UNIVERSITY OF CAPE COAST

PROSPECTS AND CHALLENGES OF PRECISION AGRICULTURE IN COCOA PRODUCTION IN GHANA

MARTIN BOSOMPEM

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PROSPECTS AND CHALLENGES OF PRECISION AGRICULTURE IN COCOA PRODUCTION IN GHANA

BY

MARTIN BOSOMPEM

Thesis submitted to the Department of Agricultural Economics and Extension of College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Doctor of Philosophy Degree in Agricultural Extension

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:……………………………….. Date……………….

Name: ………………………………………………………………..

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature: …………………… Date………………..

Name: ……………………………………………………………………..

Co-Supervisor's Signature: ………………………… Date…………………

Name: …………………………………………………………………….

ABSTRACT

The main objective of the research was to examine the prospects and challenges of developing and implementing precision agriculture (PA) in cocoa production in Ghana. Correlational research design was used to collect data using a multistage sampling technique from major stakeholders including scientists (n=12), cocoa extension agents (CEAs) (n=63) and cocoa farmers (n=416) in the cocoa industry in Ghana. Content-validated questionnaires and structured interview schedules were used for data collection. Results were analyzed using descriptive statistics, independent sample t-tests, one way ANOVA, post-hoc multiple comparison, correlation coefficients, and logistic regression. The results of the study revealed that the majority of cocoa farmers (83%) were willing to adopt precision agricultural technologies (PATs) but their level of awareness of PATs was rather low. The level of awareness of scientists and CEAs were high and fair respectively, however, they both had only a fair knowledge in PA. Five major challenges expected to pose serious challenges to the development and implementation of future PATs were (a) farmer demographic characteristics, (b) economic, (c) educational, (d) environmental, and (e) technical, with farmers' demographic characteristics expected to be the greatest. Even though correlation analysis showed that 12 out of 28 independent variables had significant relationships with cocoa farmers' willingness to adopt PATs, the regression analysis revealed only five to be best predictors. The overall best predictor was row planting which together with (a) educational level of cocoa farmers, (b) credit from financial institutions, (c) relative advantage of PATs, and the (d) perceived ease of use of PATs contributed between 38% to 60% of the variance in cocoa farmers' willingness to adopt PATs. The study concluded that even though PA has high prospects from cocoa farmers' perspectives, scientists and CEAs believe that the prospects are relatively low due to the enormous challenges that need to be overcome before PATs become a reality in Ghana. The study recommended, among others, the establishment of a PA unit in Cocoa Research Institute of Ghana (CRIG) to champion research into PATs and practices, establishment of resilient research-extension-farmer linkage system for requisite awareness creation and training of stakeholders, and mainstreaming PA topics into institutions of higher learning in Ghana.

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DEDICATION

To my wife,

Akua Fremah Bosompem

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LIST OF ACRONYMS

CCM	Climate Change Mitigation
CEAs	Cocoa Extension Agents
CHED	Cocoa Health and Extension Division
CHTP	Cocoa High Technology Programme
COCOBOD	Ghana Cocoa Board
CRIG	Cocoa Research Institute of Ghana
CSIRO	Council for Scientific and Industrial Research
CTF	Controlled Traffic Farming
DGPS	Differential Global Positioning System
DOI	Diffusion of Innovation
DSS	Decision support system
EPA	Environmental Protection Agency
FOB	Free On Board
GIS	Geographic Information systems
GIZ	German Development Cooperation Agency
GPS	Global Positioning System
ICCO	International Cocoa Organization
ICT	Information Communication Technology
ISPA	International Society of Precision Agriculture
IITA	International Institute of Tropical Agriculture
IT	Information technology
LBCs	Licensed Buying Companies
MFIs	Micro Finance Institutions

MoFA	Ministry of Food and Agriculture
NGOs	Non-Governmental Organisations
OECD	Organization for Economic Cooperation and Development
PA	Precision Agriculture
PATs	Precision Agriculture Technologies
PEOU	Perceived Ease of Use
PF	Precision Farming
PU	Perceived Usefulness
RS	Remote sensing
RTK GPS	Real Time Kinematic Global Positioning Systems
SPSS	Statistical Package for Social Sciences
SSA	Sub-Saharan Africa
TAM	Technology Acceptance Model
UNEP	United Nations Environment Programme
VIF	Variance Inflation Factor
VRA	Variable Rate Application/Applicator
VRT	Variable Rate Technology
WCF	World Cocoa Foundation

CHAPTER ONE

INTRODUCTION

Background to the Study

Agricultural development is the cornerstone to African economic transformation, stability and security (World Bank, 2013; Miller & Shinn, 2012). Agriculture is the most important sector in most African countries because it contributes an average of 24% to GDP and Agribusiness input supply, processing, marketing, and retailing add about 20 percent to GDP (World Bank, 2013)

In Ghana, agriculture used to be the major sector of the economy that contributed about 30-40% of GDP barely a decade ago. Agriculture's contribution to Ghanaian economy has declined to about 22% in 2013. However, it still contributes to about 50% of National employment (ISSER, 2014; ISSER, 2013). This decline of Agriculture contribution to the GDP has been attributed largely to the expansion of the oil sector (ISSER, 2014).

An important crop that plays an indispensable role in Ghana's Economy is cocoa (*Theobroma cacao*, L.). Cocoa has been a dominant sub-sector in the agricultural sector and has contributed to an average of 26% of Ghana's export earnings between 2007-2012 even though it contributed 20% in 2012 fiscal year (ISSER, 2013). It also accounts for 55% of the total household income among cocoa farmers in Ghana (IITA, 2002). Therefore, a significant growth of the economy, to some extent, depends on the growth of the cocoa sector. In Ghana, the average national annual yield which is around 350-760 kilograms per hectare (kg/ha), is very low compared to 800 kg/ha in Côte d'Ivoire, or 1700 kg/ha in Malaysia (Appiah, 2004; Bosompem, Kwarteng, & Ntifo-Siaw, 2011a). Hence, there is the need to increase productivity in Ghana.

However, the concerns have not only been on increasing productivity but also ensuring environmental sustainability especially in the face of the growing concern of climate change. Hence, the general consensus among many agricultural development practitioners in the world is to increase productivity (for an ever increasing population) and at the same time prevent soil erosion, reduce pesticide and fertilizer contamination, protect biodiversity, preserve natural resources and other relevant climatic indicators, thus, improving well-being (Hamideh, Kurosh & Abdol-Azim, 2011). One of the major emphases in cocoa production in Africa, especially in Ghana recently is to mitigate and adapt to the harmful effects of pesticide residuals in cocoa production as well as produce quality cocoa that will meet international regulations and legislations on pesticides residuals (ICCO, 2013).

A study conducted by Läderach, Martinez-Valle, Schroth, and Castro (2013) on predicting the future impact of climate change in the cocoa growing regions in Ghana and Ivory Coast concluded that the climate change impact on cocoa in these two countries (which happen to produce 71% of the world's cocoa) would be significant. Läderach et al. (2013) therefore, recommended among others, the development of new technologies to mitigate these effects. One of the remedies identified to have the potential of mitigating some of the effects of climate change is Precision Agriculture (PA) technologies (Najafabadi, Hosseini & Bahramnejad, 2011). Najafabadi et al. (2011) observed that the mitigation effects of precision agriculture include the following:

(a) Reducing environmental loading by applying fertilizers, pesticides and weedicide only where and when they are needed.

(b) Ensuring more targeted use of inputs that reduce losses from excess application of agrochemicals and other inputs that can affect the soil microbes as well as beneficial insects.

(c) Reducing pesticide resistance development of diseases and pest, thereby minimizing the use of and the number of different pesticides used.

Precision Agriculture is defined as an information and technologically based farm management system to identify, analyse and manage variability within fields for optimum profitability, sustainability and protections of the land resource. The main goal is to manage and distribute inputs on site- specific basis to maximise long term benefits (Singh, 2006). It also describes the integration of Geographic Information System (GIS) and Global Positioning System (GPS) tools to provide an extensive amount of detailed information on crop growth, crop health, crop yield, water absorption, nutrient levels, topography and soil variability (Najafabadi et al., 2011). Blackmore, Wheeler, Morris, Morris and Jones (2003) observed four specific objectives of precision agriculture namely: (a) increase profitability and production, (b) reduce costs, erosion and environmental impact of chemicals, (c) track and monitor the use of chemicals, and (d) manage large farms.

Various precision agriculture technologies are used for different purposes, and in various combinations, to fit the needs of individual producers. Some of these innovations include: (a) GPS, (b) Yield Monitoring and Mapping , (b) Grid Soil Sampling and Variable Rate Technology (VRT), (d) Crop Scouting, (e) Geography Information System (GIS), and (f) Information Management (Adrian, 2006; Singh, 2011; Guilian, Hongtao & qin , 2011).

There are various tools developed for each technology. Adrian (2006) observed that the information gathering tools such as yield monitors, targeted soil sampling. Remote sensing also provides information about the fields as they vary in soil chemistry, moisture, fertility, topography, and productivity (yields). These pieces of information are entered into GIS that map these varying characteristics. The farmer uses GIS to create management zones which identify segments of the fields that hold different soil properties and production potentials. Farmers enter the appropriate rates of the inputs (i.e., fertilizer) for each management zone into the GIS. The management zone mapping from the GIS is then incorporated into variable rate applicators so that the inputs are applied appropriately as the equipment passes through the fields.

Statement of the Problem

Even though Precision Agriculture (PA) has long been identified as one of the means to mitigate some of the effects of climate change (e.g reduce erosion and environmental impact of chemicals, track and monitor the use of chemicals) and at the same time increase profitability through optimum production, its technologies are not widely developed and used in most developing countries including, Ghana (Blackmore et al., 2003).

Moreover, the potentials for developing and implementing precision agriculture technologies and practices have not been fully assessed in major crops (including cocoa) in Ghana even though some aspects of various innovations developed by Cocoa Research Institute of Ghana (CRIG) sometimes included certain traces of Precision Agriculture principles and practices. For example, in 2003, the Cocoa High Technology Programme (CHTP) implemented in Ghana required (a) soil testing of cocoa farm before application of fertilizer, (b) use of ring method of application of the fertilizer, and (c) Specific rates of application of fertilizers and other agrochemicals (Bosompem, Kwarteng & Ntifo-Siaw; 2011b; Appiah, 2004; Appiah, Ofori-Frimpong, Afrifa & Asante ,1997). Also, soil diagnostic model has been used in conjunction with GIS to convert blanket fertilizer recommendations into a more effective recommendation that accounts for the actual nutrient requirements of cocoa trees through the development of a digital map of cocoa nutrient based on climatic and soil groups/associations' data (Snoeck, Afrifa, Boateng & Abekoe, 2006).

Najafabadi et al. (2011) have identified major areas of challenges that Precision Agriculture (PA) must address before it could be successfully developed and implemented. These were: educational/training, economic, data quality, farmer/operator demographic characteristics, technical, high risk, Time, educational and incompatibility challenges. These major areas of concerns for these identified challenges have not been fully assessed in the major crops in Ghana including cocoa. Also, stakeholders' level of awareness, knowledge and perceived attributes of PAT innovations are not known but these are critical for any future development and adoption of PATs among cocoa farmers in Ghana (Rogers, 2003).

Cocoa farmers' willingness to adopt the PA technologies (if developed) is not known. Therefore, there is the need to identify major challenges, awareness levels, knowledge levels, and attributes of PA as identified by major stakeholders in the cocoa industries.

Also, there is the need to identify the potentials and opportunities available to develop precision agriculture in Ghana (especially in cocoa industry) as a way of improving the productivity of farmers in Ghana and also mitigating some of the aforementioned effects of climate change in cocoa production.

Objectives of the Study

General objective

The general objective of the study was to examine the prospects and challenges for developing and implementing Precision Agriculture Technologies (PATs) in cocoa production in Ghana.

Specific objective

The specific objectives of the study were to:

1. Compare the awareness level of major stakeholders (scientists, cocoa farmers and cocoa extension agents) on PATs and practices in Ghana.
2. Compare the perceived level of knowledge of scientists and cocoa extension agents (CEAs) on PATs, principles and practices.
3. Identify scientists' and CEAs' perceived challenges and prospects anticipated in PA development in cocoa production in Ghana.

4. Compare perceived technology characteristics (attributes) of major stakeholders (scientists, cocoa farmers, CEAs) of PATs.
5. Explore the relationships between independent variables (demographic, farm related, technology-related characteristics and awareness levels of cocoa farmers) and their willingness to adopt PATs.
6. Identify the factors that best predict cocoa farmers' willingness to adopt PATs.

Hypotheses of the Study

The following five (5) main hypotheses were set to guide the study. These hypotheses were tested at 0.05 alpha levels. The hypotheses were:

1. **Hypothesis 1 :**

   $H_{O:}$ There are no significant differences among the awareness level of stakeholders in cocoa industry in PA innovation.

   H_1: There are significant differences among the Awareness level of stakeholders in cocoa industry in PA innovation.

2. **Hypothesis 2:**

   H_O: There are no significant differences between scientists' and cocoa extension agents' perceived knowledge in PATs.

   H_1: There are significant differences between scientists' and cocoa extension agents' perceived knowledge in PATs.

3. **Hypothesis 3:**

   H_O: There are no significant differences between scientists' and cocoa extension agents' perceived challenges and prospects anticipated in PAT development in cocoa production in Ghana.

H_1: There are significant differences between scientists' and cocoa extension agents' perceived challenges and prospects anticipated in PAT development in cocoa production in Ghana.

4. Hypothesis 4:

H_O: There are no significant differences among major stakeholders' perceived technology characteristics of PATs.

H_1 There are significant differences among major stakeholders' perceived technology characteristics of PATs.

5. Hypothesis 5

H_O: There is no significant relationship between demographic, farm-related, technology-related factors, and awareness level of cocoa farmers and their willingness to adopt PATs.

H_1: There is a significant relationship between demographic, farm-related, technology-related factors, and awareness level of cocoa farmers and their willingness to adopt PATs.

Variables of the Study

Dependent variable: The dependent variable of the study was cocoa farmers' willingness to Adopt Precision Agriculture in cocoa production.

Independent variables: The independent variables of the study were:

(a) Demographic characteristics,

(b) Farm- related characteristics,

(c) Technology Characteristics of PA,

(d) Awareness and knowledge level of respondents in PA technologies, and

(e) Challenges to PA technology development and implementation in Ghana.

Significance of the Study

Precision agriculture technologies are new and rarely applied in Ghana, especially in cocoa production. This research will serve as a basis for future development of tools and methods by scientists for the successful implementation of PA technologies in cocoa production in Ghana. Also, scientists' or experts' awareness and knowledge levels would also help indicate the kind of training needed by these scientists in their quest to develop PA technologies taking into consideration the soil and other climatic factors in Ghana. Moreover, PATs developed in cocoa can serve as a model for the development of PATs in other relevant crops in Ghana.

Outcome of the study on farmers' awareness level and willingness to adopt PA technology when developed would also serve as a basis for future developing technologies. This will take into consideration the characteristics of cocoa farmers or the kind of training needed by farmers before they can implement PATs in cocoa production in Ghana.

Knowledge and awareness levels of extension agents who serve as agents of transfer of technologies from scientists to farmers could also provide basis for training need assessment for the agents as well as the kind of training needed by them for successful transfer of PA technologies if these are developed.

The results from the factors or determinants of cocoa farmers' willingness to adopt PA technologies when developed would provide information to enable scientists and extension officers know the variables to target in order to improve the adoption of technology when available.

Awareness levels, knowledge levels and challenges identified among the stakeholders could also help develop strong and sustainable Research-Extension-Farmer linkages towards successful development and implementation of PA technologies in cocoa production in Ghana.

The study would also add to the body of knowledge so far as PATs development and implementation is concerned especially in the cocoa industry in Ghana.

Limitations of the Study

In the absence of adequate record keeping by farmers, the study relied on farmers' power of memory recall especially when it came to yield and other farm-related factors. Such recall from farmers could affect the accuracy and precision of data on yields of farmers as well as the quantity of inputs used by farmers.

Delimitations of the Study

The study focused on cocoa farmers who had adopted the Cocoa High Technology Programme (CHTP) or farmers who had used various types of fertilizers on their farms but not all cocoa farmers in Ghana. It is noteworthy that other cocoa farmers might have applied fertilizers on their cocoa farms, however, the study focused on cocoa farmers who received free fertilizers under the CHTP but not all cocoa farmers who may have used fertilizers on their cocoa farms.

The reason for using the farmers under the CHTP was to ensure that the targeted cocoa farmers must have applied at least fertilizers on their cocoa farms in the past since fertilizer application is not common among cocoa farmers in Ghana. Also, because PA emphasizes site-specific application of inputs (especially fertilizer), cocoa farmers under the new CHTP were identified as ideal target population since they could tell whether they are willing to us PA tools in fertilizer applications.

Definition of Key Terms

This section provides the operational definition of terms as used in this study.

Adoption: Acceptance and use of agricultural technologies for one or more seasons.

Awareness: Having heard or/and seen a technology or information related to Precision Agriculture (PA). Awareness level of a farmer who has seen or observed a technology is considered to be higher than a farmer who has only heard but not seen the technology or innovation.

Challenges: Difficult tasks that test the ability, capacity and skills of major stakeholders in developing and implementing Precision Agricultural Technologies (PATs).

Cocoa Region: is a region demarcated by the COCOBOD based on the quantity of yield or output from that region. Cocoa regions are different from the political and administrative regions in Ghana even though sometimes the names are similar but they have different boundaries. Currently, there are seven (7) cocoa regions in Ghana.

Innovation: Refers to new technologies, products, services, or practices and institutional arrangements that lead to substantial improvements in productivity or other solutions to farmers' development challenges.

Knowledge: Abilities and skills as perceived by stakeholders.

Overall awareness: composite mean score of the perceived awareness levels of major stakeholders (farmers, CEAs and scientists) in the three (3) main components of PA (information or data, technology or tool, and management).

Overall challenges: composite mean score of the stakeholders'(farmers, CEAs, and scientists) perceived challenges in the eight (8) major challenges (economic, time, educational, technical, data quality, farmer/Operator demographics, environmental, and political/governmental) expected to hinder PAT innovation development and implementation

Overall knowledge: composite mean score of perceived knowledge levels of scientists and CEAs in the three (3) main components of PA.

Overall technology characteristics (or attributes): composite mean score of attributes of PA innovation as perceived by the stakeholders in these six (6) areas relative advantage, compatibility, complexity, trialability, and observability, and voluntariness.

Perceptions: Personal indications to disregard or emphasise some things and put meaning in ones' own way. Perceptions and opinions have the same meaning in this study.

Precision Agriculture (PA): ICT-based farm management system that provides the bases for site-specific application of farm inputs (e.g fertilizer, water, pesticides) to ensure optimum productivity and environmental sustainability through the use of GIS technology. PA and precision agriculture technologies (PATs) are used interchangeably in this study

Prospects: Prospects in this study are considered as opposite to challenges. In other words, lower challenges imply higher prospects and vice versa.

Technology: The machines, tools, mechanical devices, practices, Instruments and techniques adopted for practical purposes of producing cocoa.

Willingness: The likelihood of accepting a technology based on the awareness or/ and knowledge level as well as the characteristics of the technology.

Organization of the Study

This thesis is organised into five main chapters. Chapter One consists of the background to the study, the statement of the problem, the objectives of the study, hypotheses, significance of the study, the limitations and delimitation of the study, and the definition of key terms as used in the study.

Chapter Two provides a reviewed of relevant literature including challenges to cocoa production in Ghana, precision agricultural concepts, tools and technologies, challenges to precision agriculture, theories of adoption of precision agriculture and determinants of precision agriculture adoption. Finally a conceptual framework was developed to guide the study.

Chapter Three presents the research methodology which includes the study areas, research design, population, sample and sampling techniques, research instruments used, pilot study to pretest the instruments, data collection and analysis procedures.

Chapter Four presents the results and discussion of the analysed data based on the specific objectives of the study

The fifth chapter provides summary, conclusions and the recommendations based on the findings of the study.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This chapter tries to pull together the existing theoretical and empirical studies that provide the background and necessary basis for the study. This chapter attempts to review relevant works done on various aspects of Precision Agriculture with emphasis on the adoption of the Precision Agricultural Technologies (PATs). Specifically, literature was reviewed on major topics such as Cocoa Production in Ghana, Challenges to Cocoa Production in Ghana, Precision Agriculture Technologies concepts, tools practices, and adoption; Prospects and Challenges of Precision Agriculture and Determinants of intension to adopt Precision Agriculture Technologies in Cocoa Production.

Finally, a conceptual framework was developed to serve as a guide to the study based on the review of relevant literature.

Global and Ghana's Cocoa Production

Cocoa (*Theobroma cacoa. L*) belongs to the family of sterculiaceae and has two main types Criollo and Forastero. A third variety known as Trinitario is a hybrid between Criollo and Forestero and it is more resistant to diseases (Lees & Jackson, 1973). Cocoa is believed to have originated in several areas in

Central and South America, particularly in the rainforest of the tropical Amazon area (ICCO, 2014).

World cocoa production has risen from an average of 1.28 million tonnes in 1960s to a peak of 4.3 million tonnes in 2010/2011. However, the production is estimated to have decreased by over 6% to 4.05 million tonnes in the 2011/2012 cocoa season. Africa contributes to about 71% of world cocoa output. The major cocoa producing countries in Africa are La Côte d'Ivoire, Ghana, Nigeria, Cameroon, Congo, the Dominican Republic, Gabon, Guinea and Togo. However, the combined production for La Côte d'Ivoire and Ghana contributes to approximately 58% of the total world output whereas Americas (mostly Brazil and Ecuador), Asia and Oceania (mostly Indonesia and Papua New Guinea) jointly supply 19% of the world's cocoa output (ICCO, 2013).

Cocoa, significantly contributes about 40% of agricultural exports and 12% GDP to the economic development of Ghana. It is believed to provide livelihood to over 800,000 farmers and their households or dependents (Frempong, Asase & Yelibora, 2007). It is estimated that the crop accounts for about 70 – 100% of annual household income to farm families, and contributes about 60% to the national agricultural labour force (Ntiamoah & Afrane, 2008).

Ghana (formerly Gold Coast) became the leading producer of cocoa in the world in 1920/21 season. However, in 1977/78 growing season, La Cote d'Iviore (formerly, Ivory Coast) took over the lead (Appiah, 2004). Furthermore, Ghana was overtaken by Indonesia in 2001/02 season, and dropped to the third world's largest producer. Currently, Ghana is the second leading producer of cocoa in the world (ICCO, 2013).

Even though cocoa production in Ghana has increased over the years, the increase has not been attributed significantly to increase in yield per unit area. The increases have been attributed mainly through the expansion of existing farms or development of new farms, especially in the Western Region of Ghana where forest land is abundant (Appiah , 2004; CRIG, 2010).

Challenges to Cocoa Production in Ghana

Challenges to cocoa production in Ghana are low productivity, pest and diseases, environmental concerns (low soil fertility and climate change) and marketing challenges (CRIG, 2010).

Low productivity: This has been attributed to limited knowledge of farmers on modern farming methods, limited access to finance for purchase of inputs, limited quality of planting materials to give the desired or expected quantity per hectare as well as aged cocoa trees.

