ADOPTION OF PRECISION AGRICULTURE TECHNOLOGIES IN DEVELOPED AND DEVELOPING COUNTRIES

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Abstract: Precision Agriculture (PA) deals with the fine-tuned management of the agricultural inputs including, seeds, fertilizers, water, pesticides, and energy to create savings on these inputs, increase yield, augment profitability and conserve the environment. PA technologies include soil mapping, variable rate application (tillage, seeding, fertilizing, irrigation, and pesticide application), yield monitoring mapping, automatic guidance, and autonomous vehicles. Many factors affect the adoption of PA technologies including features of the farms, affordability and profitability of equipment, characteristics of the technologies such as complexity and compatibility, personality and family structure of the farmer, legal affairs, and institutions offering support on these technologies. The level of adoption is variable in different countries as well as in different regions in a particular country. The aim of this paper was to review the studies on the adoption of PA in developed and developing countries and compare their adoption rates. The PA adoption has an increasing trend in developed countries, particularly in the US while significant increase is also observed in other developed countries. Also, PA technologies are introduced in some developing countries including Turkey in recent years. In both developed and developing countries, auto guidance is more adopted in the last decade while yield monitoring and variable rate application was more dominant earlier.

Keywords: Precision agriculture (PA), Adoption, Developed countries, Developing countries.

Introduction

Technological developments in agricultural sector yield better management practices resulting in more precision in agricultural operations from tillage to harvesting to reduce inputs, increase profits, and protect environment (Ess & Morgan, 2003; Rains & Thomas, 2009). The term Precision Agriculture (PA) or precision farming comprise these improved management technologies such as soil sensing and mapping, yield monitoring and mapping, satellite-based positioning, remote sensing, field and crop scouting, geographical information systems (GIS), variable rate application, and automatic steering (Ess & Morgan, 2003; Rains & Thomas, 2009) (Table 1).

Table 1: Precision Agriculture (PA) technologies

Data Collection Technologies	Data Process & Decision MakingTechnologies	Application Technologies
Soil sampling and mapping	Geographical info systems (GIS)	Variable rate application
Yield monitoring and mapping	Agricultural mapping software	Section control
Global satellite positioning (GNSS)	Economical analysis	GNSS-based guidance
Remote sensing	Geostatistics	Agricultural robots
Field / crop scouting	Modelling	

Awareness and adoption rate of PA technologies are affected by many factors including characteristics of the farms, personality and family structure of the farmer, features of equipment, characteristics of the technology, legal affairs, social interaction, etc. (Table 2).

Farmers adopt and use PA technologies for specific benefits. For instance, in England, surveyed farmers reported that they use PA technologies mostly for improving accuracy (%76), reducing input costs (%63), improving soil conditions (%48), improving operator conditions (%36) and reducing greenhouse gas emissions (%17) (DEFRA, 2013). Also, reasons for not using PA included being not cost effective and/or high initial setup costs (47%), being not suitable for type or size of farm (28%), being too complicated to use (27%), and not accurate enough (2%) (DEFRA, 2013). Keskin et al. (2017) reported that the farmers using tractor auto guidance in the Adana province of Turkey had such benefits from this technology as creating straight crop rows (98.2%), flexible working hours (92.7%), time saving (80.0%), fuel saving (80.0%), labor saving (50.9%), agricultural input saving (18.2%) and yield increase (14.5%). In the same study, farmers did not want to use other PA technologies mainly due to not having detailed knowledge (54.5%), satisfaction with the available technology (23.6%), high equipment cost (18.2), and complication of the technology (3.6%) (Keskin et al. 2017).

Table 2: Factors affecting the adoption level of PA technologies

Factor	Explanation	Source
Personality of the farmer	Age, education, gender, personality, computer usage, willingness to take risks	Daberkow and McBride (2003) Edwards-Jones (2006) Lowenberg-DeBoer and Griffin (2006)
Family structure of the farmer	Work status (full time, part time, retired), availability of extra job, job of the spouse	Edwards-Jones (2006)
Features of the farm	Farm size, farm type, indebtedness, soil texture, field variability	Isgin et al. (2008) Paudel et al. (2011)
Social interactions	Local cultures, social milieu, attitude of trusted friends	Edwards-Jones (2006) Kutter at al. (2011)
Sufficiency of classical methods	Sufficiency satisfaction of classical methods used currently by the farmer.	Paudel et al. (2011)
Supporting institutions and firms	Numbers and structures of supporting institutions and firms (dealers, technical supports, consultants)	Edwards-Jones (2006) Fountas et al. (2005)
Legal issues	Rules and laws encouraging new technologies to reduce chemical inputs, to favor environment protection, sustainability	Edwards-Jones (2006)
Economic factors	Cost of equipment, return of investment time, profitability, possibility of renting	Whipker & Akridge (2009) Paudel et al. (2011)
Features of the technology	Availability, amount of time taking to learn the usage of equipment, easiness of usage, availability of technical support, complexity of the system, compatibility among different brands and models	Fountas et al. (2005) Edwards-Jones (2006) Paudel e al. (2011) Kutter et al. (2011)
Advertisement	Exhibitions, fairs, seminars, workshops, demonstration farms, field days	Kutter et al. (2011)
Technical staff	Quality and quantity of the technical staff, higher labor costs, availability of technical staff, closeness of technical staff	Whipker & Akridge (2009) Kutter et al. (2011)
Multidisciplinary cooperation	Availability of cooperation among engineers, agronomists, scientist	Ess (2002)
Decision support systems	Easiness of data processing, easiness and accuracy of decision making	Fountas et al. (2005)

