Adoption of precision agriculture technologies by german crop farmers. Precision Agriculture 18(5): 701-716.

Payero J and AK Edisto. 2017. What is variable rate irrigation? Clemson Cooperative Extension USA. Precision agriculture: A learning community approach. Remote Sensing of Environment, 88, 157–169.

Portz G, JP Molin, and J Jasper. 2012. Active crop sensor to detect variability of nitrogen supply and biomass on sugarcane fields. Precis. Agric. 13: 33-44.

Raun WR, JB Solie, GV Johnson, ML Stone, RW Mullen, KW Freeman, WE Thomason, and EV Lukina. 2002. Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application. Agron. J. 94: 815-820.

Reichardt M and C Jürgens. 2009. Adoption and future perspective of precision farming in Germany: Results of several surveys among different agricultural target groups. Precision Agriculture 10(1): 73-94.

Rezene Fessehaye, Taye Tessema, Kidir Nefo, Agmas Belle, Takele Negewo and Assefa Tea. 2009. Weed Research in Small Cereals in Ethiopia. pp. 431-475. *In:* Abraham Tadesse, (eds.). Increasing crop production through improved plant protection Vol. II, Plant Protection Society of Ethiopia (PPSE), PPSE and EIAR Addis Abeba Ethiopia.

Roberts RK, BC English, JA Larson, RL Cochran, WR Goodman, SL Larkin, MC Marra, SW Martin, WD Shurley, and JM Reeves. 2004. Adoption of site-specific information and variable-rate technologies in cotton precision farming. Journal of Agricultural and Applied Economics 36(1): 143-158.

Rumiao Y, J Li, and W Zhao. 2015. Influence of variable rate irrigation on growth and yield of winter wheat in the alluvial flood plain, ASABE Annual International Meeting Paper, ASABE, USA.

Seleshi Bekele Awulachew. 2010. Irrigation potential in Ethiopia Constraints and opportunities for enhancing the system, International Water Management Institute, Addis Abeba.

Sharma R, ML Jat, KL Martin, P Chandna, OP Choudhary, and RK Gupta. 2011. Assessment of the nitrogen management strategy using an optical sensor for irrigated wheat. Agronomy for Sustainable Development 31: 589-603.

Solari F. 2006. Developing a crop based strategy for on the go n management in irrigated cornfields. Ph.D. diss., University of Nebraska, Lincoln, NE.

Sugar Australia. 2015. Information Sheet IS14017.

Sui R, DK Fisher, and KN Reddy. 2015. Yield response to variable irrigation in corn. Journal of Agricultural Sciences 7:11-17.

Tesfaye A, G Agegnehu, A Gebeyehu, and M Haile. 2004. Analysis of tef production systems and constraints in Ejere and Ada Berga Woredas, West Shewa Zone, Agricultural Systems Analysis and Constraints Identification. Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia, pp. 83-96.

Tey YS and M Brindal. 2012. Factors influencing the adoption of precision agricultural technologies: a review for policy implications. Precision agriculture 13: 713-730.

Thorp KR and L F Tian. 2004. A. review on remote sensing of weeds in Agriculture, Precision Agriculture %:477-508.

Torres G M. 2011. Precision planting of maize (*Zea mays* L.) Faculty of the Graduate College of the Oklahoma State University, USA.

Vellidis G, H Savelle, RG Ritchie, G Harris, R Hill, and H Henry. 2011. NDVI response of cotton to nitrogen application rates in Georgia, USA. In: J.V. Stafford (Eds.). Precision agriculture. Proceedings of the 8th Conference European on Precision Agriculture. Czech Republic, Prague: ECPA. p. 358-368.

Vellidis, George Ed Barnes, and SH Brannen. 2013. Why Yield Maps? University of Georgia, USA.

Walton JC, DM Lambert, RK Roberts, JA Larson, B English, SL Larkin, SW Martin, NC Marra, KW Paxton, and JM Reeves. 2008. Adoption and abandonment of precision soil sampling in cotton production. Journal of Agricultural and Resource Economics: 428-448.

Whelan B and A McBratney. 2000. The "null hypothesis" of precision agriculture management. Precision Agriculture 2(3): 265-279.

Yang Li, Yan Bingxin, Cui Tao, Yu Yiming, He Xiantao, Liu Quanwei,Liang Zhijie, Yin Xiaowei, Zhang Dongxing. 2016. Global overview of research progress and development of precision maize planters, Int J Agric & Biol Eng 9(1):9-26.

Yirga C and RM Hassan. 2010. Social costs and incentives for optimal control of soil nutrient depletion in the central highlands of Ethiopia. Agricultural Systems 103(3): 153-160.

Yirga C, A Tesfaye, G Agegnehu, G Keneni, B Kassa, and G Asefa. 2002. Crop-livestock farming systems of the highlands of Welmera Wereda: The case of Welmera Goro bench-mark site, Towards farmers' participatory research: In: Proceedings of Client Oriented Research Evaluation Workshop, Holetta Research Center, Holetta, Ethiopia, pp. 147-174.

Zeleke G, G Agegnehu, D Abera, and S Rashid. 2010. Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system. International Food Policy Research institute (IFPRI), Washington, DC, USA, pp. 63.

Zude-Sasse M, S Fountas, TA Gemtos, and N Abu-Khalaf . 2016. Applications of precision agriculture in horticultural crops, Eur. J. Hortic. Sci. 81(2), 78–90.