Pest and diseases: It is estimated that about 30-40% of the cocoa crop is lost to pests and disease (ICCO, 2010). There are a number of pests that attack cocoa and these include mirids (capsids), stem borers, shield bugs, pod bearers, rodents and termites. Mirids are the major insects that affect cocoa worldwide. Mirids are sucking insects that damage the soft tissues of the tree by piercing the young shoots with their mouthparts injecting poisonous saliva into the tree and then sucking liquid food out of the wound made on the tree and as a result, the affected shoot dies. In young cocoa, the whole plant may be killed. On mature cocoa, capsid damage occurs year after year in small scattered areas called ‘capsid pockets’, again causing die back. Cocoa mirids have been identified as a serious pest in Ghana since 1908 due to their devastating effect. It is estimated that mirid damage alone, if left unchecked for three years, can reduce yields by as much as 75%. The insects usually are most destructive from September to March particularly when moisture deficit is severe.

Other pests and diseases of minor effect are cocoa mosquito, pod boring caterpillar (*Marmara sp*.) and mealybug (*Stictococcus sp*.). The current recommended chemicals for controlling the Black Pod Disease, in Ghana include Fungaran, Ridomil Gold Plus and Cocide. Spraying against Black Pod disease with knapsack spraying machine is done at three or four weekly intervals. Shade and canopy managements are the cultural practices that farmers undertake as cultural measures in controlling the Black Pod disease. However, cultural practices are not effective against *P. megakarya* (ICCO, 2010). Insecticides are applied as foliar spray using motorized mist-blowing machines to control mirids. Mistletoe is a parasitic plant that destroys the young branches of cocoa trees, rendering the tree unable to bear healthy and good fruits. Mistletoe is controlled by removal of the affected parts of the tree to prevent it from spreading to other parts of the tree.

Soil fertility management challenge: Soil fertility depletion has been recognized as one of the major biophysical constraints limiting agricultural production, particularly, nitrogen and phosphorus deficiencies (Ahenkorah, 1981). In cocoa production, the case has been worse. A survey conducted by CRIG in 1990 showed that virtually no cocoa farmer in Ghana included soil fertility maintenance in his or her farm management programme, though fertiliser application has been adopted in other cocoa producing countries on the basis of earlier result at CRIG. According to Appiah, Ofori-Frimpong, Afrifa, and Asante (1997) and Appiah (2004), on-farm fertiliser verification trials began in the Ashanti Region in 1991/92 cocoa season and ended in 1994/95 season. The result showed that significant responses of cocoa to fertiliser application on experimental farms (average of 13000kg/ha) and this was higher than the national average (350kg/ha or 140kg/acre). It was seen that if the results from the trials are extrapolated on the national scale, the national production could be doubled within a four year period (Appiah et al., 1997; Appiah, 2004). The results from these trials “gave birth” to the development of the Cocoa High Technology programme in 2002.

Marketing challenges: Low producer price compared to Free On Board (FOB) price has been a major challenge that had been expressed by both farmers and researchers in the cocoa industry over the years (Amoah 1998; Dormon, Van Huis, Leeuwis, Obeng-Ofori, & Sakyi-Dawson, 2004). The FOB price always differs from the world market price because of the ‘forward sale’ policy of COCOBOD. This means that cocoa sent to a foreign buyer at any point in time has already been sold at an earlier time and that price is not necessary the same as the prevailing market price (Dormon et al., 2004). Hence, the producer price for cocoa do not necessary increase even if there is a significant increase in the world market price. The lowest cocoa producer price for cocoa farmers was recorded in 1983/1984 season when the government paid 21.3% of the FOB price, however, 68% of the FOB price was paid to farmers a decade later in 2003 (Amoah,1998).The current producer price (2015/2016 season) is about 74% of the FOB price (COCOBOD, 2015).

The Cocoa High Technology Programme (CHTP)

The ‘Cocoa High Technology’ of cocoa production is defined as “the sustainable cocoa production by which the farmer increases and maintains productivity, through soil fertility maintenance at levels that are economically viable, ecologically sound and culturally acceptable using efficient management of resources” (COCOBOD, 2002, p. iv). The programme emphasizes the use of fertilizer and proper farm management practices to achieve higher cocoa yields. The holistic approach of the CHTP involves five (5) main components namely, (a) cultural maintenance of farm, (b) application of fertilizer, (c) spraying of fungicide, (d) Spraying of insecticide, (e) harvesting, fermentation and drying technologies. Under the programme, fertilizer, fungicides and insecticides are given to farmers on credit by the government (represented by CRIG) through licensed buying companies (LBCs) that registered farmers. Beneficiary farmers pay part of the credit (about one-third) and the LBCs deduct the rest of the credit from the produce of farmers when they sell their produce to them at the end of the cocoa season. Farmers receive equal quantity of the package irrespective of the size of their farms provided they have a minimum of 2 acres of mature cocoa farm and the initiative was started in 2002 (CRIG, 2004). The impact of the programme in the Eastern Region three (3) years after the programme, showed about 72% increase in farmers’ yield. However, the programme faced major challenges of farmers paying back the inputs as agreed, hence the arrangement of supplying inputs to the famers through the LBCs virtually collapsed as reported by Bosompem, Ntifo-Siaw and Kwarteng (2010).

In 2014, the government of Ghana through COCOBOD initiated the CHTP again with emphasis on supplying selected cocoa farmers in all the cocoa regions with fertilizers but at this time free of charge. Generally, inorganic fertilizers were supplied to farmers even though few farmers were given organic fertilizer. The inorganic fertilizers were either solid or liquid (CRIG, 2010). The solid fertilizers were mainly Asaase Wura (NPK 0-22-18+9CaO+7S+6MgO) and Cocofeed (NPK 0-30-20). Sidalco liquid fertilizers that come in three formulations include (i) N:P:K 10:10:10 (Balanced), (ii) N:P:K 20:2:4 (Nitrogen-rich) and (iii) N:P:K 6:0:20 (Potassium- rich) were also supplied to the some cocoa farmers (CRIG, 2010).

Environmental concerns

The most important environmental concerns result from agrochemical use and climate change issues. Agrochemicals are substances used in agriculture to overcome constraints leading to increase in production (CRIG, 2010). These include fertilizers, pesticides, and insects or plant growth regulators. However, the most widely used agrochemicals on cocoa are pesticides which give most benefits and at the same time pose problems to farmers themselves, the crop and the environment.

According to Pidwirny (2002), over the last 50 years many human illnesses and deaths have occurred as a result of pesticide contamination (up to 20,000 deaths per year) due to accidental exposure of farm workers to pesticides. Accidental exposure may result from improper handling, or the non-use of protective clothing when applying pesticides. Another potential hazard of pesticide use is the ability of pesticides to interfere with the endocrine system (which produces hormones) and the immune system of both animals and humans. It is estimated that up to 90% of the pesticides applied never reach the intended targets, therefore, many other organisms sharing the same environment (beneficial insects) as the pests are accidentally poisoned (Pidwirny, 2002).

"**Climate change**" is a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere in addition to natural climate variability observed over comparable time periods. There is the need to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (EPA, 2007).

According to CRIG (2010), future climate change scenarios developed based on a 40 year historical data observed by the Ghana Meteorological Agency showed that temperature will continue to rise on average of about 0.6, 2.0 and 3.9^{o}C by the year 2020, 2050 and 2080 respectively, in all agro-ecological zones in Ghana. This report generally predicts a gloomy future for most agricultural commodities including cocoa. For example, it is predicted that there will be a drop of cocoa yield of dry cocoa beans of 14% and 28% for 2020 and 2050 respectively in Ghana (Anim-Kwapong & Frimpong, 2007). The scenarios also show that moisture levels in 2080 would not be adequate for profitable cocoa production in Ghana. Climate change mitigating strategies have been advocated by Kyoto protocol to mitigate some of the effects of climate change.

Climate Change Mitigation refers to efforts to reduce or prevent emission of greenhouse gases. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behaviour. Protecting natural carbon sinks like forests and oceans, or creating new sinks through silviculture or green agriculture are also elements of mitigation. Efforts are being made to help countries move towards a low-carbon society (UNEP, 2015).

Precision Agriculture Technologies

What is Precision Agriculture?

Gandonou (2005) defines PA as "Tailoring soil and crop management to match varying conditions (soil texture, moisture and nutrient status, seeding, etc.) within a field" (p 1). Precision agriculture (PA) can also be defined as an information and technological based farm management system to identify, analyse and manage variability within fields for optimum profitability, sustainability and protections of the land resource. The main goal is to manage and distribute inputs on site- specific basis to maximise long term benefits (Singh, 2006). According to Mandal and Maity (2013), PA can "loosely be defined as the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for improving production and environmental quality" (p 203). PA also describes the integration of geographic information system (GIS) and global positioning system (GPS) tools to provide an extensive amount of detailed information on crop growth, crop health, crop yield, water absorption, nutrient levels, topography and soil variability (Najafabadi et al., 2011).

Blackmore et al. (2003) observed the four specific objectives of precision agriculture namely: (a) increase profitability and production; (b) Reduce costs, erosion and environmental impact of chemicals; (c) track and monitor the use of chemicals; and (d) Manage large farms. Mandal and Maity (2013), in summarizing the importance of Precision Farming, enumerated the following:

(a) enhance productivity in Agriculture,

(b) prevent soil degradation in cultivatable land,

(c) reduce agrochemical use in crop production,

(d) efficient use of water resources, and

(e) disseminate modern farm practices to improve quality and quantity of production.

Advantages of PA can be looked under four (4) perspectives namely:

(a) Agronomical: agronomical practices are based on specific crop requirement;

(b) Technical: allow efficient time management;

(c) Environmental : eco-friendly practices in crop; and

(d) Economical: increased crop yield, efficient use of inputs, labour, water etc. to achieved quality and reduced cost of inputs. (Mandal & Maity, 2013).

Components, Tools and Practices of Precision Agriculture

Components of precision agriculture

Literature provides three (3) main components of PA namely:

(a) Information or data base, (b) Technology, and (c) Management (Mandal & Maity, 2013).

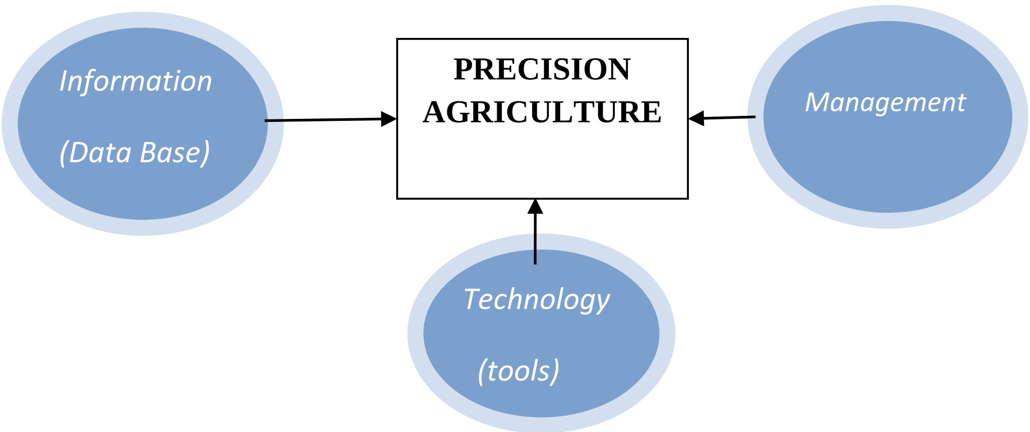

Figure 1: Components of Precision Agriculture by Mandal & Maity (2013)

Source: Author's Construct (2015)

As a system, these three main components have different tools and or practices that ensure successful implementation of the PA as shown in Figure 1

Information or data base

To be successful, precision agriculture concepts must start from a reliable and accurate information or data base systems that show information on the properties of soil, crop information and the climatic conditions in the specific area or location (Mandal & Maity, 2013).

The data base of the soil properties often include soil texture, soil structure, physical condition, soil moisture and soil nutrients in the area. Crop data base includes types of crop, plant population, crop tissue, nutrient status, crop stress, weeds patches (weed type and intensity), pest infestation (species and intensity), crop yield and harvest swath width. Climate data base also includes temperature, humidity, rainfall, solar radiation and wind velocity, in-field variability and in-soil related variability.

Aside these three (3) specific data bases, information on the interrelationship among these such as, spatial or temporal in-fields variability, soil-related properties, crop characteristics, weed and insect-pest population and harvest data are important databases that need to be developed to realize the optimum potential of precision agriculture.

Technology

Technologies developed to make precision agriculture a reality include tools of hardware, software and equipment. The technologies include:

*1. **Global Positioning System (GPS) Receivers:*** GPS provides continuous position information in real time while in motion. This helps to have precise location information at any time and this ensures that soil and crop measurements are mapped. GPS receivers can either be carried to the field or mounted on implements to allow users to return to specific locations to sample or treat those areas (Mandal & Maity, 2013).

2. Differential global positioning system (DGPS**)** :The GPS technology is essential for all phases of precision agriculture because PA requires positioning information (Pierce & Nowak, 1999). GPS is able to provide the positioning in a practical and efficient manner. The Differential GPS technique helps to improve GPS accuracy. The DGPS uses pseudo range errors measured at a known location to improve the measurements made by other GPS receivers within the same general geographic area (Mandal & Maity, 2013). Even though high-precision differential GPS (DGPS) systems that are available that can achieve centimeter accuracies, they are very expensive (Lange, 1996).

3. Geographic information systems (GIS): GIS is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information [Environmental Systems Research Institute (ESRI), 1997 cited in Pierce & Nowak (1999)]. Simply put, GIS are computer hardware and software that use feature attributes and location data to produce maps. Agricultural GIS usually store layers of information, such as yields, soil survey maps, remotely sensed data, crop scouting reports and soil nutrient levels (Mandal & Maity, 2013).

4. Remote sensing: Remote sensing is the collection of data from a distance (Mandal & Maity, 2013). Sensors are devices that transmit an impulse in response to a physical stimulus such as heat, light, magnetism, motion, pressure, and sound (Pierce & Nowak, 1999). Therefore, computers record the sensor impulse, a GPS measures position, and a GIS to map and analyze the sensor data, and any sensor output can be mapped at very fine scales.

Data sensors can be mounted on aircraft or satellite-based or even sometimes as a simple hand-held device. These sensors can remotely-sensed data hence providing a tool for evaluating crop health. Therefore, plant stress as a result of moisture, nutrients, compaction, crop diseases and other plant health concerns are often easily detected in overhead images (Mandal & Maity, 2013). Remote sensing can also detect in-season variability that affects crop yield, and can be timely enough to make management decisions that improve profitability for the current crop.

5. Variable rate applicator: Variable rate application refers to the application of agricultural inputs in specific and changing rates throughout the field (Watkins, Lu, & Huang, 2008). Watkins et al. (2008) observed that the conventional method of agricultural input application normally treats the entire field as a homogeneous unit; therefore, inputs are applied uniformly throughout the field in one fixed rate of application. This traditional method of application ignores spatial variations in soil type, soil fertility, and yield potential that are likely to be present in the field. As a result, the inputs can be under-applied in some areas and over-applied in other areas. The goal of variable rate application is to apply the exact amount of fertilizers, pesticides, water, seeds, or other inputs to specific areas in the field where and when they are needed for crop growth. According to McChesney, McChesney, Schamp, and Schulte (2012), variable rate application was originally thought of as visually looking at fields and taking soil samples of the deprived looking areas of the field. However, with the advent of the technology of GPS and computers, yield monitors and aerial photography have greatly increased the awareness of precise application of fertilizer and other inputs where they are actually deficient (Fasching, 2011).

The variable rate applicator is designed to ensure that inputs are applied in specific and changing rates depending on the nutrient requirement of each plant. The variable rate applicator has three (3) components:

a. Control computer,

b. Locator and

c. Actuator.

The application map is loaded into a computer mounted on a variable-rate applicator. The computer uses the application map and a GPS receiver to direct a product-delivery controller that changes the amount and/or kind of product, according to the application map.

Morgan and Ess (2003) identified two basic methods for implementing variable-rate application (VRA) (i) Map-based VRA and (ii) Sensor-based VRA. Map-based VRA systems adjust the application rate of the input based on information contained in a digital map of field properties, while sensor-based VRA systems use data from real-time sensors to match inputs to the needs of the soil and crop. The type of input to be applied determines the kind or method of VRA to be used (Forouzanmehr & Loghavi, 2012). For fertilizers application, map-based methods are preferred to the sensor-based ones because of the lack of sufficient sensors for real-time monitoring of soil and crop conditions.

6. Combine harvesters with yield monitors: Yield monitors continuously measure and record the flow of grain in the clean grain elevator of a combine harvester. When linked with a GPS receiver, yield monitors can provide data necessary for yield maps.

Management

The management includes the following: information management, decision support system and identifying precision agricultural providers.

1**.** ***Information management*****:** The adoption of precision agriculture requires the joint development of management skills and relevant information databases. A farmer must have a clear idea of objectives of precision farming and crucial information necessary to make decisions effectively. Effective information management requires much more than just keeping analysis of tools. It requires an entrepreneurial attitude toward education and experimentation.

2. ***Decision support system (DSS):*** Combination of information and technology into a comprehensive and operational system gives farmers a decision to treat the field. For this purpose, DSS can be developed through the utilization of GIS, agronomic, economic and environmental software, to help farmers manage their fields.

3. **Identifying a precision agriculture service provider:** It is also advisable for farmers to consider the availability of custom services when making decisions about adopting precise/site specific crop management.

Purchasing the equipment and learning the necessary skills for precision farming is a significant up-front cost that cannot be affordable for many farmers. Therefore, farmers are advised to take services of agricultural service providers or properly trained extension workers for precision agriculture.

The most common custom services that precision agriculture service providers offer are intensive soil sampling, mapping and variable rate applications of fertilizer and lime. Equipment required for these operations include a vehicle equipped with a GPS receiver and a field computer for soil sampling, a computer with mapping software and a variable rate applicator for fertilizers and lime. By distributing capital costs for specialized equipment over more land and by using the skills of precision agriculture specialists, custom services can decrease the cost and increase the efficiency of precision agricultural activities.

There are many topics in the field of precision agriculture; therefore the topics that are addressed include but are not limited to; natural resources variability, managing variability, engineering technology, profitability, environment and technology transfer.

Precision Agriculture in Africa and Ghana

With the exception of few yield monitors in South Africa and some VRA fertilization in isolated plantation enclaves, adoption of PA technologies was virtually unknown in Africa (Swinton and Lowenberg-Deboer, 2001). However, the use of GPS which is the cornerstone of PA is readily available in almost all the countries in Africa. It is reported that by the end of 2013, GPS services provided by TomTom company now covers all 54 African countries with maps that are 3D and interactive (African Business, 2014). Even though these services are mainly for the roads, it can be harnessed to develop vegetation and soil maps to facilitate the development of PA.

Precision agriculture is still new in Ghana because its development and implementation has been rather slow (Allavi, 2014). There is however, an example of the use of PA which focuses primarily on location determination by mango growers in the Volta region of Ghana. With support from the Market-Oriented Agriculture Programme, which is funded by the German Development Cooperation agency (GIZ), these farmers have been trained to use specific devices, such as the Trimble Juno 3B Handheld GPS device and the TerraSync mobile application for farm GPS mapping (collection of geo-reference farm data) (Allavi, 2014).

Syecomp Business Services Ltd, a market leader in the use of GPS applications in Ghana, was contracted to provide on-field technical training and assessment (Robinson et al., 2014). Farmers were taken to mango farms where they were shown how to conduct field boundary mapping. Relevant farm features, such as farmhouses, farm equipment and streams were captured with the integrated digital camera. Farm information, such as farm size, GPS coordinates, shapes, elevation and other features were presented via the TerraSync application in real-time on the field (Robinson et al., 2014). The adoption of GPS mapping technology has helped the cooperative determine the gross margin of their farm produce so it can conduct comparative assessments. It has also resulted in a host of other benefits, such as transparency regarding crop volumes under production and easier logistic planning between mango farmers and buyers.

The same company used GIS and GPS to help improve the marketing of agricultural produce **(**ISPA, 2013**).** The technology determines the supply base of producing firms and establishes a system for traceability and precision production for the farmers through mapping, helping to establish the spatial locations and concentrations of fruits and vegetable farms. This helped to solve the problems of dispersion of farms and the lack of location-specific data for production planning, monitoring and targeting which result in an inability to forecast farm yields; inaccurate assessment of supply base; over-estimation of farm sizes; over-paying for labour and other services (ISPA, 2013).

Challenges to Precision Agriculture

Challenges have been defined as difficult tasks that test the ability, capacity and skills of a person, organization or community (Wehmeier, 2008). Therefore, problems of implementing PA can be regarded as challenges not necessarily as barriers. Studies have identified several challenges when dealing with PA systems (e.g. Daberkow & McBride, 2003; Hudson & Hite, 2001; Kutter, Tiemann, Siebert, & Fountas, 2009; Reichardt, Jurgens, Klobe, Huter, & Moser, 2009). These challenges have contributed significantly to the slow rate of adoption of PA by farmers (Kutter et al., 2009). A careful review of literature on PA has resulted in categorizing these challenges into eight. (Najafabadi et al., 2011; Mcbratney, Whelan & Ancev, 2005; Tey & Brindal, 2012). These are (a) Economic, (b) Time, (c) Educational/Training, (d) Technical, (e) Data quality, (f) Farmer/Operator demographics, (g) Environmental/Abiotic, and (h) Political/Governmental challenges.

Economic challenges

An important drawback to the adoption of PA is the initial cost investment. The cost for PA technologies may range from several thousands of dollars to tens-of-thousands of dollars. Incentives or subsidies have not generally been provided to enhance the affordability of PA technologies. Although the initial cost of PA technologies have decreased over the years because of increasing availability of PA technologies, prices still remain relatively high (Tey & Brindal, 2012). As at 1996-1997, VRT controllers cost as much as $250,000.00 (Anderson, 1998). Reetz (2012) observed that one of the reasons for the lack of advancements in variable rate technology and its adoption when the technology was originally released in the mid 1990's was the relatively cheaper price of fertilizer vis-a-vis the high cost of VRA. In other words, because the price of fertilizer was so cheap and the VRA was so expensive, farmers could afford to buy enough fertilizer to apply to the entire field rather than only the areas where fertilizer was needed.

Some estimated spending were over A$100 000 on hardware and A$70 000 on information for PA including data interpretation, soil testing and consultancies (Lawes, 2013). Some forms of PA systems that do not require very high-tech equipment (GIS systems, VRT without using variable rate controllers, guidance or a history of yield mapping) cost relatively lower. The cost shoots up astronomically if auto-steering technology and other much-advanced forms of technology are involved (Robertson, Llewellyn, & Griffiths, 2010). For example, high-precision and high-cost auto steer systems cost as much as $60, 000.00 (in Australia) (Robertson et al., 2010). A Sub-Metre guidance system with precision of 10 cm, has initial capital cost of $20,000, and annual costs of $500 (Knight & Malcolm, 2009), and Real-Time Kinematic (RTK) guidance system with precision between 2-3 cm cost between $25,000.00- $50,000.00 (depending on whether it is static or otherwise) (Knight & Malcolm, 2009; Yagi & Howitt, 2003). In Japan, the initial investment cost for PA in one survey, pegged each surveyed farm at an estimated initial cost of 32,000 to 63,000 US dollars (Yagi & Howitt, 2003). It is also estimated that Zone Management involves investing about $36,000 in enabling technology and an annual 'start-up' cost of $3,600.00 (Knight & Malcolm, 2009). In Argentina, Satellite DGPS cost USD 2,000 (plus tax) per year (Bongiovanni & Lowenberg-DeBoer, 2005). Also, GIS software (ArcView™) cost USD 2,300 for the basic software (Bongiovanni & Lowenberg-DeBoer, 2005). In addition, the price of the high definition Ikonos™ images costs USD 6,000 in Argentina and USD 3,000.00 in the US (Bongiovanni & Lowenberg-DeBoer, 2005).