The objective of this article was to review the studies on the adoption of PA technologies in developed and developing countries and compare the similarities and differences in adoption pattern.

Materials and Methods

In this study; literature was collected on the adoption rate of Precision Agriculture (PA) technologies in different countries. Scientific articles, reports, books and relevant web pages found after the review process were studied and information on the adoption of PA technologies in different countries was compiled.

The countries are divided into two groups as developed countries and developing countries based on United Nations classification (UN, 2014). The data are summarized in tables to make the data more readable and comparable.

Results and Discussion

a) Adoption Level of PA Technologies in Developed Countries

Adoption level of Precision Agriculture (PA) technologies in the US and in other developed countries was summarized in Table 3 and Table 4, respectively. The countries were listed in an alphabetical order in the tables.

The US is a leading country in many innovative technologies. This is valid for the PA technologies as well. Fountas et al. (2005) reported that about 90% of the yield monitors in the world were operated in the US (Table 3). The adoption rate of automatic guidance technology in some states / regions reaches to about 60-80% recently (Table 3) (Erickson & Widmar, 2015; Miller et al., 2017). While yield monitoring technology and variable rate technology was more dominant earlier (Norwood & Fulton, 2009; Schimmelpfennig & Ebel 2011), the auto guidance systems and automatic section control systems caught more popularity in the last decade (Holland et al, 2013; Erickson & Widmar, 2015; Miller et al., 2017).

GNSS-based automatic guidance systems offer many benefits to the farmers including more accurate field works, higher operation speeds, easy operation, working at night, less affection by bad weather, reduced operator fatigue, low setup time, reduced overlapping, reduced skips, working without foam markers, and reduced inputs (fuel, fertilizer, pesticides, seeds, etc) (Grisso et al. 2009). In the near future, auto guidance could be considered a standard feature for new high-powered farm tractors. Furthermore, driverless autonomous tractors are currently being tested in some developed countries particularly in the US.

Along with the US, Australia, Canada, and some European Union countries including Germany, Finland, Denmark and Sweden has some level of adoption for PA technologies (Table 4). Particularly, Leonard (2014) reported that about 80% of the grain growers use automatic guidance in Australia. Also Steele (2017) indicated that 98% of surveyed farmers used GPS guidance in western Canada. Main similarity among these three countries (the US, Australia, Canada) is that the farm sizes are bigger in these countries making the farmers more willing and able to adopt new technologies. Farm size is one of the most crucial factors affecting the PA technologies (Keskin 2013; Keskin & Sekerli, 2016). In general, farmer having at least a few hundred hectares are most likely to adopt high cost new technologies. Fountas et al. (2005) stated that farmers with fields larger than 300 ha tend to be the first to invest in new technologies while Paustian and Theuvsen (2016) reported that.having a farm of less than 100 ha and producing barley were factors that exerted a negative influence on the adoption of PA in Germany. Keskin et al. (2017) reported that majority of the farmers (56.4%) using tractor auto guidance in the Adana province of Turkey had a field size of bigger that 100 ha.

b) Adoption Level of PA Technologies in Developing Countries

Adoption level of Precision Agriculture (PA) technologies in developing countries was presented in Table 5 where the countries were listed in an alphabetical order. Similar observation is valid for the developing countries as well. While yield monitoring technology and variable rate technology was more dominant earlier, the auto guidance systems caught more popularity in the last decade (Table 5).

Argentina, Brasil, South Africa and Turkey are among the ones employing some level of PA technologies. It should be noted that there could be other countries that were not reported in publications and still use PA technologies.