Rental cost of PA tools and consultancy fees have been another dimension of economic challenge which has hampered the adoption of PA in several countries (Lambert & Lowenberg-DeBoer, 2000). Renting PA tools and services may seem a plausible idea rather than outright purchase considering the expensive nature of PA tools. However, a careful estimate of the cost of renting (hiring) PA tools and services has shown it to be on the higher side for a considerable period. For example, in Missouri (15 years ago), annualized costs of agricultural services in implementing VRT cost was US$27.88 per hectare (Wang, et al., 2003). This covers the cost of nine services (Variable rate N application, Uniform rate N application, Variable rate lime application, Uniform rate lime application, Soil testing for pH and N.A. with VRT, Sample handling for pH and N.A. with VRT, Soil electrical conductivity mapping, Soil testing for pH and N.A. with URT, and Sample handling for pH and N.A. with URT). At such a rate, the cost of PA services could range between US$2,788.00 (for a 100-acre crop farm) and US$27,000.00 (for a 1000-acre cash crop farm). However, this challenge seems to have reduced. One report (Zarco-Tejada, Hubbard, & Loudjani, 2014) suggests that the cost of services of PA has reduced significantly from the year 2004 to the present (2014) (Zarco-Tejada et al., 2014). In that report, out of 171 responses, 53.3% had indicated the high cost of PA services as a major barrier to the adoption of PA in the United States. By the year 2014, however, this figure had reduced up to 22.2% (Zarco-Tejada et al., 2014).

Obsolescence potential of hardware and software used in PA systems is yet another aspect of economic challenge that hampers PA (Kitchen, Snyder, Franzen, & Wiebold, 2002). Precision agriculture is still relatively an infant technology and almost every week new equipment and software are put on the market to enable farmers have access to improve our ability to collect and use site-specific data (Alley, 1997). Technology is changing rapidly, and hardware and software purchased today may be obsolete in a few years (Day, 1997). For example, the results from a round table discussion of a group of farmers, scientists and industry representatives during a discussion of the possibilities and pitfalls of PA at a National Conservation Tillage Systems Cotton and Rice Conference in Houston revealed that equipment bought just three years ago was already obsolete (Smith, 2007). In one case study, the respondent highlighted the issue of software challenges. In his own words, software has been difficult to understand because of constant software changes and upgrades (Arnholt, 2001). In fact, a study quotes respondents from the UK, Denmark and the USA in an interview as indicating that keeping up with new software products was a significant task (Fountas, Pedersen, & Blackmore, 2006). Yet, these software and hardware are very expensive. Hence, this discourages several potential farmers from adopting PA.

Then comes also the cost of training and learning how to use PA equipment (Kutter et al., 2009). In 2006, a five-day training programme on PA in Australia costs as much as $1,200.00 (Birchip Cropping Group, 2006). In the UK, a five day module training course on PA also costs as much as £1200.00 (Agrifood, 2015).

High interest rates also contribute to the economic challenges of adoption of PA (Lowenberg-DeBoer, 2005). The challenge is even accentuated in developing economies that struggle with external debt. For example, in Argentina, the average real interest rates for production loans are in the range of 16% - 24% annually, and longer-term credit is not easily available at that time (Bongiovanni & Lowenberg-DeBoer, 2005). In Ghana, the interest rates hovers around 28%. Such a high interest rate (compared to 3.3% in the US) hampers the adoption of PA because several of the technology must be imported to developing countries. For instance, a yield monitor with GPS costs twice as much in Argentina than in the USA (Bongiovanni & Lowenberg-DeBoer, 2005).

The supposed uncertainty of PA's return on investments reported to be a high-risk challenge (Adrian, 2006), could at best be described as a mere perception. This is so because a careful and diligent review of almost all the literature that reports on the economic advantage (profitability) indicates that PA is advantageous in most cases. For example, of the 108 studies that reported economic figures [from both scientific journals or proceedings (86%), and non-technical or non-refereed magazines and monographs specializing in agribusiness services (14%)], 63% indicated positive net returns for a given PA technology, while only 11% indicated negative returns with 27 articles indicating mixed results (26%) (Lowenberg-DeBoer & Lambert, 2000).

According to the same authors, for all PA technology combinations identified, over 50% of the studies reported positive benefits, except for VRT-yield monitor systems. About 60% of the studies of N or NPK VRT systems reported profits (Lowenberg-DeBoer & Lambert, 2000). In addition, out of the 63 documents reporting benefits authored by economists, 73% reported positive benefits from PA, 16% reported mixed results and 11% negative results (Lowenberg-DeBoer & Lambert, 2000). Furthermore, of the nine documents with agribusiness authors reporting benefits, two-thirds (66%) of these articles reported positive results from PA, while two articles (22%) reported mixed results (Lowenberg-DeBoer & Lambert, 2000). According to their report, only one individual employed by the agri-business sector reported negative returns. For these reasons, Lowenberg-DeBoer and Lambert (2000) concluded that in terms of positive benefits, economists and agribusiness authors seem to be coming to the same conclusions.

In order to create a holistic picture of the outcomes of all the studies as at the time of their report, Lowenberg-DeBoer and Lambert(2000) categorized all the studies by crop. Their report indicated that corn, soybean and sugar beet studies showed positive profits in over two thirds of cases whiles only 20% of the studies on wheat showed profits, and another 20% results were mixed. It is noteworthy that all the studies discussed were limited to states in the USA and Argentina (Lowenberg-DeBoer & Lambert, 2000).

The lack of allocation of funds to PA poses considerable drawback (Daberkow, Fernandez-cornejo, & McBride, 2000). In several countries, (especially developing economies such as Ghana), the universities do not have the necessary budget for research in precision agriculture. In countries where PA adoption is on the rise (e.g. Argentina), all researches carried out so far have been possible through the collaboration of commercial companies, and top farm managers who are willing to do on-farm trials (Bongiovanni & Lowenberg-DeBoer, 2005).

Despite the aforementioned high cost involved in PA, investment in precision agriculture is worthwhile because of proven substantial reduction in cost of inputs and production. For example, Yule and Radford (2003) estimated 28% reduction in labour cost as a result of adoption of PA and Controlled Traffic System (CTF). Jensen, Jacobsen, Pedersen and Tavella (2012) observed that site-specific application of herbicides contributed about 50% of the profit due to reduction in herbicides cost among farmers in Denmark. PA site-specific weed management could reduce the amount of herbicides used by as much as 40-60% under best practices. (Jensen et al. 2012). Van Alphen and Stoorvogel (2000) also observed that precision fertilization was efficient in reducing nitrogen fertilizer inputs by 23% while improving grain yields by 3% among wheat fields in the Netherlands.

Time challenges

Time input of the farmer is significant as it is necessary for the farmer to be part of the data interpretation (CSIRO, 2013). Several facets of the time factor contribute to the implementation of PA techniques. For example, it has been opined that large-scale farmers may not be able to spend as much time on PA technologies as medium-scale farmers (Anderson, 1998). Also, small-scale farmers who spend a lot of time working off the farm may not be able to devote much time to precision farming (Anderson, 1998). Importantly, the time required to learn about PA equipment is not a challenge limited only to consumers (farmers) but also to producers of PA equipment. This is the case because time may be needed to improve performance, reduce costs, and increase reliability sufficiently to make this technologies attractive to large number of producers (Press, 1997). In 2001, over 26% of farmers surveyed in Germany indicated that large amount of time spent to get used to the technology was a challenge to them. The figure increased to 44.2% (out of 171) in 2003. In 2005 and 2006, 43.8% (out of 152) and 26% (out of 51) of the farmers indicated the same challenge in Germany (Reichardt & Jurgens, 2009).

In addition, the time that is used to introduce PA's technologies and problems occurring at the initial stages is another concern (Reichardt & Jurgens, 2009). For example, in the same survey in Germany, 8.8% of the farmers indicated that bad descriptions of the machines posed considerable challenge in the year 2001 (Reichardt & Jurgens, 2009). In 2003 and 2005 respectively, 10.4% and 11.8% indicated the same challenge while it reduced to 4% in 2006 (Reichardt, Jurgens, Klobe, et al., 2009). Furthermore, there was steady increase in the percentage of farmers who indicated that bad description of the computer equipment was a challenge to them (5.5%, 7.1%, 9.7% and 10%) for the years 2001, 2003, 2005, and 2006 respectively. Unreliable computer equipment appeared to be the most pressing challenge at the initial stages of PA adoption. This is apparent by comparing the percentages of farmers in the survey in Germany for the corresponding years. In 2001, 16.5% of the farmers indicated that unreliable computer equipment was a challenge and this rose to 18.2% in 2003. However, it decreased to 13.9% in 2005 and further decreased to 8% in 2006. These initial setbacks could even lead to loss of significant data due to machine or human error. All these aforementioned are challenges experienced at the initial stages of PA adoption.

Further, the time taken to experience any investment returns has been identified to be another time-factor challenge (Wiebold, Suduth, Davis, Shannon, & Kitchen, 1998). The time it takes to reap any investment returns varies depending on which technology is being implemented. For example, auto steering and variable rate applications are fast, and can easily be put into use to provide immediate returns (Graham, 2014). On the other hand, technologies such as yield mapping and soil analysis provide a slower return on investment (Graham, 2014). For example, a simple investment analysis has shown that a 1–11% increase in gross margin is required over a 10-year period to recover an initial investment of $5000– $20,000 (Robertson et al., 2010). Another case study in Australia in 2007 revealed that it took three (3) years for a PA farmer (VRT) to reap benefits from an initial investment of about USD$30,200 (Robertson, Carberry, & Brennan, 2007). Similarly, the study in Australia revealed that it took two years to return profits after an initial investment of USD$201 500 (Robertson et al., 2007). Two other case studies all in Australia, indicated that there were negative returns in the first years, and that positive returns were from the second year onwards, after substantial initial benefits. In one instance, there was negative returns in the first three years, with benefits only from the fourth year onwards (Robertson et al., 2007).

The time it takes to properly calibrate PA equipment without which the data collected and subsequent maps generated are of no use is another critical step in the use of PA equipment (Mauzey, 2010). However, large amount of time is required to learn the proper calibration of these equipment (Reichardt & Jurgens, 2009). Also, the time and attention required to set up and operate PA systems (variable rate machinery) often conflicts with the urgency of sowing a crop in a timely manner (Robertson et al., 2010; Wiebold et al., 1998).

Data quality challenges

Data quality challenges comprise difficulty in maintaining quality data, difficulty in storing and retrieving data with different formats, and difficulty in analysing data to understand yield-limiting factors (Kitchen et al., 2002). In addition, difficulty of data transfer to external sources for analysis (Fountas et al., 2006), difficulty of data interpretation (Reichardt & Jurgens, 2009), and lack of appropriate measurement and analysis techniques for agronomical important factors (NRC, 1997) have been highlighted. Again, difficulties in managing such a large amount of data and using them efficiently (Reichardt & Jurgens, 2009), incompatibility of software packages (Wiebold et al., 1998), problems related to data ownership and data handling (Reichardt & Jurgens, 2009) have equally been implicated among these challenges. Data accuracy concerns have also generated skepticisms among some farmers (Lavergne, 2004).

Maintaining quality data in precision agriculture is a challenge because precision agriculture involves the use of sensor and wireless communication technologies (Kitchen et al., 2002; Kotamäki et al., 2009). In order for such sensor and wireless networks to function properly, it requires a relatively dense deployment of sensors embedded in vehicles or deployed *in–situ* in the field (Kotamäki et al., 2009). However, several factors related to the communication network, the stations or sensors themselves and the outdoor conditions could interfere with the data quality. For example, the improper functioning of the communication network can obstruct the data transfer and battery consumption because a weak signal consumes more power than a strong signal. Such poor signals from communication networks result in missing data or delayed data delivery (Kotamäki et al., 2009).

Difficulty in storing and retrieving data with different formats arise because by using different devices, which support different data formats (including PAR data collected from an infrared sensor array and GPS position of the array), and improperly spatial reference systems, the farmer has to transform the data between proprietary GIS and coordinate systems (Korduan, Bill, & Bölling, 2004). In order to convert the data from one system to the data format of another system, look up tables were used (Sondheim, Gardels & Buchler, 1999). However, using this strategy could result in errors, redundancy and inconsistency in the data (Korduan et al., 2004). For this reason, efforts have been made to create a programme (software) capable of importing and integrating heterogeneous data sets and processing data in different formats from an array of devices (Nikkila, Seilonen, & Koskinen, 2010; Peets, Mouazen, Blackburn, Kuang, & Wiebensohn, 2012). For example, some researchers have proposed and demonstrated the use of an extensible and integrated software architecture for data analysis and visualization (Korduan et al., 2004; Tan, Haley, & Wortman, 2009).

Spatial variation in landscape and soil properties combined with temporary variations in weather can result in crop yield patterns that vary annually within a field and making it difficult in analysing data to understand yield-limiting factors as a number of yield-limiting factors create this temporal and spatial variability (i.e., water stress, diseases, weeds, soil fertility) (Irmak Jones, Batchelor, Irmak, Boote, 2006). In the past several years, researchers have used empirical or process-based tools to identify various yield-limiting factors within fields and analyse causes of yield variability. For example, crop growth models like the CROPGRO-Soybean and CERES-Maize (Jones & Kiniry, 1986) have been used to identify the magnitude of yield loss attributed to yield-limiting factors such as water stress, diseases, weeds, and soil pH (Paz et al., 2001). While this approach has considerable promise, its success depends on the accuracy of relationships that are incorporated into the crop model and their transferability to other years and locations (Irmak et al., 2002a).

Data quality concerns have generated skepticisms among some farmers. For example, it has been identified that spatial modelling of farm machinery operations have several steps that can cause errors and inaccuracies for the modelled maps (Kaivosoja, 2009). Since maps are used for precision farming, inaccuracies will have direct effect on the quality of precision farming. To prove this assertion, Kaivosoja (2009) determined and evaluated the extent of the error factors that have effects on spatial modelling by examining and analyzing most common field machines including harvesters, seeding machines, harrows, sprayers and spreaders in spatial modelling perspective in Finland. The findings demonstrated that after the raw data was collected, the uncorrected lags in the measurement system could change the longitudinal location for several meters, and that all the measurement systems will have some uncertainty with log timing (Kaivosoja, 2009). Dynamic tractor-implement combination was found to generate more error sources, and that uneven field surface and curved driving lines urge the need of accurate modelling. The author noted that changes in the temporary spatial distribution were rarely taken account of but generate errors again with curved driving lines and with VRA actions.

Finally, the interpolation was found to be able to smoothen the results or lose important information. Paralleling this research, Zhou, Cong, & Liu, (2014) have indicated that, varying field slopes have visible effects on the precision of yield monitors. For example, in a field with a slope averaging 6 %, data recorded by a commercial yield monitor was found to have a 6 % difference between traveling up and down slope (Grisso, Jasa, Schroeder, & Wilcox, 2002). In addition, A laboratory test stand consisting of a combine clean grain elevator mounted on a gimbal fixture was used to simulate varying field slope, and while errors were observed during roll tests (-3.45–3.46 %), pitch tests generated higher errors (-6.41–5.50 %) (Fulton, Sobolik, Shearer, Higgins, & Burks, 2009).

Varying ground speed has been found to obviously affect the accuracy of a yield monitor (Zhou et al., 2014). For example, the average error of a yield monitor was 3.4 % at constant ground speed (8 km/h) whereas the average error was 5.2 % at varying combine speed (8–11 km/h) (Arslan & Colvin, 2002a, 2002b). Varying capacities of the combine harvester is another influential factor

(Zhou et al., 2014). Though the recommended method of calibration has been followed at varying capacities, the error of commercial yield monitors is significant when the combine harvesters are operated at under-capacity (20–30 % reduction in travel speed) and over-capacity (20–30 % increase in travel speed), even a 12.6 % error has been found on the over-capacity test (Grisso et al., 2002). Varying conditions under which the calibration of yield monitor is conducted also has substantially contributed to errors in yield measurement (Zhou et al., 2014). Significant errors arise when mass flow rates have been estimated at a certain threshold above calibration flow rates (Burks, Shearer, Fulton, & Sobolik, 2003), and increased errors have been observed for low flow rates (Jasa, Grisso, & Wilcox, 2000)

Educational/training Challenges

Educational challenges comprise lack of effective advisory services (Reichardt & Jurgens, 2009), low acceptance of PA technologies among the advisors (Reichardt & Jurgens, 2009), lack of local experts (Wiebold et al., 1998), lack of research and extension personnel who have a good handling of the practical field applications (Heiniger et al., 2002), lack of PA awareness of farmers and experts (Reichardt & Jurgens, 2009), ineffective PA education (Kitchen et al., 2002), lack of integrating agronomical knowledge and ecology with PA (Fami et al., 2005), needed skills in the application of PA software and hardware (Adrian, 2006), inadequate qualified and experienced operators (Reichardt et al., 2009), lack of technical knowledge and software skills (Fountas et al., 2005), lack of considering PA topics in universities, lack of considering PA topics in technical and vocational schools, lack of considering

PA at education institutions, lack of training courses, especially for teachers (Reichardt et al., 2009; Reichardt & Jurgens, 2009), lack of adequate training resources (Wiebold et al., 1998), lack of basic knowledge about PA (Reichardt & Jurgens, 2009) and lack of knowledge about data utilization (Fountas et al., 2005).

One of the important challenges that deter farmers from adopting PA is the time consuming nature of the introduction of PA technologies and the problems occurring at the start (Reichardt & Jurgens, 2009). After having overcome these initial problems, farmers are usually satisfied with the introduction of PA. Hence, there is the need for effective advisory services, especially during the introduction of PA. Unfortunately, however, literature available shows lack of or ineffective advisory services in PA. This has been and continues to be a challenge. For example, Reichardt and Jurgens (2009) report that 58.4% of 89 advisors from all over Germany that offer advisory services do not offer any advisory service in the field of PA. According to these authors, especially in western Germany, where the chamber of agriculture organises advisory service, there is hardly any advisory service offered for PA. There is, however, a slight improvement in advisory services provided the service is organised by private institutions. For example, in eastern Germany, where private companies organize the advisory service, the results of the survey showed a higher percentage of advisors offering information service for PA (Reichardt & Jurgens, 2009). The results also indicated that most of the advisors (80%) stated that in general that the farmer has a specific problem and must contact the advisory service for help and not the other way round. This requires the farmer to be aware of his problems. However, farmers, especially those new to PA find this to be a challenge in itself. Besides this, there is low acceptance of PA technologies among the advisors themselves which has been attributed to the fact that most of PA advisors do not recognize the advantages of this technology due to their low level of knowledge about it (Reichardt & Jurgens, 2009).

Again, many of the precision technologies dealers sell their technology without local dealer support and expertise (Heiniger, Havlin, Crouse, Kvien, & Knowles, 2002; Wiebold et al., 1998). This means that farmers must trust the person at the other end of a phone line or e-mail message for answers and service. Interestingly, however, in the case of site-specific management techniques, few research and extension personnel have tested these concepts and have a good handle on the practical field applications which makes it a real challenge to the adoption of PA (Heiniger et al., 2002). Further, the level of awareness of a farmer has been identified to be the critical first stage of agriculture technology diffusion process (Daberkow & McBride, 2003). However, available literature indicate that the level of awareness of farmers in PA is low. For example, a nationwide study of 8400 farmers conducted in the USA in 1998 concluded that the unawareness of PA technology among farmers is one main reason for the low rate of adoption (Reichardt & Jurgens, 2009). At the time of that survey, 70% of the US farmers were not aware of precision farming technologies (Daberkow & McBride, 2003). A similar survey conducted between 2001 and 2005 in Germany indicated that over 50% of the farmers interviewed were unfamiliar with the term ‘‘Precision Farming’’ or ‘‘Precision Agriculture’’(Reichardt & Jurgens, 2009). A parallel survey also in Germany at the same period (2001 – 2005) revealed that about 28% of the farmers interviewed were unfamiliar with the term ‘‘Precision Farming’’ or ‘‘Precision Agriculture’’(Reichardt & Jurgens, 2009). These results suggest that there still is somewhat low level of awareness of PA, and the level of awareness is even profound in developing countries.

In addition, ineffective PA education has been highlighted by Kitchen et al. (2002) as a contributing challenge to PA. This is so because the new management complexities that PA technology adds to an operation require expanded skills and tools not previously taught or provided from an educational standpoint.

Another educational challenge is that several vocational and technical training institutions do not consider, PA (Reichardt et al., 2009; Reichardt & Jurgens, 2009). In one survey in Germany for example, it was reported that the majority (57%) of the teachers interviewed (n = 89) at technical and vocational schools stated that PA was not a subject of the agricultural education (Reichardt, Jurgens, Hutter, & Kloble, 2009). In instances where they are considered, only basic information was provided, mostly in terms of single oral presentations or single lessons (Reichardt, Jurgens, Hutter, et al., 2009). In addition, at most (89%) of the schools for the survey, PA was not a subject of tests or final exams (Reichardt, Jurgens, Hutter, et al., 2009).The case of Germany may well reflect the attitude of stakeholders towards the integration of PA in current curricula.

According to certain authors (Reichardt, Jurgens, Hutter, et al., 2009), some vocational and technical schools refuse the introduction of PA topics into their curricula because PA topics were perceived to be too complicated for the teaching level, especially at vocational schools. Some teachers also were of the view that the curricula were filled with other topics considered more important, so that there was not enough time to integrate PA. An interesting dimension to the resistance to the introduction of PA in schools and colleges is that most teachers have no knowledge about PA, because their own education was long time ago (Reichardt, Jurgens, Hutter, et al., 2009). This challenge seems to have been identified, and efforts are being made by various universities to tackle it. In view of that, several universities started to offer courses in PA back in the 1990's. For example, about 21 universities have been identified to offer PA courses in Germany (Reichardt, Jurgens, Hutter, et al., 2009). Since 2005, PA has been part of the courses at all agricultural universities in Germany, though the extent of this topic differs from institution to institution. Thus, there appears to be positive development in terms of inclusion of PA topics in institutions of higher learning.

Technical challenges

Technical challenges comprise complexity of PA technologies (Bongiovanni & Lowenberg-Deboer, 2004), difficulty of quantifying PA profitability because of its complexity with other benefits such as environmental benefits and food safety (Reichardt & Jurgens, 2009) and missing computer equipment (Reichardt & Jurgens, 2009), unreliable computers and equipment (Reichardt & Jurgens, 2009). It also includes unchangeable machines (Reichardt & Jurgens, 2009), lack of PA research (Mcbratney et al., 2005), low mechanization level on the farms (Cook et al., 2003), smaller farms (Zarei, 2007) and poor internet connectivity.

Another technical challenge is low level of standardization in the manufacturing of PA tools and software. This challenge comes about as a result of the following:

(a) incompatibility of machinery from different manufacturers (Kutter et al., 2009),

(b) incompatibility of new equipment with older equipment (Lavergne, 2004),

(c) lack of integration of PA technologies with current equipment and farming practices (Hudson & Hite, 2001), and

(d) incompatibility between hardware and software (Fountas et al., 2005).

The technicality of PA technologies poses challenges in making full use of these innovations. Several people imagine that because of its technological demands, PA has little to no application in the developing world (Mcbratney et al., 2005). For example, besides requiring sophisticated knowledge in respect to mechanical operation for data collection (Tey & Brindal, 2012), PA technologies also involve a high-level of complex data management, interpretation, and decision-making in respect to agronomic solutions (Robertson et al. 2012).

The difficulty to quantify PA profitability is another technical concern. The challenge arises because of a number of factors. For example, in nearly all case studies that sort to quantify PA profitability, there is no valid base case of uniform management with which to compare performance of any PA technology (Robertson et al., 2012). In order to deal with the lack of baseline for comparing profitability, various strategies have been developed by economists. For example, some have estimated what the yield *would have been* in each management zone, based on yield performance under any PA technology and some estimates from the farmers (Robertson et al, 2009). Clearly, this approach is not ideal. However, it is difficult to imagine farmers maintaining large commercial areas of uniformly managed fields just so a valid comparison could be made (Robertson et al., 2012). Compounding this challenge is that farmers modify the definition of management zones over time as they learn. Hence, certain authors have proposed a better approach. For example, Robertson et al. (2012) have proposed that an approach based on whole-of-block experimentation may be better.

Another drawback is that experimental comparisons to quantify PA have a backward-looking or ex-post perspective. That is, the contribution of those factors are analysed after they have been fully revealed. This does not account for the reality of a farmer's forward-looking or ex-ante perspective with imperfect information (Anselin et al. 2004). In response to this limitation of ex-post analysis of trials and farm case studies, a number of researchers have resorted to economic modelling to quantify the benefits of PA (e.g. Brennan et al. 2007; Robertson et al. 2009; Havlin & Heiniger 2009). These model results suffer from the lack of grounding in reality that farmers and advisors wish to see in any test. Yet, it has the advantage of being able to vary systematically, the separate and interacting effects of the shape of the input–output response function (Robertson et al., 2012). Nevertheless, some economists have been able to quantify the profitability of certain PA technologies with reasonable degree of convergence. For example, according to one estimate in Australia, the average increase in grain crop gross margin that occurs with the adoption of

VRT ranges from less than AUD5/ha up to an upper limit of around AUD50/ha (Robertson et al., 2012). This implies that for a farmer who owns 100 hectares of farmland, s/he will expect an increase in gross margin of between AUD250 and AUD5000. It is important to note that several of farmers may not even own up to 100 hectares of farmland. The situation will even be more profound in developing countries where field size is typically less than 0.5 ha (Cassman, 1999).

In addition, there is low mechanisation in agriculture in developing countries. It has been identified, for example, that farm power available per area of agricultural land has been declining in sub-Saharan Africa (SSA) (Baudron, 2014). Since 1970 for example, the number of tractors shipped annually to SSA has declined steadily (Baudron, 2014), yet, precision agriculture depends heavily on mechanisation (to different degrees depending on several factors). As a result, there is an increasing reliance on human muscle-power which consequently leads to high labour drudgery. For this reason, making a switch from manual mode of agriculture to the more sophisticated PA is a challenge, and will particularly affect those in Africa since agriculture is practiced mostly manually.

Further, there is also the challenge of unreliable internet access and connectivity, particularly in Sub Saharan Africa. Yet, Precision agriculture machine control requires the use of Real Time Kinematic Global Positioning Systems (RTK GPS) which depends on access to GPS base Stations. This in turn depends on (wireless) internet access as a cheaper means of access to Real Time Network GPS (Lyle, 2013). Nevertheless, unreliability, poor quality, and high costs define Sub-Saharan Africa’s internet market (MainOne, 2010). For example, statistics from MainOne (an ICT company in Nigeria) indicate that, in Sub Saharan Africa, a lack of network infrastructure and international bandwidth capacity has resulted in a low internet penetration rate of 8 percent, well below the world average of 23 percent (MainOne, 2010). In addition, 3G/4G coverage outside metro areas in the rural community is limited (Lyle, 2013). In Ghana, high-speed 4G networks are rare. Further, sparsely populated areas with small amounts of revenue for cellular suppliers have limited expansion of updated towers (Lyle, 2013). These factors will no doubt affect the successful downloading of RTK GPS corrections along with geospatial data in the field via the internet.

In a series of survey in Germany for the years 2001, 2003, 2005, and 2006, 16.5% (out of 1489), 18.2% (out of 2319), 13.9% (out of 1913), and 8% (out of 462) indicated that unreliable computers and equipment were a challenge respectively (Reichardt & Jurgens, 2009). An earlier study had come to a similar conclusion (Pedersen, Ferguson, & Lark, 2001). It seems from the findings of Reichardt & Ju (2009), however, that the trend seems to be declining.

Low level of standardization in the manufacturing of PA tools and software: The hurdle of incompatibility of hardware and software arises because every equipment company had their own proprietary wiring, devices and file formats for recording and transferring data to and from the field (Russo, 2014; Whelan & Taylor, 2013). Hence, it has been a meticulous and painful process to get machinery and programmes to talk with one another (Russo, 2014).

Incompatibility results in high level of frustration among growers and their providers. It also slows the adoption of a beneficial technology (Russo, 2014; Whelan & Taylor, 2013). As increasing numbers of growers implemented precision Agriculture hardware and software solutions into their management practices, the lack of standards hinders their ability to take advantage of innovations (Russo, 2010).

Furthermore, the lack of standards stifles competition and prevents the creation of a viable infrastructure of interoperable technologies (Russo, 2010). Upon making a first purchase of hardware or software, a grower may feel locked into that precision agriculture technology either due to the inability to incorporate other offerings or simply because of economics (Russo, 2010). Consequently, if something better comes along, the grower may be forced to start over again with a new investment in time and money (Russo, 2010). Without the ability to make easy and cost-effective changes, the grower ultimately misses new solutions that could reduce operational costs or add value to production (Russo, 2010). However, efforts have been made to bridge this gap by adopting a common standard. The global trend now, is to use standardized systems in accordance with ISO 11783 standard (also known as ISOBUS) on devices, or Electronics Control Units (ECU), of the agricultural production (Pereira et al., 2009).

Operator/Farmer socio-demographic challenges

Operators' (farmers') socio-demographic factors have been found to clearly influence farmers' adoptive decision to use PATs on their farm (Daberkow & Mcbride, 1998). These refer to the personal background of the farmer's main decision maker (Tey & Brindal, 2012). The factors found to be significant to farmers' decision to adopt PA throughout literature are operator's age, years of formal education, years of farming experience and farm size

(Larson et al., 2008; Tey & Brindal, 2012; Torbett, Roberts, Larson, & English, 2007; Khanna, 2001 ; Daberkow & McBride, 2003).

Aging is known to be a challenge to the adoption of PA. It has been suggested that older farmers have shorter planning horizons, diminished incentives to change and less exposure to PA whereas younger farmers, in contrast, have a longer career horizon and are more technologically-orientated (Larson et al., 2008; Roberts et al., 2004). Younger farmers, therefore, may be more motivated to try PA technologies than their older counterparts may. For this reason, Ghana seems to have a particularly unfavourable challenge about farmers' age. Available literature from the ministry of food and agriculture indicates that the average age of farmers in Ghana is 55 years (MoFA, 2011). The implementation of PATs requires substantial technological and informational driven analytical skills and knowledge-based interpretation. Farmers' agedness coupled with reduced life expectancy (between 55 – 60 years) reduces the likelihood of PA adoption.

The challenge of farmers' experience is also worth considering. Greater experience is expected to lead to better knowledge of spatial variability in the field (Khanna, 2001) and to operational efficiency to the extent that farmers learn by doing (Adhikari, Mishra, & Chintawar, 2009). More experienced farmers may thus feel less need for the supplementary information provided by PAs, hence, decrease their adoption (Isgin, Bilgic, Forster, & Batte, 2008). On the other hand, uncertainty regarding farm investment reduces with learning and experience (Feder 1982). Hence, confidence is boosted in PAs. This induces more risk- averse farmers to adopt PAs as long as they are profitable (Daberkow and McBride 2003). A number of studies in Ghana have pecked the mean number of years of experience of farmers (cocoa) around 24 (e.g. Bosompem, 2006; Dankwa, 2002). Thus, in the light of the above discussion, the high level of experience of Ghanaian farmers is likely to foster adoption of cocoa technologies if socioeconomic problems are addressed.

Formal education is expected (hypothetically) to have a positive relation to the adoption of PA. This is because more highly educated farmers are most likely to meet the human capital requirements (Larson et al., 2008). Such results have been found in a number of adoption studies on various PAs (Larson et al., 2008; Walton et al., 2008). In the context of Ghanaian farmers, most are uneducated. A number of studies have indicated that over 50% of farmers (cocoa) in Ghana have no formal education (e.g. Bosompem, 2006; Dankwa, 2002; Kumi, 2003).

Environmental /Abiotic challenges

In Ghana, cocoa is grown in the forest areas of Ashanti, Brong Ahafo, Central, Eastern, Western and Volta Regions with Rhodic Ferralsols soil types (CRIG, 2010). Soil quality has been found to be the single significant factor of adoption of PATs (Tey & Brindal, 2012). Also, since the vegetation of the areas where cocoa is grown is mostly forest and trees, it has been found to hinder the movements of PA tools and machinery to cocoa farms.

Also most lands in the cocoa growing areas have undulating topography coupled with numerous streams of water and rivers that are likely to hinder the movement of heavy equipment and farm machinery such as tractors, VRA, harvesters and planters. These make it difficult to have accessible roads that lead to the cocoa farms. Hence, it is difficult for vehicles/tractors move inputs to cocoa farms. Few farms happened to be situated along of roadsides.

Political/Governmental challenge

The political dimension covers a wide range of partly ideological perspectives of potential users (Mcbratney et al., 2005). For example, some potential adopters think that adoption of PA is a way of enhancing the control of multinational farming corporations. For this reason, they consider the adoption of PA to be dangerous in developing countries (Mcbratney et al., 2005). The political challenge could be perceived in two forms: (1) internal and (2) external.

The internal dimension involves the lack of political will by developing countries. This is the case because even the best laws and innovations in the world will not matter if countries do not have the political will to take them seriously and to enforce them (Lattus, 2014). Such lack of political will hampers the propagation and implementation of PA by governments even if funds are available because PA principles and practice may not appeal to politicians. Juma (2011) cited the example of Malawian president Bingu wa Mutharika - whose policies ensured food security within a year - to show the importance of political will in ensuring technology adoption. The series of policies put in place did not only result in Agricultural development but also overall economic development. By investing 16% of National budget in agriculture and particularly in maize innovation, the national maize output was doubled within a year (2006-2007) and the country started exporting maize to food insecure neighbouring countries (Juma, 2011).

The second dimension involves the dependence of developing countries on donor partners (developed countries) for support (external) in terms of capacity building. Several developing countries do not have the needed technical and financial capacity and the infrastructure to enforce the laws (Lattus, 2014) and innovations such as PA. For the last 20 years and more, the developing world has looked to countries like the US, Europe and the organisation for economic cooperation and development (OECD) to provide financial support. Regrettably, the developed countries do not always meet such financial commitment, mostly due to their own selfish interest. Failure to honour such a commitment translates into lack of funds from government to develop and implement PA technologies.

Factors Influencing the Adoption and Willingness to Adopt Precision Agricultural Technologies.

Rogers (2003) defined adoption as the use of a technology for its intended purpose. Adoption of agricultural innovation can be affected by factors such as Demographic/Socio-Economic characteristics of farmers, Awareness-Knowledge of farmers, PA technology characteristics and perceived challengers of the potential adopters.

Demographic and farm related characteristics

The demographic and farm-related factors that affect adoption reviewed were: sex , marital status, age, educational background, experience in farming, household dependents, size of farm, agrochemical use, source of finance and labour, yield and income of farmers etc. (Agudugu, Deo & Dadzie ,2012; Rogers ,2003; Maheswari, Ashok & Prahadeeswaran, 2008).

Sex and marital status of farmers

Studies show that males have dominated cocoa production in Ghana. A survey by CRIG in 1995 in Ashanti and Eastern Regions of Ghana showed that about 71% of cocoa farmers were males. Bosompem and Nunoo (2009) reported 72% male and 28% female cocoa farmers in the Brong- Ahafo Region of Ghana. Anang, Fordjour, and Fiatusey (2011) work on Farmers' Management Practices and the Quality of Cocoa Beans in the Upper Denkyira District of Central Region, Ghana also reported 79% male and 21% female cocoa farmers. Again, Bosompem and Mensah (2012) found 71% of 160 cocoa farmers sampled in Birim South in the Eastern Region to be males and results from Okorley, Adjargo and Bosompem (2014) showed about 76% of the 140 cocoa farmers sampled in Mpohor Wassa East District in the Western Region of Ghana to be males.

Studies in adoption of agricultural technologies in general show that men are more likely to adopt new technologies in Ghana than women. This has been attributed to the fact that men mostly make production decisions in a household because they control most of the production resources such as land, labour and capital which are critical for the adoption of new technologies (Akudugu, Guo, & Dadzie, 2012). Akudugu et al. (2012) found a significant positive relationship between Sex (1=males, 0=females) and adoption of agricultural technologies among farmers in rural Ghana. This implies that male farmers are more likely to adopt PA technologies than their female counterparts.

Age of operator or Farmer

Cocoa farming in Ghana has been dominant by the aged with few youth taking interest in cocoa production and agriculture or farming in general. Marcella (2007) reported that most cocoa farmers in Ashanti and Brong-Ahafo regions of Ghana were aged (65-70 years). Bosompem and Mensah (2012) found 72% of the cocoa farmers were above forty (40) years old while 26% were 40 years or below (20-40). Okorley et al. (2014) reported a mean age of 50 years of cocoa farmers (79%) with most of them between 41 to 80 years.

A comprehensive review of literature by Tey and Brindal (2012) on factors influencing the adoption of precision agricultural technology around the world reviewed that Age of operator, years of experience and years of formal education were significant personal background that influenced the adoption of PA technologies. In terms of the relationship between age and potential adoption of PAT, the literature reviewed presents a mixed picture. For example, age has been found to have a negative relationship with the adoption of highly technological innovation or practices such as the use of computers which is very significant in precision agricultural practices (Batte, Jones, & Schnitkey, 1990 ; Gloy & Akridge, 2000 ; Batte & Arnholt, 2003). Robert at al. (2004) attributed this negative relationship to older farmers having diminishing incentive to change, less exposed to PA technologies, shorter planning horizons. Hence younger farmers are more motivated to try PAT than the older ones. Other studies by Deberkow and McBride (2003) ; Robertson et al. (2012) and Aubert, Schroeder, and Grimaudo (2012) found age to be insignificant whereas Deberkow and McBride (1998) ; Isgin et al. (2008) ; Pierpaoli, Carli, Pignatti, and Canavari (2013) found age to have positive significant impact on adoption of PATs.

Educational level of farmers

Education enhances one's ability to receive, decode, and understand information and that information processing and interpretation are important for performing many jobs and by extension adoption (Byrness and Byrness, 1978) Bosompem et al. (2011b) reported about 80% of respondent cocoa farmers in Eastern Region of Ghana having formal education and Okorley et al. (2014) also found 78% of cocoa farmers in Western Region having formal education even though their level of education was low (67% having basic education i.e up to Junior High or Middle School level). Aryeetey (2004) also reported that in the rural areas where the majority are farmers, only 29.3% of the people sampled had formal education. Dankwa (2002) and Kumi (2003) also reported that 50-55% of cocoa farmers have been found to have no formal education in Ashanti and Eastern Regions of Ghana.

Rogers (2003) had opined that early *adopters of technologies have more years of formal education than those who do later adoption. Also literate are more likely to adopt technologies than illiterates.* Therefore, it is expected that cocoa farmers' level of formal education attainment should be positively (hypothetically) related with adoption and intension to adopt technologies (Tey & Brindal, 2012). This is because implementation of PATs largely depends on knowledge-based interpretation and substantial technological and analytical skills (Tey & Brindal, 2012). Aubert et al. (2012) found in Canada that formal education was positively significant with the adoption of PATs by farm operators. Walton, Lambert, Roberts, Larson, English, and Larkin (2008) also found a positive and significant relationship between education and adoption of precision soil sampling among cotton farmers in 11 southern states of USA (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Virginia). Larson et al. (2008) also found that the educational level of farmers was positively significance to adoption. Educational level was found to have a positive influence on farmers intension to adopt PAT (Adrian, Norwood, & Mask, 2005). However, Gamble and Gamble (2002), pointed out that at times, high level of education can sometimes become a barrier rather than a facilitator or aid to communication. Therefore, higher level of education in some instance could negatively affect the way a farmer encodes and decodes information which by extension can negatively affect potential adoption of PA technology.

Years of farming experience

Farming experience quantifies the number of years that a farmer has been involved in cocoa production. Farming experience has been found to have ambiguous impact or predictions on adoption of PATs. Greater experience can lead to better knowledge and understating in field and operational efficiency since farmers can learn by doing. Tey and Brindal (2012) reported that, empirically years of experience has largely been insignificant with adoption of PAT. On the other hand, Insgin et al. (2008) opined that more experienced farmers may feel less need for additional or supplementary information provided by PATs, hence can negatively affect their adoption. A positive impact have been found between experience and the adoption of variable rate applicators (Khanna, 2001). However, negative past experiences of using a technology that has similar characteristics of the components of PAT can negatively influence the adoption of PAT since negative history of adoption may create a barrier to adoption of new technologies (Antolini, Scare, & Dias, 2015).

Household size

Household size consists of dependents who live in the same household. This includes mainly the spouse and children but most farming households may include the nephews, nieces and grandsons and granddaughters of the household head or the spouse. Aryeetey (2004) reported a mean of 6.9 household size in rural forest in Ghana. Bosompem (2006) found that the mean household size of cocoa farmers in Eastern Region of Ghana was nine (9). Household size has implication for availability of labour since family labour has been found to be the most prevalent source of labour in cocoa farming in West Africa and about 87% of the permanent labour used in cocoa farming comes from the family (IITA, 2002). Hence, technologies that require less use of human effort are likely to require less family or household labour.

Farm-related characteristics

The farm-related characteristics that affect the potential of adoption of agricultural technology and PA technology are farm size, access to credit, land tenure, cultural practices, access to labour and extension, yield, income and profitability of farmers.

Farm size / land size, number of farms and land tenure

Farm size is the total land size available for cocoa production and it is a proxy for economies of scale - which is an important consideration in adoption of high level technology like PAT (Tey & Brindal, 2012). Because of the capital intensive nature of PA and high cost of PA tools, large scale farms are likely to adopt PA technology than small scale farms. However, most farmers in Ghana including cocoa farmers are largely small scale with fragmented number of farms.

In general, about 85% of all farms in the country has been found to be between 1.2 and 2.0 hectares (Oppong-Anane, 2006). The lack of several large-scale commercial agricultural projects in Ghana can be partly attributed to the problems associated with acquiring land for economic activities. Usually, acquiring land for large scale and commercial is compounded with problems pertaining to land tenure system.

For example, MoFA (2003) estimated that about 31% of the farm holdings in Ghana are less than 1.6ha while only 18% are more than 4.0ha per farmer. Bosompem (2006) found that the mean land under cocoa cultivation in Eastern Region was 10.5 acres (4.2 ha) whiles the majority (66%) had less than 4.2 ha of land under cocoa cultivation. Okorley et al. (2014) reported that all the cocoa farmers sampled had between 0.4 and 4.0 ha in Western Region of Ghana. Edwin and Masters (2003) also reported a mean land size of 3.50 ha (8.8 acres) among cocoa farmers 123 cocoa farmers surveyed Ashanti and Western regions. However, the farmers had between 1 to 3 cocoa farms scattered at different locations. Therefore, this is expected to hinder the potential adoption of PA technology among cocoa farmers.

Many PA advocates are sceptical about whether PA is feasible for small scale farmers. However, Shibusawa (1999) showed that PA is feasible even in small scale farming once the main fundamental principles of PA which is site specific application of inputs through Variable Rate Technology is applied. Shibusawa (1999) contended that whether PA is feasible in small-scale farms is a leading issue for PA scientists and politicians in Japan. Even in Asian countries like India, Sri-Lanka, China, Korea and Bangladesh where average land holdings is less than 4 ha, it is reported that PA is receiving substantial improvement for potential adoption of PA technologies (Mandal & Maity, 2013). Yohn, Basden, Rayburn, and Fullen (2009) demonstrated the feasibility of PA adoption by small scale farmers through the stimulation of interest in the adoption of soil sampling methods on small farm operations in various counties in USA. And even within these smaller farms (less than 6 ha) economic advantage was demonstrated.

It should be noted that, farmers with larger farm size are more likely to adopt PAT than those with smaller farms (Tey & Brindal, 2012). A probit analysis by Walton et al. (2008) showed that land size was a positive significant predictor of Adoption of PAT on precision soil sampling among cotton farmers in USA. Pierpaoli et al., (2013) also reported a generally positive significant relationship between land size and intension to adopt PAT in a review of drivers of Precision Agricultural Technologies worldwide. Adrian et al. (2005), also found a positive relationship between land size and intension to adopt PATs. Aubert et al. (2012) found a positive but no significant relationship between farm size and farmer’s adoption decision of PAT.

In terms of land tenure, Antolini et al. (2015) noticed that farmers are more likely to manage their own land in a more favourable way than rent lands, hence have more chances to enjoy the advantages. Therefore, if farmers have highest land rights (for example if they buy or inherited) they are more likely to adopt PAT since they have the advantages of enjoying their own farm management practices and investments.

Age of cocoa tree, fertilizer application, yield and income

The exact number of cocoa farmers in Ghana is not known. It is estimated that there are approximately between 500,000- 700,000 cocoa farmers in Ghana who produce an average of 550,000 metric tonnes of cocoa annually (Takrama, 2006, CRIG, 2010). Appiah (2004) also noted that the average national annual yield in Ghana is 350 kg/ha or 140 kg/acre. IITA (2002) reported that the average yield of cocoa farmers in Ghana was 207 kg/ha. Edwin and Masters (2003) also reported that the average yield of farmers in Ashanti and Western regions was 294.8 kg/ha. However, they reported an average of 258 kg/ha and 497 kg/ha for traditional and hybrid varieties respectively indicating that yield of hybrid is approximately twice that of the traditional variety. A mean yield increase from 448.9 kg/ha to 768.5kg/ha has been reported by cocoa farmers 3 years (2002-2005) after the adoptions of fertilizer application in Eastern Region of Ghana (Bosompem, Kwarteng, & Ntifo-Siaw, 2011a &b).

Edwin and Masters (2003) reported further that in 2002, the age of cocoa trees in Ashanti and Western regions affected the yield of cocoa plants and that yields declined with age of cocoa even when fertiliser was applied. They found that yields of cocoa farms were highest when trees were between 8 to 15 years old for both hybrids and traditional varieties and declines with age even when fertiliser was applied. They also reported that of the 192 farms surveyed, the average age of cocoa trees was 20 years with a minimum and a maximum 3 and 56 years respectively. Bosompem (2006) also found a mean age of 24 years of 200 cocoa farmers surveyed in Eastern Region with a rage of 54 years (minimum = 4 years, Maximum=60 years) and about 30% of respondent cocoa farmers having trees more than 30 years.