Table 3: Adoption level of PA technologies in the USA

Country / Region / State	Technology & Its Adoption Level	Source
USA	About 90% of yield monitors in the world were in the US; in 2003, there were around 45.000 combines with yield monitor; about 46% of corn, 36% of soybeans and 15% of wheat was harvested by combines with yield monitor	Fountas et al. (2005)
USA / Ohio	36% of farmers participated in survey used at least one PA technology	Isgin et al. (2008)
USA	28% of US corn planted acres (in 2005), 10% of winter wheat (in 2004), and 22% of soybeans (in 2002) were harvested with a combine with a yield monitor.	Griffin and Erickson (2009)
USA	54% of the farmers used one or more PA technologies; yield monitoring (32%) and auto steering (32%)	Norwood & Fulton (2009)
USA	85% of agricultural dealers used at least one PA technology	Whipker & Akridge (2009)
USA / 12 states	About one-third of the cotton farmers (34%) adopted PA technologies	Paudel et al. (2011)
USA / Corn Belt region	Yield monitoring on over 40% of US grain acres; GPS maps on 24% corn acres; variable-rate technologies (VRT) on 16% of corn acres; GPS maps on 17% corn acres; VRT on 12% of soybean acres; and nationally VRT 12% for corn and 8% for soybeans	Schimmelpfennig & Ebel (2011)
USA / 34 states	Mostly-offered-technologies by surveyed dealerships were GPS guidance systems with manual control (light bar) (65%) and automatic (autosteer) control (61%)	Holland et al (2013)
USA	Three most popular technologies were GPS guidance with auto control / autosteer (83%), GPS-enabled sprayer section control (74%) and GPS guidance with manual control (63%); 82% of the dealers offered PA services	Erickson & Widmar (2015)
USA	Over 60% of agricultural-input dealers offer variable-rate-technology (VRT) services, but USDA indicate despite subsidies and educational efforts, less than 20% of corn acreage is managed using VRT. About 40% of fertilizer and other chemicals are applied with auto guidance.	Lowenberg-DeBoer (2015)
USA	About 25% of peanut farms adopted GPS soil mapping and over 40% used auto steering; variable rate fertilizing had a higher adoption rate in peanut production at over 20% of farms than for many other crops	USDA (2015a)
USA	60% of rice farms adopted yield monitoring technology and about 55% used auto guidance systems	USDA (2015b)
USA	In a survey of nearly 200 strip-till farmers, 79.4% use RTK GPS correction; use of variable-rate fertilizing increased to 36.2% in 2015 from from 31.5% in 2014; use of implement guidance was 19.7%.	Zemlica (2015)
USA / 14 states	In the 2005 survey, 23% of cotton producers used GPS guidance as in 2013 survey, about 31% adopted auto section control and 59% auto guidance systems.	Velandia et al. (2016)
USA	Until 2000s, adoption of different PA technologies varied up to 22% across major field crops. Tractor guidance grew faster than variable-rate application for all major field crops over the last 10 years.	Schimmelpfennig (2016)
USA / Kansas	66% of surveyed farmers used automated guidance and 47% use automated section control	Miller et al (2017)

Table 4: Adoption level of PA technologies in other developed countries

Country / Region	Technology & Its Adoption Level	Source
Australia	30% of broadacre crops are sown and/or sprayed using GPS guidance. Other PA technologies such as yield mapping and variable rate is less common with <1% of adoption.	McCallum and Sargent (2008)
Australia	About 800 yield monitors were used in the country in the 2000 harvest year.	Mondal and Basu (2009)
Australia	Variable rate technology adoption in 2008–2009 has increased significantly to 20% nationally	Robertson et al. (2012)
Australia	80% of the grain growers use automatic guidance technology	Leonard (2014)
Canada	Based on a survey in 2006, 23.2% of farms use GPS equipment or products, 77.9% use guidance systems, 23.5% use variable rate fertilizer application and 27.4% use variable rate pesticide application	Haak (2011)
Canada / Western	98% of surveyed farmers used GPS guidance, 84% at least one PA technology, 84% had combine with yield monitoring capability, 73% used auto section control, 75% intend to use more PA in the future	Steele (2017)
Europe	70% of all fertilizing and spraying machines are equipped with PA technologies and smart or ISO-Bus enabled equipment.	Armagan (2016)
Europe	Despite the wide range of PA solutions being offered, only 25% of EU farms use technologies with a PA component.	EPRS (2016)
Europe / Denmark Britain, Sweden, Germany	About 400 Danish, 400 British, 300 Swedish and 200 German farmers adopted yield monitors by the year 2000	Fountas et al. (2005)
Europe / England	Ratio of farms using GPS increased from 14% to 22%, soil mapping from 14% to 20%, variable rate application from 13% to 16% and yield mapping from 7% to 11% in 2009 compared to 2012.	DEFRA (2013)
Europe / France	150 000 ha are managed using PA. 50% of the arable crop holdings have a tractor with a console, an essential tool for PA. One in four modulates inputs of fertilizers and crop protection products.	Invivo (2016)
Europe / Germany	Between 6.6% and 11.0% of surveyed farmers used PA mainly for data collection techniques such as GPS-based area measurement and soil sampling	Reichardt et al. (2009)
Europe / Germany, Finland, Denmark	36% of the surveyed farmers had previous experiences with PA technologies	Bligaard (2013)
Europe / Sweden	Nitrogen sensors are used in about 20% of wheat fields primarily for nitrogen fertilizer application	Söderström (2013)
Europe / UK	Around 60% of UK farmers already use some sort of precision agriculture on their farms, although for the most part this simply means using GPS tractor steering	Norris (2015)
Japan	In rice farming, ground vehicles spray about 22% (in 2014) and the proportion of large-scale UAV plant protection has reached 36%.	Liao (2017)