Yield and income have been found to have a direct relationship with adoption of new technologies (Antolini et al., 2015). Walton at al. (2008) found a positive but no significant relationship between adoption and income of farmers.

Planting and cultural practices

Most farms in Ghana are not generally planted in roles using the recommended planting distance of 3m x 3m (10ft x 10 ft) spacing which is expected to give 1,111 cocoa trees per hectare i.e 435 cocoa trees per acre (CRIG, 2010). It is, therefore, difficult to estimate the plant pollution in the field. It would also be difficult to use machinery and equipment such as plough, tractors, power tillers as well as PA tools like VRA, yield monitors, planters even when these tools are available.

Access to credit, labour use and extension services

Access to credit, labour and extension services are vital to improving the productivity of cocoa farms. This is because credit is needed to hire both skilled and unskilled labour, acquire other inputs, and also provide extension services to cocoa farmers so that they can apply the recommended cultural practices to enable them increase their productivity and also ensure environmental sustainability.

Unfortunately, the majority of farmers including cocoa farmers do not have access to credit. About 98% of farmers surveyed in West Akim District in Ghana did not have access to credit (Baidoo & Amoatey, 2012). It has been observed that adoption of PATs is likely to continue into expand very fast in areas where land is abundant and where human and financial capital are available. The implication is that, availability of financial capital either from farmers' own resources or credit from other sources is expected to have positive impact on adoption (Swinton & Lowenberg-Deboer, 2001). Swinton and Lowenberg-Deboer (2001) observed that there will likely be adoption in enclaves where land and capital are available and well-managed in plantation agriculture in parts of the tropics as well as large farms in northern Mexico and perhaps South Africa. Access to credit (among other factors such as farming experience, membership of farm group and output) was found to be a significant positive predictor of the use of insecticides among cocoa farmers in Ashanti Region (Asare, 2011). Credit availability and access have been found to have a positive relationship with adoption of PATs since PA is capital intensive (Antolini et al., 2015).

Information on agricultural practices is normally provided by extension services or consultants. The use of effective extension services and consultants who have requisite knowledge in PATs are essential factors that positively impacted on the adoption of PATs (Tey & Brindal, 2012). Adopters of PATs was found to be those who received information from trained extension agents or those who hired consultants (Larson et al., 2008).

The majority of farmers have been using hired labour for farming activities lately. Baidoo & Amoatey (2012) found approximately 55% of farmers used hired labour on their farms. A sizeable number 26 representing 28.6% used family labour, but 7 representing (7.7%) used both hired and family labour. Few (3.3%) used ‘nnoboa’ (co-operative labour) (Baidoo & Amoatey, 2012). About 72% of PA vegetable farmers used hired-labour (Maheswari, Ashok, & Prahadeeswaran, 2008).The use of hired labour has been found to have significant influence on the likelihood of adoption of fertilizer (Degu, Mwangi, Verkuijl, & Abdishekur, 2000). Since farmers pay for hired labour, and most farmers cannot afford it, adoption of PA is likely to be low (Dormon et al., 2004).

Perceived technology characteristics of precision agriculture

The diffusion of innovation theory by Rogers (1983) identifies five (5) attributes or characteristics of an innovation that affect the likelihoods of its adoption namely: (a) relative advantage (usefulness), (b) compatibility, (c) complexity, (d) trialability, and (e) observability. Moore and Benbasat (1991**)** expanded Rogers’s five (5) attributes of technology to include a six and seventh attributes or characteristics namely Voluntariness and Image of the technology respectively.

Relative advantage is the degree to which an innovation is perceived as being better than the existing ones. The degree of relative advantage has been expressed in economic profitability and social prestige, or in other ways.

However, the nature of the innovation determines what specific type of relative advantage (economic, social, and the like) is important to adopters. The initial cost of an innovation may affect its rate of adoption since it can affect the profit levels of farmers (Rogers, 2003).

Perceived usefulness or relative advantage had been found to have a positive significant impact on farm operators decision to adopt PAT among cereal farmers who adopted GPS,GIS, yield monitors, yield maps, remote sensing, VRA and navigation systems in Quebec (Aubert et al., 2012). A positive relationship was found between perceived usefulness and intension to use mobile wireless technology adoption which is an integral part of PATs adoption (Kim & Garrison, 2009). Though Walton et al. (2008) found a positive but no significant relationship between adoption and income of farmers, perceived profitability (relative advantage) was a significant predictor of adoption of PATs. Realistically or perceptually, profitability (a measure of relative advantage) is a major concern when considering a relatively capital-intensive agricultural technology like PATs.

Compatibility: According to Rogers (2003), compatibility is the degree to which an innovation or technology is perceived as consistent with the existing values, past experiences, and needs of potential adopters. Therefore, if an innovation is more compatible, the uncertainty of its adoption is less because it fits more closely with the individual's situation. An innovation can be compatible or incompatible with (1) socio-cultural values and beliefs, (2) previously introduced ideas, and/or (3) client needs for the innovation. The more an innovation is incompatible with existing deeply embedded cultural values, the less its adoption. Also, compatibility of an innovation with preceding ones can either speed up or retard its rate of adoption. Rogers (2003) opined that old and existing ideas are the main mental tools that clients use to assess new ideas and give them meaning. Hence, previous practices serve as standards or benchmarks against which an innovation is interpreted. Therefore, a positive experience with one innovation can lead to more adoption whiles a negative experience with one innovation can prevent the adoption of future innovations (Innovation negativism). *Innovation negativism* is the degree to which an innovation's failure conditions a potential adopter to reject future innovations (Rogers, 2003). However, Rogers (2003) cautioned that a positive experience parse does not necessarily lead to increase in the potential adoption of new technologies. Sometimes**,** the perceived compatibility of the new idea with previous experience can lead to the adopters utilizing the innovations incorrectly. Another dimension of incompatibility is the degree to which an innovation is perceived as meeting the felt needs of potential adopters. The emphasis is on 'felt needs' since potential adopters may not recognize that they have a need for an innovation until they become aware of it or its consequences. The more an innovation meets the felt needs of potential adopters, the faster its rate of adoption (Rogers, 2003). Compatibility has been found to be a positive and significant predictor of perceived usefulness (relative advantage) of PAT (Aubert et al., 2012). By extension, compatibility is expected to have a positive relationship with intension to adopt PATs.

Complexity (ease of use) according to Rogers (2003) is the degree to which an innovation is perceived by potential adopters as relatively difficult or simple to understand and use compared to the existing ones. Perceived ease of use means the degree to which a farmer believes that the use of PAT would be free from effort (Pierpaoli et al., 2013). Hence, innovation can be classified on the complexity-simplicity continuum. The complexity of an innovation, as perceived by adopters, is negatively related to its rate of adoption. Rogers (2003), however, noted that complexity of an innovation though important for adoption may not be as important as relative advantage or compatibility for many innovations. However, complexity of an innovation has been found to be important for adoption in computer-based innovation and computer self-efficacy or personal skills (Pierpaoli et al., 2013; Rogers, 2003). Since PA technologies are largely computer-based, complexity is expected to be a significant factor to PATs adoption. Aubert et al. (2012) again found ease of use as a significant and positive predictor of the adoption of PATs among farmers in Canada. Perceived ease of use has also been found to have indirect relationship with intension to adopt PAT, mediated by perceived net adoption (Adrian et al., 2005). Perceived ease of use can be influenced by other factors such as education level of farmers, farmers' previous experience with PA tools, availability of technical support or presence of experts, and possibility of trial period with PAT by farmers (Pierpaoli et al., 2013).

Trialability is the degree to which an innovation may be experimented or tried on a limited basis. Innovations that can be tried on the limited basis are likely to be adopted more rapidly than innovations that are not divisible. Trying innovation helps potential adopters to see how it works under context and conditions of the individual adopter. The trialability of an innovation, as perceived by the farmers, is positively related to its rate of adoption. However, trying an innovation may result in re-inventing – customizing it more closely to the individual's adopter needs which can be positive or negative to the adoption and use of the original technology (Rogers, 2003). Trailability was found to be a negative significant predictor of adoption of PAT among farmers in Canada (Aubert et al., 2012).

Observability is the degree to which the results of an innovation are visible to others. Some ideas are easily observed and communicated to other people, whereas other innovations are difficult to observe or to describe to others. (Moore & Benbasat (1991), however, demonstrated that observability could be divided into two different construct: results demonstration and visibility. According to Rogers (2003) t*he observability of an innovation, as perceived by potential adopters, is positively related to its rate of adoption.*

Voluntariness: Moore & Benbasat, (1991) expanded the five range of innovation characteristics in Rogers' (1983) diffusion of innovation theory to include Voluntariness and Image of the technology. Voluntariness of use of an innovation is defined as "the degree to which use of the innovation is perceived as being voluntary, or of free will" (Moore & Benbasat,1991, p.195). They argued that, consideration must also be given to whether potential users of an innovation are free to implement personal adoption or rejection decisions since the use of a particular innovation within organizations may be either mandated or discouraged by corporate policy and by extension, governmental policies. Even though potential adopters may feel that adoption of a certain innovation is not strictly by force, some adopters may feel it is free of compulsions, therefore, Moore & Benbasat, (1991, p.196) pointed out that "it is often not actual voluntariness which will influence behaviour, but the perception of voluntariness". Perceived voluntariness has been found to reduce the pressure of acceptance of information technology, therefore, perceived voluntariness of an innovation is expected and had been found to have negative impacts on its potential adoption (Agarwal & Prasad, 1997; Aubert et al., 2012). Aubert et al. (2012), confirmed that voluntariness was a significant (negative) predictor of the adoption of PATs among farmers in Quebec, Canada.

Image of the technology*:* The image of a technology is defined as "the degree to which use of an innovation is perceived to enhance one's image or status in one's social system" (Moore & Benbasat, 1991, p.195). Rogers (1983) however, included 'Image' as an aspect of Relative Advantage. A meta-analysis by Tornatzky & Klein (1982) showed that the effect of Image (social approval) has been found to differ enough from Relative Advantage to be considered a separate factor. Therefore, Image (like Relative advantage) is expected to have a positive impact on adoption of PATs.

In conclusion, three (3) innovation characteristics (compatibility, relative advantage and complexity) had the most consistent significant relationships to innovation adoption in the adoption literature, especially information technology adoption.

Theoretical and Conceptual Framework

The study was guided by three (3) main theoretical frameworks : (1) the Diffusion of Innovation (DOI) theory posited by Rogers (1983) ; (2) The expanded Rogers' Attributes of Innovation model by Moore & Benbasat (1991) and (3) the Technology Acceptance model by Davis (1989).

The diffusion of innovation (DOI) theory

Diffusion is defined as the process in which an innovation is communicated through certain channels over time among the members of a social system and *Rate of adoption* is the relative speed with which an innovation is adopted by members of a social system (Rogers, 1983). The theory focuses on the five (5) main variables (see Figure 2) that determine the rate of adoption namely (a) Perceived attributes of the innovation, (b) the type of innovation-decision, (c) the nature of communication channels diffusing the innovation at various states in the innovation-decision process, (d) the nature of the social system in which the innovation is diffusing, and (e) the extent of change agents' promotion efforts in the innovation diffusions (Rogers, 2003). However, Rogers (2003) noted that because most adoption studies have shown that between 49 to 87 percent variance in the rate of adoption of innovations, has been explained by 'Perceived attributes of the innovation', the other four (4) aforementioned variables have not received much attention by most diffusion scholars.

Hence, the DOI theory has focused on Perceived attributes of innovation (namely: relative advantage, compatibility, complexity, trialability, and observability) to explain the variance in adoption. Adoption decision or intension is, therefore, driven by the five attributes of innovation discussed earlier.

It should be noted that even though DOI research originally focused on the innovation attributes to determine its rates of adoption, further studies have showed that the adopter characteristics are also very important to the decision to adopt. Applied to Precision Agriculture Technology adoption, these five

(5) attributes of innovation as well as adopter characteristics were adapted by the researcher to design a conceptual framework of Prospect and Challenges of Precision Agriculture in Cocoa Production, Ghana.

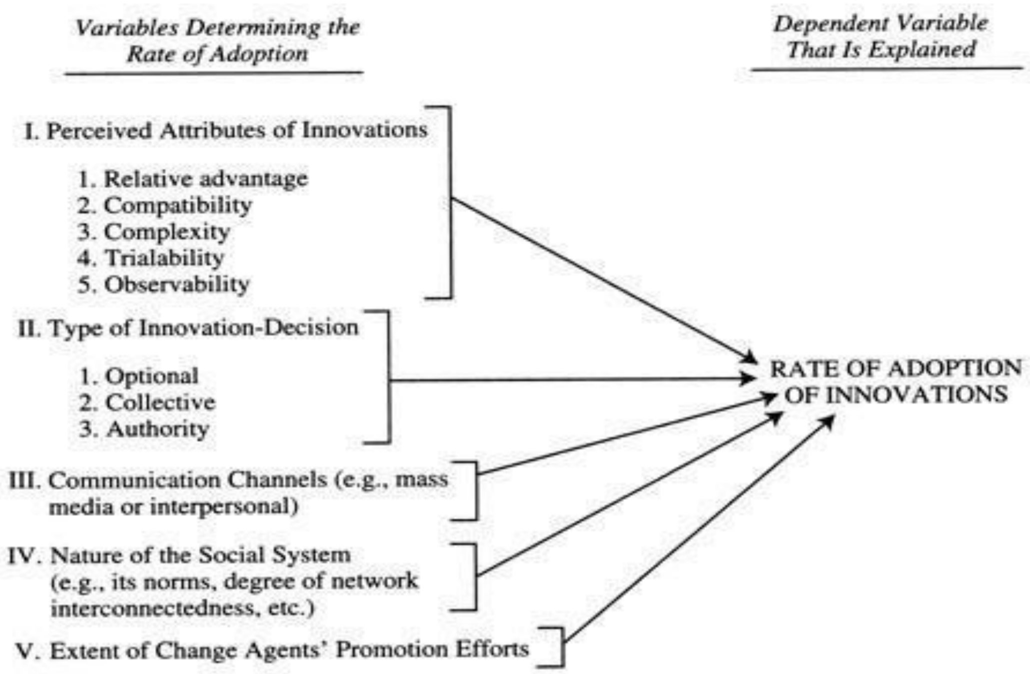

Figure 2: Rogers' Diffusion of Innovation Model

Source: Rogers (2003)

The expanded Rogers' attributes of innovation model by Moore and Benbasat

Moore and Benbasat (1991) expanded the five attributes of innovations of Rogers to include two (2) main additional attributes namely (1) *voluntariness and (*2) image. As stated earlier, *voluntariness was defined as,* "the degree to which use of the innovation is perceived as being voluntary, or of free will" whereas (2*) image, as* "the degree to which use of an innovation is perceived to enhance one's image or status in one's social system" (Moore & Benbasat,1991, p.195). Results from Moore and Benbasat (1991) suggested that observability of Rogers' model produced two distinct construct: result demonstrability and visibility, hence, Moore and Benbasat (1991) used result demonstrability and visibility to substitute the concept of observability by Rogers (1985). It can be deduced from the explanations that, even though Moore and Benbasat (1991) observed eight (8) attributes of innovation namely Relative Advantage, Compatibility, Ease of Use, Result Demonstrability, Visibility, Trialability, Image and Voluntariness, *the last two (Image* and Voluntariness) were the two additional constructs considered as the expansion of Rogers' five attributes of an innovation since both visibility and result demonstrability were considered similar to Rogers' attribute of "observability" (see Figure 3).

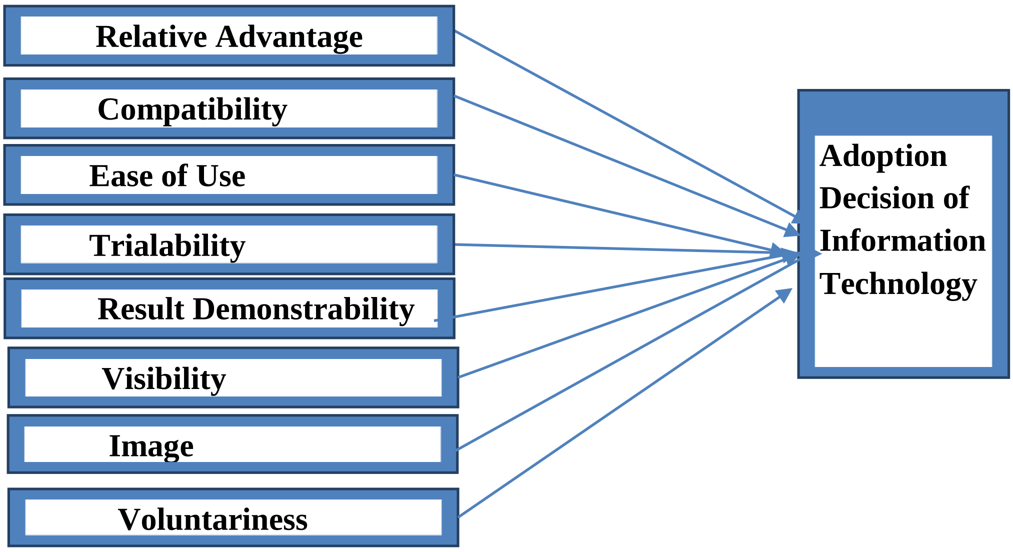

Figure 3: The Expanded Roger's Attributes of Innovations Model by Moore & Benbasat (1991)

Source: Author's Construct (2015)

The technology acceptance model by Davis (1989)

The Technology Acceptance Model (TAM) focuses on the behavioral attitudes towards a technology (especially Information Technology) whiles Rogers' DOI focuses on the perceived characteristics of an innovation (Aubert et al., 2012). The TAM posits that individual's acceptance and Usage of a technology are determined by two key perceptions: (1) Perceived Ease of Use (PEOU) and (2) Perceived Usefulness (PU) of the technology (Davis, 1989). Accordingly, Davis (1989, p.310) defined Perceived usefulness as "the degree to which a person believes that using a particular system would enhance his or her job performance." and Perceived ease of use refers to "the degree to which a person believes that using a particular system would be free of effort". Figure 4 shows the Davis' (1989) original TAM model illustrated by Kim and Garrison (2009).

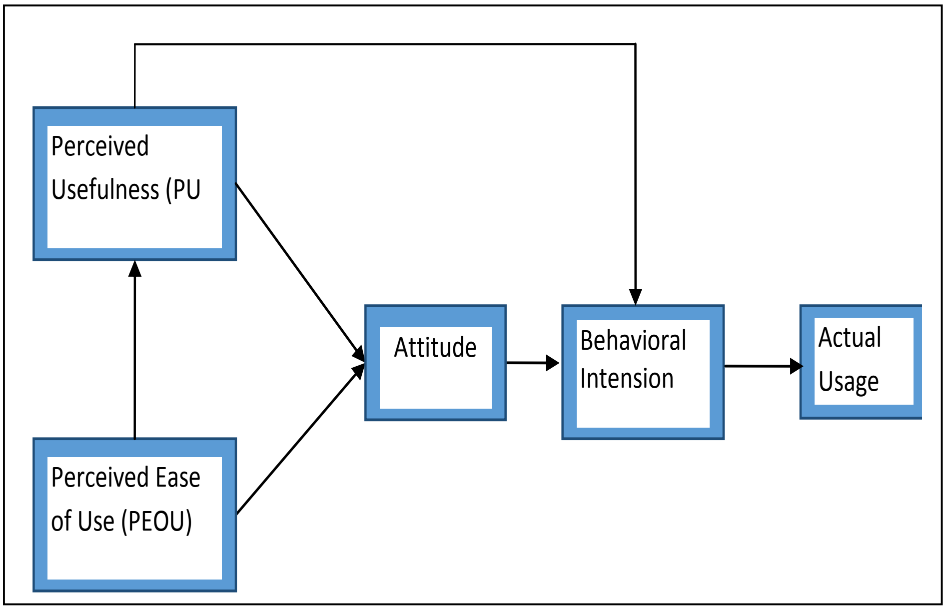

Figure 4: Technology Acceptance Model by Davis (1989)

Source: Kim & Garrison (2009)

Figure 4 shows relationship between Perceived Usefulness and Perceived Ease of Use of an innovation and their effects on individual's attitudes, behavioral intensions to adopt and actual adoption of the technology. Therefore, PEOU has direct effect on PU and PEOU, again, having a positive relationship with users' intension to adopt an innovation. Applied to PAT adoption model, farmers' perceived ease of use and perceived usefulness of precision agricultural technology affects directly the PAT (in the case of PU) and indirectly (in the case of PEOU) farmers intensions to adopt and consequently the actual adoption of PATs (Aubert et al., 2012).

Therefore, TAM is rooted in two (2) of the five (5) attributes of innovation by Rogers: 1.Relative Advantage and 2: Complexity for which TAM called it 'Perceived Usefulness' and 'Perceived Ease of Use' respectively, hence this study used Relative advantages and Complexity instead of Perceived Usefulness' and 'Perceived Ease of Use' respectively.

Conceptual Framework of Prospects and Challenges of Precision Agriculture

The conceptual framework for this study pulls together the theoretical underpinning of Diffusion of Innovation (DOI) theory posited by Rogers (1983) ; (2) The expanded Rogers' Attributes of Innovation model by Moore & Benbasat (1991) and (3) the Technology Acceptance model by Davis (1989) discussed.

Figures 5 shows the conceptual framework used for the study. The researcher posits that cocoa farmers' willingness to adopt Precision Agricultural Technologies **(Dependent variable)** is dependent on the **four (4) main factors** (Independent Variables) namely:

(a) Demographic and Farm related characteristics;

(b) Perceived Technology Characteristics of Precision Agriculture;

(c) Awareness and Knowledge level of stakeholders (esp. cocoa farmers) in PA; and

(d) Challenges and Prospects to PA technology development and implementation in cocoa production in Ghana as perceived by stakeholders (Scientists, Extension Agents, and Cocoa Farmers).

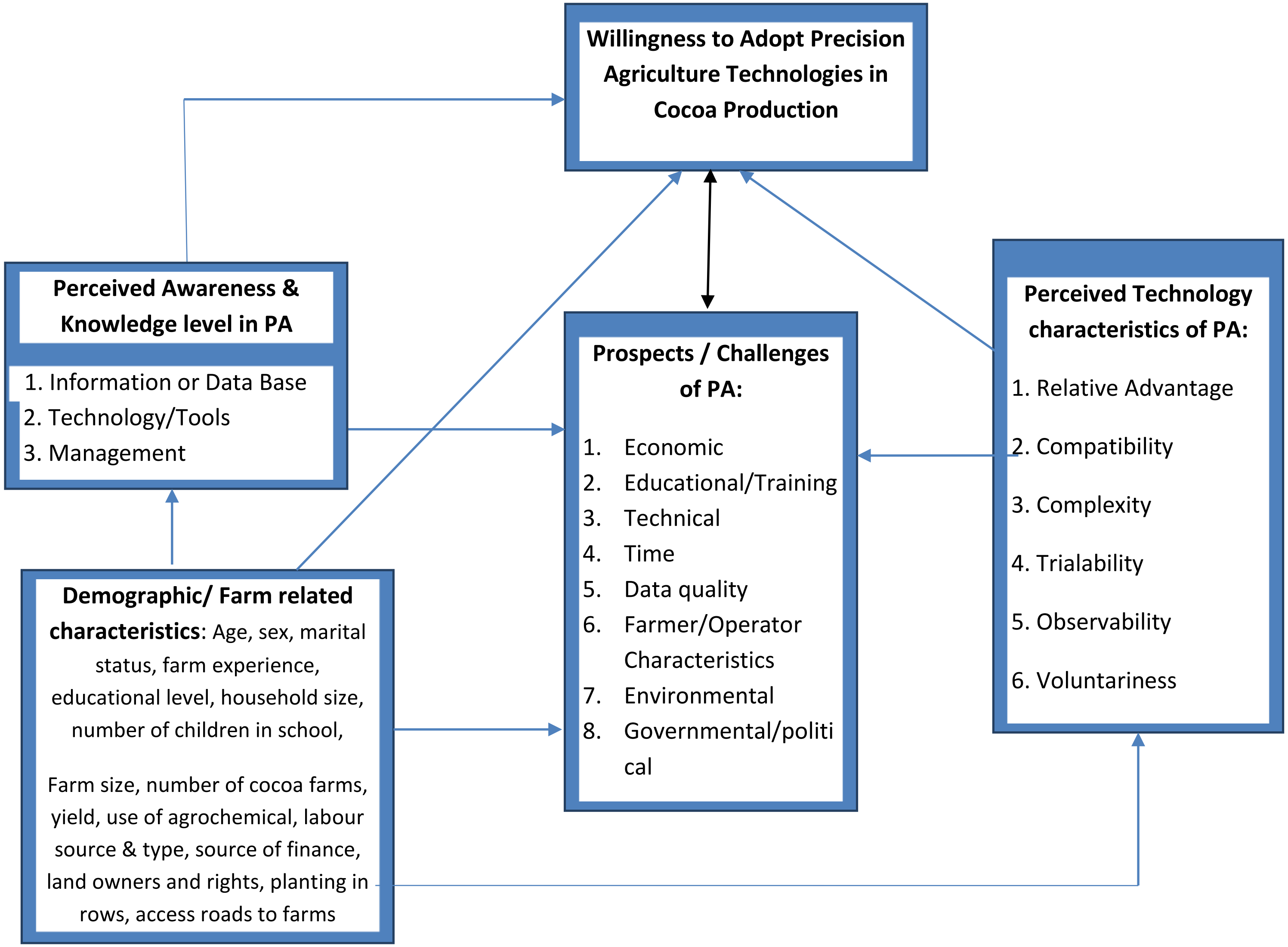

Figure 5: Conceptual Framework of Prospects and Challenges of Precision Agriculture in Cocoa Production in Ghana   Source: Author's Construct (2015)

The demographic and farm related characteristics

The study considered the following demographic and farm related characteristics**:** sex**,** age, educational background, years of experience in cocoa farming, household dependents, size of farm, agrochemical use, source of finance and labour, yield and farmers etc. (Akudugu et al., 2012; Rogers, 2003; Maheswari, Ashok, & Prahadeeswaran ;2008). These individual variables (as discussed earlier) are expected to have either positive or negative impact on cocoa farmers' willingness to adopt of PATs if available.

Technology characteristics of precision agriculture

The study adapted Rogers' (1985) five (5) characteristics of innovations that affect the likelihoods of its adoption namely (a) relative advantage, (b) compatibility, (c) complexity, (d) trialability, and (e) observability. Even though Moore & Benbasat (1991) expanded the five attributes of innovations of Rogers to include two (2) main additional attributes namely voluntariness and image, the study adapted only voluntariness since image has been found to be embedded in Rogers' attribute of 'Relative advantage'(Rogers, 2003). Moreover, since the Technology Acceptance Model (TAM) by Davis (1989), is rooted in two of the five attributes of innovation by Rogers (2003): 1. Relative Advantage and 2: Complexity for which TAM called it 'Perceived Usefulness' and 'Perceived Ease of Use' respectively, the study viewed Relative Advantage and "Perceived Usefulness' to mean the same and Complexity and Perceived Ease of Use also the same.

Hence, six main constructs of cocoa farmers' perceived technology characteristics or attributes of PA innovation – (a) relative advantage, (b) compatibility, (c) complexity, (d) trialability, and (e) observability, and (f) *voluntariness)* were considered to have impact on the willingness to adopt PA in cocoa production as shown in Figure 5. Figure 5 also shows that cocoa farmers' perceived technology characteristics could also have effect on their perceived prospects and challenges of PATs.

Awareness and knowledge of PA.

Generally, stakeholders perceived awareness and knowledge of the three (3) main components of PA namely: (1). Information or data base (2). Technology and (3) Management would have direct and indirect impact on cocoa farmers willingness to adopt the PA (Watkins, Lu, & Huang, 2008; Morgan & Ess, 2003; Forouzanmehr & Loghavi, 2012).

However, the conceptual framework focuses on awareness and knowledge of scientists and extension agents but on only the awareness level of cocoa farmers of precision Agriculture. This is because, literature and reconnaissance study done showed that precision agriculture technologies are limited or practically none existing in Ghana (especially among cocoa farmers) hence; it would be practical to focus on their awareness at this initial study.

The study then posits that cocoa farmers perceived awareness level of the three (3) main components of PA, would have direct relationship with cocoa farmers' willingness to adopt PATs when available. Perceived awareness of the components of PATs can also have impact on the perceived challenges and prospect of PA as shown in Figure 5.

Challenges and prospects of PA

The study viewed problems of implementing PA technologies as challenges not necessarily as barriers. The study identified and categorized eight (8) major areas of challenges that precision agriculture must address before PA can be successfully developed and implemented. These broader areas of the challenges were: (a) Educational and training challenge, (b) Economic challenges, (c) Technical challenge (d) Data quality challenge, (e) Operator demographic challenge, (f) Time challenge, (g) Environmental/Abiotic challenge, and (h) Political/governmental challenge (Najafabadi et al., 2011).

The study, however, did not measure prospects (opportunities) separately from challenges but viewed prospects as when the challenges in a particular area are less. For example, if the education and training challenges stated (see Figure 6) are very minimal, then the prospects becomes higher in the area of education and training or vice versa. Therefore, the greater the challenges of a specific PAT, the less its prospects and the negative its impacts on willingness to adopt PA.

Even though the framework shows that perceived prospect and challenges seem to be core in impacting farmers' willingness to adopt PATs, a reversal relationship can also exist i.e. famers' willingness to adopt PATs could also be a determinant of challenges and prospects of PATs.

Again, the study focused on the challenges as perceived by scientist and CEAs but not as perceived by cocoa farmers since the concept of PATs is generally new vis-a-viz the depth of investigations proposed and discussed in the literature and in the framework.

Interrelationships among the independent variables

Apart from the relationships described between the dependent (Willingness to adopt PA) and independent variables, Figure 5 also shows interrelationships between some of the independent variables. For example, the Awareness and Knowledge levels of the stakeholders (farmers, Extension officers and Scientist) have relationship with the demographic/farm related characteristics such as educational background, age and experience in the field of stakeholders. The awareness and knowledge level in turn can affect the perceived prospect and challenges of Precision Agriculture. Thus, the more stakeholders are aware and have knowledge of the technologies, the better they are likely to understand the technology and then perceive the challenges and prospect better.

CHAPTER THREE

RESEARCH METHODOLOGY

Introduction

This chapter describes the procedures and techniques used to collect and analyse data for the study. It captures the study area, research design, the study population, the sampling procedure, the sample size, the research instrument, data collection, data processing and analysis that were used as well as the rationale behind choosing these techniques for the study.

Study Area

Cocoa can be grown successfully in areas with rainfall between 1100mm and 3000mm per annum. However, optimum production can be achieved in areas with annual rainfall between 1500-2000mm (CRIG, 2013). The rainfall regimes in cocoa growing regions in Ghana range from 1200 to 1600 mm as (Figure 6). The average annual temperature that favours cocoa growing is around 25°C. Cocoa is also grown in areas with temperature of 25 °C, relative humidity ranging from 70 to 80%, and Rhodic Ferralsols soil types.

The aforementioned characteristics in addition to the output of cocoa in these area has resulted in the demarcation of the cocoa growing areas into seven (7) cocoa growing regions namely: (a)Western North, (b) Western South, (c) Ashanti, (d) Brong Ahafo, (e) Eastern, (f) Central, and (g) Volta regions. Figure

6 shows the cocoa growing regions in Ghana. Boundaries of these cocoa regions differ from the administrative regions (10 regions) in Ghana.

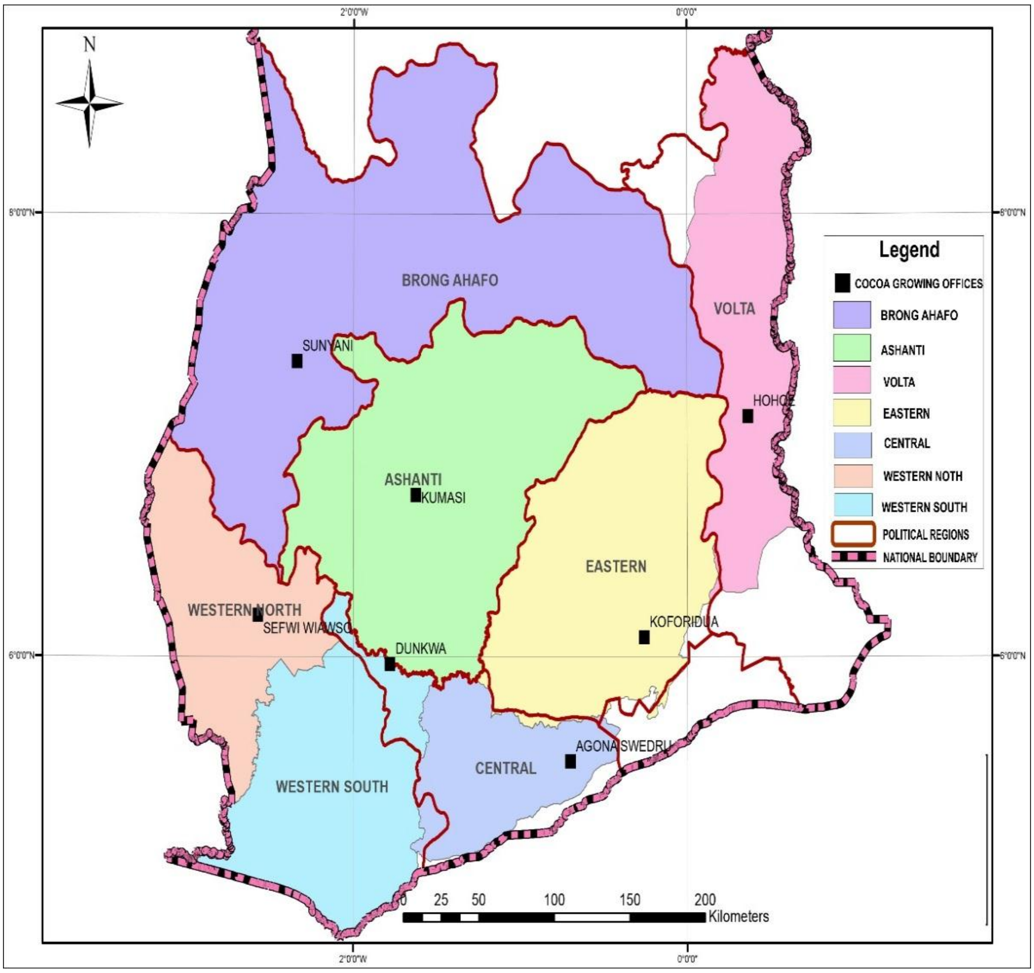

Figure 6: The Cocoa Growing Regions in Ghana (Source: COCOBOD, 2016)

Research Design

The study employed mainly quantitative research approach using correlational survey design was. According to Aliaga and Gunderson, quoted in Muijs (2004, p.1), quantitative research is "explaining phenomena by collecting numerical data that are analysed using mathematically based methods (in particular statistics)". Surveys generally "gather data at a particular point in time with the intention of describing the nature of existing conditions, or identifying standards against which existing conditions can be compared, or determining the relationships that exist between specific events"(Cohen, Manion, & Morrison, 2005, p. 205). Miller (2005) stated that even though correlational studies do not establish causality (cause and effect), it can show how two characteristics are related to each other or how one can be predicted with the knowledge from the other or others. Correlational design was chosen because it allows the researcher to test relationships and predict the factors that affect the willingness of cocoa farmers to adopt precision agriculture technologies.

Study Population

Three (3) different sets of population were used in this study:

(a) All cocoa farmers who benefited from or adopted the Cocoa High Technology Programme in the seven (7) cocoa growing regions in Ghana since 2014;

(b) All Cocoa Extension Agents in the cocoa regions in Ghana; and

(c) All cocoa researchers (scientists) who are involved in the development of cocoa innovation and are from the Cocoa Research Institute of Ghana (CRIG).

The new Cocoa High Technology programme (CHTP) was instituted by government of Ghana in 2014. Under the new programme, bags of fertilizers were distributed to selected cocoa farmers in all the cocoa regions in Ghana. A total of 143,546 cocoa farmers out of the estimated 500,000 to 700,000 cocoa farmers in Ghana benefited from the programme (Takrama, 2006, CRIG, 2010). Because PA emphasizes site-specific application of inputs (especially fertilizer application) using PA tools and technologies, cocoa farmers under the new CHTP were identified as ideal target population. This was to ensure that the targeted cocoa farmers must have used fertilizers and other inputs since fertilizer application is not common among cocoa farmers in Ghana.

There are 200 Cocoa Extension Agents (CEAs) in the seven (7) cocoa regions in Ghana (COCOBOD, 2015). These extension agents provide extension services to cocoa farmers in Ghana.

There are thirty-five (35) Cocoa researchers (scientists) in CRIG (COCOBOD, 2015). CRIG was established at Tafo (Akim) by Department of Agriculture in June 1938 as the Central Cocoa Research Station of the Gold Coast on the recommendation of the Agricultural Adviser to the British Minister of State for the Colonies, Sir Frank Stockdale. Even though their main focus is on cocoa, these scientists also research into coffee, cashew, kola, and sheanut.

Sampling Procedure and Sample Size

For the cocoa farmers, a multistage sampling technique was used to select 422 cocoa farmers in the six (6) out of the seven (7) cocoa growing regions in Ghana. The remaining region which was Central Region was used for pilot study. The six regions were Western North, Western South, Ashanti, Brong Ahafo, Eastern, and Volta regions (these cocoa regions are different from the political regions in Ghana). At the first stage of the sampling, simple random sampling was used to select three (3) cocoa regions namely Western North, Western South and Eastern Cocoa Regions. Secondly, three or four cocoa districts were selected by simple random selection based on the number of cocoa districts in the regions. Then two (2) or three (3) villages/operational areas were selected from each district using simple random sampling. Finally, the systematic random sampling was used to select 422 cocoa farmers form the selected villages in the districts.

The sample size of 422 was based on the sample size determination table from Krejcie and Morgan (1970) and Payne and McMorris (1967) with a given a population of 143546, alpha level of 5% and 5% margin error of precision as well as 10% non-response rate anticipated from non-respondents and mortality (i.e. 384 sample size for the 143546; 10% of 384 is 38 hence, 384+38=422). Table 1 shows the population and the sample size of cocoa farmers chosen from each districts. The sample size of 422 is suitable for the logistic regression analysis with about 25 predicators (independent variables) since a minimum of 274 cases (respondents) are required for about 28 predictors i.e. $N \geq 50+8m$, where N= minimum sample and m= the number of independent variables or predictors (Tabachnick & Fidell, 2013).

For the Cocoa Extension Agents (CEAs), 141 out of the 200 CEAs were selected from the already selected (3) cocoa regions (Western North, Western South, and Eastern Cocoa Regions) where the cocoa farmers had been sampled using the simple random sampling. The second stage of the sampling of CEAs was done using the non-proportionate stratified random sampling. The number 141 was also based on Krejcie and Morgan (1970) and Payne and McMorris (1967) sample size table with 10% additional anticipated non-response rate. Hence, Krejcie, and Morgan (1970) prescribed a minimum sample size of 127 for a population of 200 and 10% of sample size (127) is approximately 14 (127+14=141). Hence, 47 CEAs were sampled from each of the three (3) selected regions totaling 141. Table 1 shows the sample size of both cocoa farmers and CEAs chosen from each the three cocoa regions in the study area.

A census of 30 out of 35 scientists in Cocoa Research Institute Ghana (CRIG) was taken since five scientists where used during the pilot study.

Table 1

The Population and Sample Size used for the Study

Cocoa Region	Number of Cocoa High Tech farmers*	Sampled Cocoa Farmers	Sampled Cocoa Extension Agents
Western North	22,055	113	47
Western South	15,652	189	47
Eastern	30,239	120	47
Total	67,946*	422	141

*Source: COCOBOD (2015)

Data Collection Instruments

A combination of content-validated questionnaires and structured-interview schedules were used to collect primary data for the study. Both face and content validity of the instruments were ensured. The researcher ensured face validity whiles the supervisors and scientists at the CRIG ensured content validity of the set of instruments used for the study.

The questionnaire was used to elicit information from scientists and CEAs whereas an interview schedule was used to gather data from cocoa farmers. These instruments consisted of five (5) main parts:

(a) Part I: Demographic and farm-related characteristics of framers

(b) Part II: Perceived Technology Characteristics of PA

(c) Part III: Awareness and knowledge level of respondents in PA technologies, tools and methods

(d) Part IV: Challenges/Prospects regarding PAT development and implementation in Ghana

(e) Part V: Willingness of cocoa farmers to adopt PATs.

Items in part I were measured using open-ended, close-ended and partially close-ended items. Items in the parts II, III and IV were mainly measured using a six-point Likert-type scale ranging from 0 to 5 with 1 representing lowest level of awareness, knowledge, challenge or agreement and 5 representing the highest level of measurement. Zero on the scale represented no awareness, no knowledge, no challenge or no agreements on individual items in the scale. Table 2 shows the summary of the Likert-type scales and their respective interpretations used in the instruments

Table 2

Interpretations of Likert-type scales used in the study

Ratings	Interval or Range	Awareness level	Knowledge level	Perceived Challenges	Level of Agreement
5	4.45 – 5.00	Very much aware	Very good	High	Strongly Agree
4	3.45 – 4.44	Much aware	Good	Substantial	Agree
3	2.45 – 3.44	Fairly aware	Fair	Moderate	Fairly Agree
2	1.45– 2.44	Less aware	Poor	Low	Less Agree
1	1.00 – 1.44	Least aware	Very poor	Negligible	Least agree
0	0	Not aware	No knowledge	No challenge	No Agreement

Source: Author's Construct (2015)

Carifio and Perla (2007) have clarified the misconception and alleged abuse of Likert scales raised by Jamieson (2004) that Likert-type scales are originally ordinal-level scales, and could not be considered as interval level-scale and only non-parametric statistical tests should be used with them. Carifio and Perla (2007) referred to studies like the Gene Glass Monte Carlo study of ANOVA (Glass, Peckham & Sanders, 1972) which showed that Likert response formats could be considered as interval scales and even ratio scale logically with correct anchoring terms and conditions. The three (3) main conditions identified according to Glass et al. (1972) as cited in Carifio and Perla (2007) were that:

(a) the "scale or subscales should have 4 to 8 items but preferable closer to 8" ,

(b) the level of the data should be collected using 5 to 7 point likert-response format, and

(c) analysis should generally be done not on item by item (micro) bases on the format but on the scale bases (macro).

They even proved that analysis could be done on item by item basis under certain condition such us if there are sufficient number of scale points under them.

Glass et al. (1972, p. 237) opined that "the relevant question is not whether ANOVA (a parametric statistics) assumptions are met exactly, but rather whether the plausible violations of the assumptions have serious consequences on the validity of probability statements based on the standard assumptions". Hence, Glass et al. (1972, p.237) stated that "the flight to non-parametrics was unnecessary principally because researchers asked 'Are normal theory ANOVA assumptions met?' instead of 'How important are the inevitable violations of normal theory of ANOVA assumptions?'. In effect, researchers have been asking wrong questions in other to negate the use of likert-type scale as interval scales.

Additionally, Carifio and Perla (2007; p.111) pointed out that "one does not have to lose statistical power and sensitivity by using non-parametric statistical tests in its (parametric) place when analyzing likert scale data and even analyse such data selectively at the item level". For these reasons, the researcher considered the Likert-type scales used in this study (see Table 2) as interval scales because the scales met the criteria opined by Carifio and Perla (2007) and Glass et al. (1972).

Hence, parametric statistics like ANOVA and t-test proposed in the data analysis section were appropriate as opposed to its non-parametric equivalent: Kruskal Wallis test and Mann Whitney U test prescribed by other researchers when using Likert-type scales in all situations.

Pilot study

A pilot study was carried out in the Central Region (one of the 7 cocoa regions) to pretest the instruments for the cocoa farmers and Cocoa Extension Agents so as to ensure their reliability. Twenty five (25) cocoa farmers and ten (10) CEAs were selected from the Central Region and five (5) scientists from CRIG for the pilot study.

The researcher distributed the questionnaires to the scientists and CEAs while four (4) trained enumerators interviewed the selected cocoa farmers. The pilot study was done in the first week of April, 2015.

The responses were coded into IBM SPSS Version 22. Cronbach's alpha reliability coefficient and Kuder-Richardson (20) coefficient were used to determine the internal consistency of the items on all Liker-type scales and dichotomous scales respectively in the instruments (Nunnelly, 1998). The reason was to check if items in various scales and sub-scales have the same underlying construct. Table 3 shows the reliability coefficients of various constructs in the instruments for the three (3) different set of instruments.

Table 3

Reliability Analysis of Subscale of the Research instruments using Cronbach's Alpha and Kuder-Richardson 20 coefficient

	Construct	Scientists (n=5)		Cocoa Extension Agents (n=10)		Cocoa Farmers (n=25)	
		Alpha	No. items	Alpha	No. items	Alpha	No. items
1	Perceived Technology Characteristics of PA	0.877	18	0.866	18	0.753	18
2	Awareness level of PA	0.947	35	0.904	35	0.914*	32
3	Knowledge Level of PA	0.971	35	0.944	32	-	-
4	Challenges/Prospects of PA	-	-	-	-	-	-
a	Economic Challenge	0.765	9	0.888	9	-	-
b	Educational/Training	0.868	10	0.947	10	-	-
c	Technical challenge	0.823	10	0.879	10	-	-
d	Time Challenge	0.980	3	0.637	3	-	-
e	Data quality challenges	0.810	9	0.948	9	-	-
f	Farmer/Operator demographic Challenges	0.918	9	0.839	9	-	-
g	Environmental/Abiotic challenges	0.625	5	.853	5	-	-
h	Political /Governmental Challenge	0.750	4	.880	4	-	-
5	Level of Willingness to Adopt PA Components	0.911	10	.778	10	0.964	10

* Kuder Richardson (20)

Source: Pilot Study, Bosompem (2015)

The Cronbach's alpha of the five (5) main constructs (Perceived technology characteristics, Awareness levels, knowledge levels, perceived challenges and level of willingness to adopt. For the scientist's instrument the coefficient ranged from 0.750 – 0.980 indicating that the scientists questionnaires had a very good reliability. The exception was the subscale "Environmental/Abiotic challenges" where the Cronbach's alpha was 0. 625 which was relatively low. According to Pallant (2013), Cronbach's alpha coefficient of a scale should ideally be above 0.7. However, since Cronbach's alpha coefficient is sensitive to the number of items in the scale, it is normal to find quite low Cronbach' values of 0.5 in shorter scales (e.g. scales with fewer than 10 items) [(Pallant, 2013)]. Therefore, the 0.625 on 'Environmental/Abiotic challenges subscales' is relatively good since the number of items in the subscale are 5 (see the first column Table 3).