Table 5: Adoption level of PA technologies in developing countries

Country / Region / State / Province	Technology & Its Adoption Level	Source
Argentina	There were about 560 yield monitors in 2001; about 4% of the grain and oil seed area was harvested by combines with yield monitors.	Mondal and Basu (2009)
Argentina	Yield monitors, positioning systems (GPS), auto guidance, and satellite images are increasingly used; it is the second country after the US with number of yield monitors (1200) and fifth country with yield monitor density of 51 monitors per million hectares (after the US, Denmark, Sweden, and Great Britain).	Bongiovanni & Lowenberg-DeBoer (2005)
Brasil / Sao Paulo state	58% of domestic and 38% of foreign sugar and ethanol companies adopt PA; most preferred technologies are satellite imaging (76%), auto pilot guidance (39%), geo-referenced soil sampling (31%), and variable rate fertilizing and liming (29%).	Silva et al. (2011)
Brasil	Mostly accepted technologies by the survey participants were GPS guidance with manual control (89%), GPS guidance with auto control (56%) and yield maps (56%).	Borghi et al. (2016)
Brasil	Adoption rate of PA is estimated at about 20% with a very diverse distribution. Soil sampling is the most adopted one. Some technologies like GPS guidance have larger adoption than others.	Albuquerque (2017)
China / Heilongjiang province	Tractor auto guidance was the most accepted technology and about 25% of the farmland was managed using PA	Verma (2015)
India	Leaf color chart (LCC) based N management and laser based land leveling are effective tools in rice farming.	Mondal and Basu (2009)
Kazakhstan*	Several auto guidance systems were introduced into agriculture.	Samruk-Kazyna. (2017).
Russia*	PA came to Russia about eight years ago. It is adopted slowly due to the high costs. Some elements of PA such as navigation on combines and cultivators are used.	Anonymous (2013)
South Africa	The number of yield monitors increased to more than 600, variable rate lime applications to 244, manual guidance systems to 200, and auto guidance to 60	Helm (2005)
South Africa	About 15 farmers used yield monitoring system in the 1999–2000 crop season	Mondal and Basu (2009)
Turkey	About 500 combine harvesters (about 3% countrywide) are equipped with yield monitoring systems	Keskin & Sekerli (2016)
Turkey	About 310 combine harvesters are equipped with yield monitors. About 110 automatic steering systems and 25 steering assistance systems were sold to the farmers. Number of variable rate applicators is less than 20.	Akdemir (2016)
Turkey / Adana province	About 110 farmers use GNSS-based auto guidance systems in Adana province.	Keskin et al. (2017)
Turkey	About 60 cotton harvesters (about 6% countrywide) are equipped with yield monitoring systems.	Erzurumlu (2017)

* These countries are classified as "Economies in transition" (UN 2014)

Conclusions

Precision Agriculture (PA) technologies provide better management practices resulting in more precision in agricultural operations from tillage to harvesting to reduce inputs, increase profits, and protect environment.

Adoption rate of PA technologies is in an increasing trend in some developed and developing countries. The auto guidance systems caught more popularity in the last decade while other PA technologies such as yield monitoring technology and variable rate technology was more dominant earlier in both developed and developing countries.

The US is the only leading developed country in the adoption of PA technologies. Other developed countries adopting PA technologies the most are Australia, Canada and European countries. Regarding the developing countries, countries such as Argentina, Brasil, South Africa and Turkey have an increasing adoption rates in the last decade.

One of the most important factors in favor of the adoption of the PA technologies is farm size. It can be said that the countries with bigger farms such as the US, Australia, Canada, Brasil, and Argentina tend to adopt these technologies in a bigger margin.

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