The second column in Table 3 also shows the reliability coefficients of the instrument (questionnaire) for CEA with the same aforementioned five (5) main subscales (Perceived technology characteristics, Awareness levels, knowledge levels, perceived challenges and level of willingness to adopt). The table shows that Cronbach's alpha coefficients range from 0.637 – 0.944 indicating that the subscales are reliable (Pallant, 2013).

The last column in Table 3 also depicts the reliability coefficients of the CEA instrument (the structured interview schedule). The interview schedule of the farmers had three (3) main constructs (Perceived technology characteristics, Awareness levels, and level of willingness to adopt the components). The reliability of the two constructs (Perceived technology characteristics and level of willingness to adopt the PA components) was determined using Cronbach's alpha coefficients. The results showed that the two construct were highly reliable with the alpha of 0.753 for Perceived technology characteristics construct and 0.964 for level of willingness to adopt the PA components. Kuder-Richardson (20) reliability coefficient was used to determine the internal consistency of "awareness" construct since the ratings were re-coded to dichotomized the scale (i.e. 0=not aware and 1= aware). Thus, the ratings on their levels of awareness were very low to warrant the use of Cronbach's alpha coefficients (Pallant, 2013). The Kuder-Richardson (20) coefficients of the "awareness" subscale yielded 0.914 indicating that the construct was reliable.

Data Collection Procedures

Data was collected by the researcher and four (4) trained enumerators used in the pilot study. The data collection started on June 8th 2015 and ended on the last week of July, 2015. The researcher personally distributed the questionnaires to the scientists and CEAs. Personal interviews were conducted by the four (4) enumerators with the sampled cocoa farmers using the content-validated and pre-tested structured interview schedule. The interviews were translated into the local dialect (Akan) of the individual cocoa farmers and their responses ticked or written on the structured interview schedule.

At the end of the data collection period 416 out of the 422 interview schedules, 63 out of the 141 questionnaires from CEAs and 12 out of the 30 were received. The response rate from the various sample sizes were 98%, 45% and 40% for cocoa farmers, CEAs and scientists respectively.

Data Analysis

With the help of IBM Statistical Product and Service Solutions (SPSS) version 22.0, frequencies, percentages, means, standard deviations were used to describe the awareness level, knowledge level, perceived challenges and prospects of PA technologies in the cocoa production in Ghana, and the demographic and farm related characteristics of respondents.

One way analysis of variance (ANOVA) was used to compare significant differences among the awareness level of the stakeholders-cocoa farmers, scientists and CEAs (ie Hypothesis 1 or objective 1). Eta-squared was estimated to measure the magnitude or the effect size of the significance since the ANOVA showed significant differences among the three (3) major stakeholders. Hochberg's GT2 Post Hoc multiple comparison was also used to determine were significant differences existed among the stakeholders mean perceived awareness level. Even though Pallant (2013) recommends Scheffe post hoc multiple comparison technique as appropriate when equal variances are assumed in addition to the robustness of Sheffe's test, Field (2013) recommended Hochberg's GT2 as most appropriate when the sample sizes of the groups are very different in addition to when the Levene's test of homogeneity of variance is not significant (i.e equality of variance was assumed among the three (3) stakeholders). Hochberg's GT2 was chosen over Scheffe, since the sample sizes of the three (3) stakeholders (Scientists: n=11; CEAs: n=63; Cocoa farmers: n=331) used for the ANOVA test greatly differ (Field, 2013).

The difference between the knowledge levels of experts/scientists and CEAs was analysed using independent sample t-test (Hypothesis 2 or objective 2).

The differences between scientists' and Cocoa Extension Agents' perceived challenges/prospects in PA technology development in cocoa production in Ghana were analysed using independent sample t-test (Hypothesis 3 or objective 3).

One way ANOVA was used to compare stakeholders' (cocoa farmers, experts (scientists) and Cocoa Extension Agents) perceived Technology characteristics (attributes) of PATs. (i.e. Hypothesis 4 or objective 4). Eta-squared was estimated to measure the magnitude or the effect size of the significance since the ANOVA showed significant differences among the three (3) major stakeholders. Tamhane's T2 Post Hoc multiple comparison was also chosen to determine where significant differences existed among the stakeholders mean perceived technology characteristics. Tamhane's T2 was used based on the outcome of the Levene's test of homogeneity of Variance (i.e equality of variance was not assumed among the three (3) stakeholders). Also, Tamhane's T2 is known to be more conservative (control for type I error) compared to other multiple comparison techniques recommended when equal variances are not such as the Dunnett's T3 and Games-Howell (Field, 2013).

For hypotheses 1 to 4 that compare means using either the ANOVA (F-test) and t-test analyses, bootstrapping was performed for samples of 1000 to ensure robust estimates of significant or p-value, standard errors and the confident intervals (IBM, 2013;Tabachnick & Fidell, 2013; Field, 2013). When F-test, was significant, bootstrapping was also performed to ensure robust estimates for the mean differences and significant test in the Post Hoc Multiple Comparison. To ensure robust confidence intervals, Bias corrected and accelerated (BCa) intervals were used since it ensures adjusted intervals that are more accurate (IBM, 2013). Mersenne Twister Random number Generator was set to replicate a sequence of random numbers. This helped to preserve the original state of the random number generator and restore that state after the analysis was completed (IBM, 2013). The stratified method was used during the bootstrapping resampling with replacement from the original dataset, *within* the strata of the three (3) main stakeholders (in the case of cocoa farmers, scientists and CEAs) in the case of F-tests and the t-tests.

Different correlation coefficients (Spearman's rho, Rank Biserial (r_{rbi}) , biserial (r_{bi}) and Phi correlation coefficients) were used to explore the relationships among the independent variables and the willingness to adopt PA technology depending on the level of measurements of the independent variables against the dependent variable (i.e Hypothesis 5 or objective 5). Biserial correlation coefficient (rbi) is used when measuring the degree of association between artificial dichotomy nominal variable and ratio or interval level scale. This is almost similar to the Point Biserial correlation (rpbi) but the nominal dichotomy must be a naturally occurring variable (e.g. Sex). Rank Biserial (rbi) is used when measuring the degree of association between any nominal dichotomy (e.g willingness to adopt: 1=adoption and 2 =No adoption) and ordinal or ranked level measurements (e.g. Level of education). Table 4 shows the different type of correlations used based on their levels of measurements of the variables used.

Table 4

Codes, sign of predictors and type of correlation used for data analysis

Demographic/Farm Related Variables	Codes	Sign	Type of Correlation
Sex (X_1)	1=Male, 0=otherwise	+	Phi
Marital status (X_2)	1=Married,0=otherwise	-	Phi
Age at last birth day (X_3)	Number of years	-	Biserial
Educational Level (X_4)	Ordinal scale	+	Rank Biserial(r_{rbi})
Farming Experience (X_5)	Number of years	+	Biserial
Household size/Dependents (X_6)	Number of years	-	Biserial
Size of land under (X_7)	Number of Acres	+	Biserial
Land size where fertilizer applied (X_8)	Number of Acres	+	Biserial
Access to Credit (X_9)	1=yes, 0=otherwise	+	Phi
Access to credit from financial institution (X_{10})	1=yes, 0=otherwise	+	Phi
Row planting (X_{11})	1=yes, 0=otherwise	+	Phi
Access road to farm (X_{12})	1=yes, 0=otherwise	+	Phi
Land Ownership (X_{13})	1=Inherited , otherwise	+	Phi
Land Rights (X_{14})	1=Sell out right, 0 =otherwise	+	Phi
Main source of labour (X_{15})	1=hired, 0=otherwise	+	Phi
Amount of fertilizer applied per acreas (X_{16})	Number of bags	+	Biserial
Yield (X_{17})	Number of bags	+	Biserial
Have mobile phone (X_{18})	1=yes, 0=otherwise	+	Phi
Frequency of visits by Extension Agents (X_{19})	Ordinal scale	+	Rank Biserial(r_{rbi})

Table 4 *continued*

Technology related characteristics	Code	Sign	Type of Correlation
Relative Advantage (X_{20})	Interval Scale	+	Biserial
Compatibility (X_{21})	Interval Scale	+	Biserial
Complexity (Ease of Use) (X_{22})	Interval Scale	+	Biserial
Trialability (X_{23})	Interval Scale	+	Biserial
Observability (X_{24})	Interval Scale	+	Biserial
Voluntariness (X_{25})	Interval Scale	-	Biserial
Awareness levels			
Awareness of PA information/Data (X_{26})	Interval Scale	+	Biserial
Awareness of PA Technology /Tools (X_{27})	Interval Scale	+	Biserial
Awareness of Management of info. (X_{28})	Interval Scale	+	Biserial

Source: Author's Construct (2015)

Phi correlation, on the other hand, measures associations between two naturally dichotomous nominal variables (e.g. Sex measured as 1=Male ; 0=female and Adoption measured as 1=Adoption, 2=No adoption) whiles Spearman rho measures association between two ranked or ordinal level variables (Pallant, 2013; Cohen et al., 2005).

Binary Logistic Regression was used to determine the best predictors of cocoa farmers' willingness to adopt PA technologies from the independent variables (demographics and farm-related characteristics, perceived technology characteristics and farmers' awareness levels) of the study. An alpha level of 0.05 was set as a priori for all test of significance in the study. Logit, Probit and Tobit regression models have been used in most studies that focus on farmers intension to adopt (ex-ante) and actual adoption(ex-post) studies (Antolini, Scare, & Dias, 2015; Pierpaoli, Carli, Pignatti, & Canavari, 2013; Tey & Brindal, 2012). In most binary situations (i.e. adoption and non-adoption) either the Binary Logit or Probit regression is chosen over Tobit since in Tobit models, both decisions of adoption and the intensity of use are done simultaneously (Feder & Umali, 1993). Even between Logit and Probit, Logit is more popular and preferred in adoption studies because it is less complicated compare to the Probit because, Probit models involve many assumptions including meeting the assumption of normal distribution for which in Logit the assumption of normal distribution is not necessary (Hill, Griffiths, & Lim, 2008).

Logistic regression was chosen over the Probit and Tobit because PAT is new and emerging area of study in Ghana and the potential awareness of farmers and other stakeholders were expected to be low, therefore, predicting the intensity of use of PAT of potential farmers who barely know the PAT was considered to be unnecessary at this initial research or study.

Model specification of the binary logistic regression

The odds of an event occurring (a farmer willing to adopt PA technologies measured as 1=adoption) is the probability that the event will occur divided by the probability that the event will not occur (.i.e. a farmer **not** willing to adopt PA technologies (Acquah, 2013). Following Greene (2008), the probability y=1 occurs varies according to the values of the explanatory variables and specified the relationship as below:

$$log\left[\frac{P(y=1)}{1-P(y=1)}\right] = logit[P(y=1)] = \beta_0 + \beta_j X \quad (1)$$

From equation 1, P(Y=1) is given by $P(Y=1) = \frac{e^{\beta_0+\beta_j X}}{1+e^{\beta_0+\beta_j X}}$

where $\ln\left(\frac{\mathrm{p}}{1-\mathrm{p}}\right)$ is the logit transformation. This value is the log of the odds of the outcome (since odds=P/(1-P)). β_0 and β_j are parameters to be estimated and X_j is a vector of explanatory variables with index *j*.

Furthermore, $\frac{P}{1-P} = e^{(\beta_0+\Sigma\beta_j X_j)}$where P is the probability that Y=1 and 1-P is the probability that Y=0 and e is the exponential constant.

In the following empirical model specified in equation 2, Y =1 defines a cocoa farmer would be willing to adopt PA technologies measured as 1 =adoption; Y=0 define otherwise. The X's define independent variables that explain the probability that a farmer would be willing to adopt PA technologies measured as 1 = adoption and ε_i is error term:

$$logit[P(Y_i = 1)] = \beta_{0i} + \beta_{i1}X_{i1} + \beta_{i2}X_{i2} + \beta_{i3}X_{i3} + \beta_{i4}X_{i4} + \beta_{i5}X_{i5} + \beta_{i6}X_{i6} + \beta_{i7}X_{i7} + \beta_{i8}X_{i8} + \beta_{i9}X_{i9} + \beta_{i10}X_{i10} + \beta_{i11}X_{i11} + \beta_{i12}X_{i12} + \beta_{i13}X_{i13} + \beta_{i14}X_{14} + \beta_{i15}X_{i15} + \beta_{i16}X_{i16} + \beta_{i17}X_{i17} + \beta_{i18}X_{i18} + \beta_{i19}X_{i19} + \beta_{i20}X_{i20} + \beta_{i21}X_{i21} + \beta_{i22}X_{i22} + \beta_{i23}X_{i23} + \beta_{i24}X_{i24} + \beta_{i25}X_{i25} + \beta_{i26}X_{i26} + \beta_{i27}X_{i27} + \beta_{i28}X_{i28} + \varepsilon_i \quad (2)$$

The dependent variable was farmers' willingness to adopt PA technologies if available. This was measured as dummy with 1 and 0 indicating willing and not willing to adopt PA technologies respectively. The main set of independent variables (determinants) were:

- Demographic and farm-related characteristics: (X_1-X_{19}).
- Technology related-characteristics (Attributes of the innovation): (X_{20}-X_{25}).
- Awareness level of cocoa farmers respectively :(X_{26}- X_{28})

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This chapter presents and discusses the results of the study in relation to the specific objectives and hypotheses of the study.

Awareness Level of Stakeholders in Precision Agriculture

The first objective was to compare the awareness level of major stakeholders (cocoa farmers, experts (scientists) and CEAs) on PA technologies/practices in cocoa production in Ghana. Table 5 presents the descriptive statistics of their perceived level of awareness in the three (3) main components of PA namely; Information or data base (17 items), Technology or tools (12) and Management (3 items) components.

Perceived awareness in information/data base component of PA

Almost all the scientists and the majority (between 75% to 89%) of cocoa extension agents were aware of the 17 items listed under the 'information or data base component' of PA. However, a relatively few number of the respondent cocoa farmers (between 13% to 60%) were aware of the information or data base component of PA (See Appendix A for details on individual items).

Table 5

Descriptive Statistics of the Awareness Level of Stakeholders in the three (3) main Components of Precision Agriculture

Main components	Scientists (n=11)		Cocoa Extension Agents (n=63)		Cocoa Farmers (n=416)		All Stakeholders (n=490)	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Information/Data base	3.88	.75	3.26	.84	2.38	.97	2.56	.97
Technology and Tools	3.73	.95	2.97	.96	2.61	1.39	2.73	1.3
Management components	3.12	1.20	2.59	1.22	1.54	.77	2.07	1.24
Overall Awareness of PA	3.58	.79	2.95	.84	2.48	.98	2.58	.99

n=490. Scale for awareness: 1=Least aware (very low); 2=Less aware (low); 3=fairly aware (moderate), 4=Much aware (Good); 5= Very much aware (very good)

Source: Field Survey, Bosompem (2015)

These items were mainly crop, soil, and climatic information required for cultivation of cocoa plant.

Results in Table 5, however, showed that whereas scientists perceived that they were 'much aware' ($\bar{X}$=3.88, SD=.75) of the information or data base component necessary for cocoa production, CEAs were 'fairly aware' ($\bar{X}$=3.26, SD=.84) and cocoa farmers were 'less aware' ($\bar{X}$=2.38, SD=.97). The standard deviations of less than 1 indicate some level of unanimity in the perceived level of awareness in information or data base component expressed by the stakeholders. The results imply that the awareness level of scientists was higher than CEAs, and in turn, the CEAs awareness level was also higher than that of the farmers. The overall level of awareness of all stakeholders in the information or data base component of PA was 'fair' ($\bar{X}$=3.56, SD=.97). Awareness levels of scientists and CEAs are essential since precision agriculture concepts start from a reliable and accurate information or data base systems that show information on the properties of soil, crop information and the climatic conditions in the specific area or location (Mandal & Maity, 2013).

Perceived awareness of stakeholders in technology/tools component of PA

While the majority of the scientists (between 82 to 100%) and CEAs (58-99%) were aware of the 'technology or tools' used in implementing PA, relatively low (less than 50%) of the cocoa farmers (i.e. between 8.2 - 40%) were aware of the technology/tools component of PA. The exception was the awareness of the GPS receivers where approximately 78% of the farmers were aware of GPS Receivers. The rest of the individual technologies or tools included Variable rate applicators (VRAs), Uniform Rate Applicators (URAs), remote sensors, yield monitors etc. (See Appendix B for details of descriptive statistics on individual technologies/ Tools).

Table 5 again shows that scientists were 'much aware' ($\bar{X}$=3.73 SD=.95) whereas both CEAs ($\bar{X}$=2.96, SD=.96) and Cocoa farmers ($\bar{X}$=2.61, SD=1.39) perceived that they were 'fairly aware' of the Technology and tool necessary for precision agriculture implementation and practices (see Appendix B for details of descriptive statistics of individual technology and tools). A significant observation about 12 technologies or tools of PA (see Appendix B) shows that all scientists (100%, $\bar{X}$= 4.1) and almost all CEAs (98%, $\bar{X}$=4.5) perceived that they were 'much aware' of GPS receiver (see Appendix B) indicating their very high awareness of the GPS receiver. Cocoa farmers perceived that their level of awareness were 'fair'. Cocoa farmers reported that Cocoa Extension Agents in Ghana used the GPS receivers for measuring their farms before the right quantity of fertilizers was given to them under the cocoa High Technology programme. Most farmers said that even though they did not know how the GPS receiver works, they held the device and traverse or walk round the boundaries of their farms and the CEAs subsequently estimated the size of their cocoa farms for them. The results indicated that farmers are aware of initial use of GPS receivers- the cornerstone of PATs development-in their cocoa farms. The use of GPS services (mainly for road users) had been reported to cover all 54 African countries with maps that are 3D and interactive (African Business, April

2014). GPS receivers and GIS have been used to determine the supply base of producing firms and established a system for traceability and precision production for some vegetable and fruit farmers through mapping to establish the spatial locations and concentrations of fruits and vegetable farms in Ghana (ISPA, 2013). Hence, it is not surprising that the majority of the farmers (about 78%) were aware of GPS receivers. Few cocoa farmers (about 22%) who were not aware reported that they were not physically present when their farms were measured but had someone else accompany the CEAs

Perceived awareness of stakeholders of the management component of PA

The management component includes information management, decision support system by precision agricultural providers. Awareness of availability and where farmers could find help and take decision use PATs is very essential.

The majority of scientists (92%) and CEAs (77%) perceived that they were aware of the management component of PA whereas very few cocoa farmers (12%) were aware of the management of the information and decision support component of PA (See Appendix B). Results in Table 5 also showed that both scientists ($\bar{X}$=3.12, SD= 1.20) and CEAs ($\bar{X}$=2.59, SD= 1.22) perceived that they were fairly aware of the management and decision support as well as PA service providers who could develop and implementing PA in cocoa production. Cocoa farmers however were 'less aware' of such support and service providers. Scientists and CEAs, however, had varied opinions about their level of awareness as shown by high standard deviation of more than 1.

Most scientists who travelled to Europe and North America for further studies had seen some of the tools, decision supports and service providers in PA. Scientists in CRIG and CEAs of Cocoa Health and Extension division (CHED) of COCOBOD have just started using GPS receivers in measuring and, in some cases; geo-tagging cocoa farmers' farms with the intention of either getting more accurate estimates of the size of cocoa farms or to use such farms for field experiments.

In Ghana, a known and emerging service provider for PA support is not providing support for farmers in the cocoa industry. In Ghana, Syecomp Business Services Ltd, a market leader in the use of GPS applications in Ghana, is only a known private and PA service provider that concentrates on providing few PA technologies/tools and services for farmers in vegetables and mango production (Robinson, Banda, Ferrand, Allavi, & Mayer, 2014). With support from the Market-Oriented Agriculture Programme, funded by GIZ, Syecomp Business Services Ltd used specific devises, such as the Trimble Juno 3B Handheld GPS device and the TerraSync mobile application for farm GPS mapping or collection of geo-reference farm data in Mango farms in Volta Region (Allavi, 2014). The same company had also used GIS and GPS to help improve the marketing of agricultural produce especially in vegetables **(**ISPA, 2013). The company provided support for farmers and sellers **to** trace concentrations of fruits and vegetable farms through the establishment of mapping and the spatial locations of farms.

Overall awareness of PA by stakeholders

The overall awareness of PA was perceived by all stakeholders (Scientists, CEAs and Cocoa farmers) to be ‘fair’ ($\bar{X}$=2.58, SD= .99). However, the scientists ($\bar{X}$=3.58, SD =.79) perceived that they were ‘much aware’, CEAs were ‘fairly’ aware ($\bar{X}$=2.58, SD= .99) and cocoa farmers ($\bar{X}$=2.48, SD= .98) were ‘less aware’ of PA (Table 5). Hence, the awareness level of scientists was higher than that of CEAs and in turn that of CEAs was better than that of cocoa farmers.

The level of awareness of PA by stakeholders, especially farmers is very crucial for PATs development in cocoa industry since the level of awareness of farmers has been identified to be the critical first stage of agriculture technology diffusion process (Daberkow & McBride, 2003). The results from the study that show generally low level of awareness of farmers in PATs corroborates other studies which focused on farmers awareness of PATs even some developed countries a decade or two ago when PA development was at its initial stages. For example, a nationwide study of 8400 farmers conducted in the USA in 1998 concluded that the unawareness of PA technology among farmers is one main reason for the low rate of adoption (Reichardt & Jurgens, 2009). At the time of that survey, 70% of the US farmers were not aware of PF technologies (Daberkow & McBride, 2003). A similar survey conducted between 2001 and

2005 in Germany indicated that over 50% (half) of the farmers interviewed were unfamiliar with the term ‘‘Precision Farming’’ or ‘‘Precision Agriculture’’(Reichardt & Jurgens, 2009). A parallel survey also in Germany in the same period (2001–2005) revealed that about 28% of the farmers interviewed were unfamiliar with the term ‘‘Precision Farming’’ or ‘‘Precision Agriculture’’(Reichardt & Jurgens, 2009).

Differences in awareness level of major stakeholders in Precision agriculture stakeholders in cocoa industry

One way ANOVA was used to determine whether statistically significant differences existed among the overall mean perceived awareness of PA innovations by major stakeholders. The results are shown in Table 6.

Table 6

ANOVA showing the Mean Awareness Level of Stakeholders in PA innovation

Stakeholder	n	$\bar{X}$	SD	F	Sig
Scientists	11	3.58	.79	12.91	.000
Cocoa Extension Agents (CEAs)	63	2.96	.84		
Cocoa Farmers	331	2.48	.97		

$p < 0.05$ **Eta-Squared = 0.06**. Scale for awareness: 1=Least aware (very low); 2=Less aware (low); 3=fairly aware (moderate), 4=Much aware (Good); 5= Very much aware (very good).

Source: Field Survey, Bosompem (2015)

Table 6 shows that there were statistically significant differences; $F (2, 402) = 12.91$, $p = .000$; among the three (3) stakeholders perceived level of awareness of PA innovation at 0.05 alpha level.

The study, therefore, failed to accept the first (1st) null hypothesis that, 'There are no significant differences among the awareness level of major stakeholders in cocoa industry (experts/scientists, CEAs and cocoa farmers) of PA innovation'. The alternative hypothesis that stated that 'There are significant differences among the awareness level of major stakeholders in cocoa industry (experts/scientists, CEAs and cocoa farmers) of PA innovation' is therefore accepted.

Table 6 again showed that the effect size (calculated using eta squared) was 0.06. This indicates that the magnitude of the significance was 'moderate effect' (Cohen, 1988). According to Cohen (1998) classification, 0.01= small effect, .06= medium effect and .14 = large effect. Hence, the effect size shows that the actual difference in mean scores among the stakeholders level of awareness is quite substantial and should not be ignored.

Table 7 shows Levene's test of homogeneity of variances among the three (3) major stakeholders. Levene's test was used to determine the appropriate post hoc multiple comparison technique to be used to determine where significant differences actually existed among the three (3) major stakeholders perceived level of awareness of PATs as shown in Table 6.

Table 7

Levene's Test of Homogeneity of Variances among Major stakeholders

Levene's Statistics	Sig.
.941	.391

p< 0.05 (Scientists: n=11;CEAs:n=63; Cocoa farmers: n=331)

Source: Field Survey, Bosompem (2015)

Table 7 reveals that variances that existed among the means were not significant (df =2, 402; p = .391) at 0.05 alpha level. This implied that the assumption of the homogeneity of variance is not violated. In other words, equal variances are assumed among three (3) stakeholders even though the sample size for each of the three (3) major stakeholders were varied, and that of scientists (n=11) were relatively smaller (Pallant, 2013; Tabachnick & Fidell, 2013). Hochberg's GT2 post hoc multiple comparison technique was chosen to determine where significant difference existed among the stakeholders because Levene's test showed that equal variances were assumed and also the sample sizes of the three (3) stakeholders (Scientists: n=11; CEAs:n=63; Cocoa farmers: n=331) used for the ANOVA were very different (Field, 2013).

Table 8 shows a multiple comparison of mean perceived level of awareness of the three (3) major stakeholders of PA innovation using Hochberg's GT2 post hoc multiple comparison for both the original sample and the bootstrapped sample of 1000. For the original samples, Table 8 revealed that there were no statistically significant (*p*=.135) differences between scientists'

($\bar{X}$=3.58., SD =.79) and CEAs' ($\bar{X}$=2.96., SD =.84) mean perceived awareness level in PA at 0.05 alpha level.

Table 8

Hochberg's GT2 Post Hoc Multiple Comparison of Stakeholders' Perceived Awareness level of PA

Stakeholders		MD	Original Samples (n=491)		
A	B	A-B	Std. Error	Sig.	CI (95%)
Scientists	CEAs	.622	.311	.132	-0.123 – 1.367
	Cocoa Farmers	1.101*	.292	.001	0.402 – 1.800
CEAs	Cocoa Farmers	.479*	.131	.001	0.165 – 0.792
Bootstrapped samples of 1000					
Stakeholders		A-B	Std. Error	Bias	BCa-CI (95%)
Scientists	CEAs	.622*	.250	.003	0.084 - 1.136
	Cocoa Farmers	1.101*	.232	.006	0.632 -1.533
CEAs	Cocoa Farmers	.479*	.116	.004	0.262 - 0.691

n=491, p< 0.05* MD=Mean Difference, CI=Confidence interval

BCa=Bias corrected and accelerated.

Source: Field Survey, Bosompem (2015)

But there were statistically significant (*p*=.001) difference between cocoa farmers' ($\bar{X}$=2.48, SD =.79) and scientists' ($\bar{X}$=3.58, SD =.79) mean perceived awareness level in PA innovation at 0.05 alpha level. Again, there were statistically significant (*p*=.001) differences between cocoa farmers' ($\bar{X}$=2.48, SD =.79) and CEAs' ($\bar{X}$=2.96, SD =.84) awareness level in PA.

However, the bootstrapped sample of 1000 (to cater for the relatively low number of respondent scientists (n=11) and CEAs (n=63) compared to that of cocoa farmers, n=331) showed that statistically significant difference existed between scientists' ($\bar{X}$=3.58., SD =.79) and CEAs' ($\bar{X}$=2.96., SD =.84) awareness level at 0.05 alpha level even though the original sample showed no significant difference (*p*=.135) at 0.05 alpha level. This is because the bootstrapped confidence interval (BCa-CI (95%) of the mean difference ranges from 0.084 to 1.136. This confidence interval being positive implies that the difference between means in the population could never cross the zero value i.e. the bootstrapped sample does not include the value of zero effect (Field, 2013; du Prel, Hommel, Röhrig, & Blettner, 2009). In other words, it is not possible that the true difference between means is zero, since the null hypothesis tests that the true difference between means is zero. It is concluded that there is a statistically significant difference between scientists' and CEAs' level of awareness.

This means that the level of awareness of scientists in cocoa industries of PATs are actually and relatively higher than that of CEAs and in turn, that of CEAs is also higher than that of cocoa farmers. This result is not surprising since in the Research-Extension-Farmer linkages, researchers/scientists often become aware of or develop innovation before it is packaged and sent by extension agents through appropriate channels to farmers (Rogers, 2003). Hence, farmers' relatively low level of awareness compared to scientists and CEAs is understandable, especially since PATs are relatively new and emerging in developing countries including Ghana (Swinton, 2011).

Perceived Knowledge Level of Experts (Scientists) and Cocoa Extension Agents in Precision Agriculture

The second objective was to compare the perceived level of knowledge of experts (scientists) and CEAs on PA technologies, principles and practices.

Table 9 presents the descriptive statistics of their perceived level of knowledge in the three (3) main components of PA namely Information or data base (17 items), Technology or tools (12) and Management (3 items) components.

Table 9

Descriptive Statistics of Perceived Knowledge level of Scientists and CEAs in Main Components of PA

Main Components	Scientists (n=12)		Cocoa Extension Agents (CEAs) (n=62)		Both scientists and CEAs (n=74)	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Information/Data base	3.41	.92	3.25	.76	3.28	.78
Technology and Tools	2.99	.65	2.70	.93	2.74	.89
Management components	2.33	.91	2.50	1.26	2.47	1.20
Overall Knowledge PA	2.93	.68	2.79	.84	2.82	.81

n=491, Scale: 5=Very Good, 4=Good, 3=Fair, 2=poor, 1= Very Poor

Source: Field Survey, Bosompem (2015)

Perceived knowledge in information/data base component of PA

A majority (between 83% to 100% of the scientist and 75% to 85% of CEAs) perceived that they had some form of knowledge in the 17 items listed under the 'information or data base component' (See Appendix C for details on individual items). This included knowledge in crop, soil, and climatic information required for cultivation of cocoa plant. Results in Table 9, however, showed that both scientists ($\bar{X}$= 3.41, SD=.92) and CEAs ($\bar{X}$=3.28, SD=.78) perceived that they have 'fair' knowledge about the information or data base component necessary for cocoa production (both $\bar{X}$=3.28, SD=.78). The standard deviations of less than 1 indicate some level of unanimity in the perceived level of knowledge in information or data base component expressed by both scientists and the CEAs.

Knowledge in the information or data base component is very essential because precision agriculture, concepts start from a reliable and accurate information or data base systems that show information on the properties of soil, crop information and the climatic conditions in the specific area or location (Mandal & Maity, 2013). These pieces of information are later fed into the technology/tools for successful implementation of PA, hence, the accuracy of the information or data base is very essential and scientists' and CEAs knowledge in obtaining these components is very essential for any future development of PA in cocoa production in Ghana.

Perceived knowledge in technology/tools component of PA

While a majority of the scientists (between 60-91%) perceived that they have some knowledge in the technology and tools used in implementing PA, relatively wide range of CEAs (34-98%) perceived that they have some form of knowledge in the technology/tools component (Table 9). Again both perceived fair knowledge (Scientists: $\bar{X}$=2.99, SD=.65; CEAs: $\bar{X}$=2.74 SD=.74) of the Technology and tool necessary for PA implementation and practices. These technologies or tools included GPS receivers, VRTs, URA, GIS, remote sensors, yield monitor etc. (See Appendix C for details of descriptive statistics on individual items). A significant observation about 12 technologies or tools of PA (see Appendix C) shows that almost all scientists (92%, $\bar{X}$=4.0) and CEAs (98%, $\bar{X}$=3.9) had knowledge in the use of GPS receiver and they perceived their level of knowledge to be 'Good' (see Appendix C).

This is not surprising since the use of GPS receivers has been found to be available for farm and non-farm use in Ghana. For example, GPS receivers are either carried to the field or mounted on implements to allow users to return to specific locations on their farms to sample or treat those areas (Mandal & Maity, 2013). Some farmers in mango production had been trained, and are using GPS devices and mobile application for farm GPS mapping and collection of geo-reference farm data in Ghana (Allavi, 2014). Cocoa Extension Agents in Ghana have been trained to use the GPS receivers for measuring cocoa farmers' farm before they are given the right quantity of fertilizers under the Cocoa High Technology Programme in Ghana. The use of GPS services (mainly for road users) had been reported to cover all 54 African countries with maps that are 3D and interactive (African Business, April 2014). GPS and GIS devices have been used to determine the supply base of producing firms and establish a system for traceability and precision production for some vegetable and fruit farmers through mapping to establish the spatial locations and concentrations of fruits and vegetable farms (ISPA, 2013).

Perceived knowledge in management component of PA

A majority (at least 83% of the scientists and about 59% to 73% of CEAs) perceived that they had some form of knowledge in the management component of PA which includes management of the information and decision Appendix D). Results in Table 9 also showed that both scientists ($\bar{X}$=2.33, SD=.91) and CEAs ($\bar{X}$=2.47, SD=1.20) perceived that they have poor or low knowledge about the Management and decision support for implementing PA in cocoa production even when it is available. Respondent CEAs, however, had varied opinions about their knowledge level as shown by high standard deviation of more than 1.

It stands to reason that low knowledge of PA management has implications for the provision of PA advice by both scientists (experts) and extension agents since good research-extension-farmer linkage is essential for ensuring effective introduction of PA. Lack of local experts and lack of research and extension personnel who have a good handling of the practical field applications of PA have been identified as challenges to PA even in developed countries (Heiniger et al., 2002; Wiebold et al., 1998). For example, Reichardt and Jurgens (2009) reported that 58.4% of 89 advisors from all over Germany that offered advisory services did not offer any advisory service in the field of PA due to low acceptance of PA technologies among the advisors themselves.

In general, the overall perceived knowledge level of scientists alone and CEAs alone in PA was 'fair' (means of 2.93 and 2.79 respectively). Even though both perceived that they have 'fair' knowledge in PA, scientists' perceived knowledge levels were slightly higher than that of CEAs (Table 9). Also, the respondent scientists and CEAs altogether perceived that they had fair knowledge in PA.

Results in Table 10 show Independent sample t-test between the perceived level of knowledge of scientists and CEAs in cocoa production in PA. The results of the original sample show that there were no significant (sig=0.62) difference between scientists' and CEAs' level of knowledge at 0.05 alpha level.

Table 10

Independent Sample t-test between Scientists and CEAs mean Perceived Knowledge level in PA

Original Samples (n=72)							
Stakeholder	n	$\bar{X}$	MD	SE	t	Sig	CI (95%)
Scientists	11	2.93	.135	.268	.505	.615	-0.400 – 0.671
CEAs	61	2.79					
Bootstrap samples (n=1000)							
Stakeholder	n	Bias	MD	SE	t	sig	BCA-CI (95%)
Scientists	11	.000	.135	.227	.505	.533	-0.309 – 0.611
CEAs	61						

n=72 p< 0.05 Levene's statistics (F= 2.483; sig=.0.120), CI = Confidence interval. Scale: 5=Very Good, 4=Good, 3=Fair, 2=Poor 1=Very Poor

Source: Field Survey, Bosompem (2015)

A bootstrap of 1000 samples using stratified sampling with replacement also showed no significant (sig=0.55) difference between the knowledge level of scientists and CEAs in PA at 0.05 alpha level. This is further confirmed by the bootstrapped confidence interval of the mean difference which ranges from -0.309 to 0.611. The confidence interval implies that the difference between means (df =70, MD =.135) in the population could be negative, positive or even zero since the interval ranges from a negative value to a positive). In other words, it is possible that the true difference between means is zero since the null hypothesis tests that the true difference between means is zero – no difference at all. Therefore, the bootstrap confidence interval confirms the conclusion from the original samples that there is no significant difference between the knowledge level of scientists and CEAs in PA.

The second null hypothesis that stated that "there are no significant differences between scientists' and CEAs' perceived knowledge level in PA was accepted". The alternative hypothesis was rejected. This implies that both scientists in cocoa research and CEAs perceived that they have similar (fair) knowledge in the technologies and practices in PA.

Scientists' and Cocoa Extension Agents' Perceived Challenges/Prospects Anticipated in PATs Development in Cocoa Production in Ghana

The third objective was to identify experts' (scientists') and Cocoa Extension Agents' perceived challenges and prospects anticipated in PA development in cocoa production in Ghana.

Table 11

Descriptive Statistics of Scientists' and CEAs' Perceived Challenges anticipated in PA Development in Cocoa Production

Challenge	Scientists (n=12)		CEAs (n=62)		Overall (n=74)		Rank
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	
Economic	4.06	.63	3.58	.79	3.65	.78	4th
Educational	3.69	.78	3.65	.91	3.66	.89	3rd
Technical	3.55	.75	3.65	.78	3.63	.78	5th
Time	3.36	1.01	3.32	.95	3.33	.95	6th
Data Quality	2.79	1.00	3.34	.97	3.26	.99	8th
Farmer Characteristic	3.94	.56	3.74	.785	3.77	.76	1st
Environmental	3.73	.800	3.71	.91	3.72	.89	2nd
Governmental/Political	3.22	1.11	3.27	1.09	3.29	1.09	7th

Scale = 5= High, 4= Substantial; 3=Moderate, 2= Low, 1=Negligible

Source: Field Survey, Bosompem (2015)

Results in Table 11 provides a summary of mean perceived challenges of PATs development and implementation in cocoa production in Ghana as perceived by scientists and Cocoa extension agents. The eight (8) major challenges studied were economic, time, educational/training, technical, data quality, farmer/operator demographics, environmental and political/governmental challenges.

Farmer/Operator socio-demographic characteristics

The results in Table 11 showed that scientists ($\bar{X}$=3.94 SD =.59) and extension officers ($\bar{X}$=3.74, SD=.76) both considered "Farmer socio-demographic characteristics" (overall $\bar{X}$= 3.77, SD =.79) as 'substantial' challenge. It also emerged as the most important challenge that needed to be surmounted before that PATs development in cocoa production becomes a reality. Items measured under this construct included aged farmers, low education level of farmers, lack of computer knowledge, negative attitude towards new technologies among others (see Appendix E).

Aging, for example, has been known to have been a challenge to the adoption of PA. Older farmers have been found to have shorter planning horizons, diminished incentives to change and less exposure to PA whereas younger farmers, in contrast, have a longer career horizon and are more technologically-orientated (Larson et al., 2008; Roberts et al., 2004).

In the context of Ghanaian farmers, most are uneducated. A number of studies have indicated that over 50% of cocoa farmers in Ghana have no formal education (e.g. Bosompem, 2006; Dankwa, 2002; Kumi, 2003). No wonder both scientists and CEAs ranked it as the most important challenge that would hinder PA development in cocoa production in Ghana.

Environmental challenge

Table 11 also shows that scientists ($\bar{X}$=3.73, SD=.80) as well as CEAs ($\bar{X}$=3.71, SD=.91) perceived 'environmental challenge' to be 'substantial' (overall $\bar{X}$=3.72, SD=.89). Environmental challenge was perceived to be the second most important challenge that would militate against PAT development in cocoa sector in Ghana. The items that made the 'environmental challenge construct' that both scientists and CEAs perceived to be 'substantial' included (a) undulating or sloppy topography of most cocoa farms, (b) Vegetation mostly forest and trees, and (c) lack of accessible roads to farms (see Appendix E). Respondents perceived that the aforesaid issues would make access to machinery and PA tools such as tractors, combine VRAs and planters to farms very difficult.

In Ghana, cocoa is grown in Rhodic Ferralsols soil types which is mainly found in forest areas of Ashanti, Brong Ahafo, Central, Eastern, Western and Volta regions (CRIG, 2010). Since soil quality has been found to be the single significant factor of adoption of any crop and PATs (Tey & Brindal, 2012), and since the type of soil required by the cocoa plant is found in these forest areas. It stands to reason that the vegetation would make it difficult for the movement of vehicles/tractors and PA tools to cocoa farms to work or even move inputs to cocoa farms since about 58% out of 399 farmers' farms happened to be situated along roadsides as shown by this study (see Table 18).

Educational/Training challenge

Educational challenge also emerged as the 3th challenge that needed to be considered in PA development in cocoa production in Ghana. Items measured under this construct were, lack of effective advisory service, lack of local experts on PA, lack of extension personnel knowledgeable of PATs, lack of farmers awareness and basic knowledge of PA technologies, lack of PA topic consideration in educational institution and lack of adequate training resources among others (see Appendix F)

The results in Table 11 again showed that scientists ($\bar{X}$=3.69 SD =.78) and extension officers ($\bar{X}$=3.65, SD=.91) both considered "educational Challenge" (overall $\bar{X}$= 3.66, SD =.89) as 'substantial'. Lack of PA education has been highlighted by Kitchen et. al. (2002) as a contributing challenge to PA development since PA requires expanded skills and tools not taught or provided by the educational system. It was reported that even in advanced countries like Germany, integration of PA in current curricula was difficult (Reichardt, et. al., 2009). Some vocational and technical schools for example refused the introduction of PA topics into their curricula because PA topics were perceived to be too complicated for the teaching level especially at vocational schools. However, the situation was positive as far as integrating PA education in the university curricula in Germany was concern since about 21 universities were identified to offer PA courses in Germany and since 2005, PA has been part of the courses at all agricultural universities in Germany (Reichardt, et. al., 2009).

Economic challenge

The results in Table 11 again showed that scientists ($\bar{X}$=4.06 SD =.63) and extension officers ($\bar{X}$=3.58, SD=.79) both considered "Economic Challenge" (overall $\bar{X}$= 3.65, SD =.78) as 'substantial'. Economic challenge also emerged as the 4th most important challenge that needs to be surmounted towards PA development and implementation in Ghana. However, available literature shows that Economic challenge which includes items such as (1.High initial cost of investment in PA 2. Accessibility of funds for investments 3.Very expensive equipment, 4. High consultancy and rental fees and 5.uncertainty of PA returns on investments) is the most important drawback to the adoption of PA, especially the initial cost investment (Tey & Brindal, 2012). In Japan, for example, the initial investment cost for PA in one survey done even a decade ago, pegged each surveyed farm at an estimated initial cost of 32,000 to 63,000 US dollars (Yagi & Howitt, 2003).

Robertson et al. (2010) had observed that some forms of PA systems that do not require very high-tech equipment (e.g. GIS systems, VRT without using variable rate controllers, guidance or a history of yield mapping) cost relatively lower, however, the cost shoots up astronomically if auto-steering technology and other much-advanced forms of technology are involved. For example, it is estimated that, high-precision and high-cost auto steer systems cost as much as $60, 000.00 in Australia (Robertson et al., 2010). A Sub-Metre guidance system with precision of 10 cm, has initial capital cost of $20,000, and annual costs of $500 (Knight & Malcolm, 2009), but a Real-Time Kinematic (RTK) guidance system with precision between 2-3 cm costs between $25,000.00- $50,000.00 (depending on whether it is static or otherwise).

Despite the high cost investment in PA, there are proven evidences of substantial reduction in cost of inputs which still makes PA economically advantageous over conventional farming. Yule and Radford (2003) had estimated 28% reduction in labour cost as a result of adoption of PA. Site-specific weed management could reduce the amount of herbicides used by as much as 40-60% (Jensen et al. 2012). Alphen and Stoorvogel (2000) had observed PA can reduce nitrogen fertilizer by 23% while improving grain yields by 3%.

Technical challenge

Table 11 also shows that scientists ($\bar{X}$=3.55, SD=.75) as well as CEAs ($\bar{X}$=3.65, SD=.78) perceived "technical challenge' to be 'Substantial' (overall $\bar{X}$=3.63, SD=.78). Technical challenge included difficulty of quantifying PA profitability, unreliable equipment, lack of PA research centre in Ghana, low mechanization level on the farms, lack of standardization and unreliable internet connectivity in Ghana (See Appendix G). Low mechanisation level on cocoa farms and unreliable internet connectivity are very critical technical challenge that both scientists and CEAs perceived to hinder the development of PA in cocoa production in Ghana.

It has been identified, for example, that farm power available per area of agricultural land has been declining in sub-Saharan Africa (SSA) in general (Baudron, 2014) and in cocoa production mechanisation is virtually not existing, however, PA depends heavily on mechanization and this will significantly affect PA implementation in cocoa production since cocoa production in Ghana is mostly manual. Also unreliability, poor quality, and high costs define Sub-Saharan Africa's internet market (MainOne, 2010), however, Precision agriculture machine control requires the use of Real Time Kinematic Global Positioning Systems (RTK GPS) which depends on access to GPS base Stations and this in turn depends on (wireless) internet access as a cheaper means of access to Real Time Network GPS (Lyle, 2013). Moreover, 3G/4G coverage outside metro areas in most rural communities is limited (Lyle, 2013). In Ghana, high-speed 4G networks are rare.

Time, data quality and political challenges

Time, data quality and political challenges were perceived by both scientists and CEAs to be 'moderate' (means approximately 3) challenge to PA development in cocoa industries in Ghana as shown in Table 11 (see Appendix H). In other words, these three (3) aforesaid challenges are less critical from scientists and CEAs point of view towards PA development in cocoa in Ghana compared to the farmer demographic, economic, environmental, technical challenges discussed, therefore, the prospects in these three (3) areas can be harnessed.

Time challenge included items such as the (1) time it takes to introduce PATs, (2) time taken to learn how to use PA equipment and (3) time taken to experience significant returns on investments. It is known that it takes relatively longer time to introduce PA's technologies (Reichardt & Jurgens, 2009). Unreliable computer equipment has been identified to be the most pressing challenge at the initial stages of adoption of PA. The time taken to experience any investment returns varies depending on which technology is being used (Wiebold et al., 1998). According to Graham (2014), auto steering and variable rate applications are fast, and can easily be put into use to provide immediate return, however, technologies such as yield mapping and soil analysis provide a slower return on investment (Graham, 2014). A case study in Australia in 2007 revealed that it took three (3) years for a PA farmer with VRT to reap benefits from an initial investment of about USD$30,200 (Robertson et al., 2007). Similarly, the study in Australia revealed that it took two years to return profits after an initial investment of USD$201500 Robertson et al., 2007). Two other case studies all in Australia, indicated that there were negative returns in the first years, and that positive returns were from the second year onwards, after substantial initial benefits (Robertson et al., 2007). Negative returns in the first three years, with benefits only from the fourth year onwards has been observed by Robertson et al. (2007).

In the case of data quality concerns, inaccuracies in modelled maps have generated skepticisms among some farmers since maps are used for precision farming, inaccuracies will have direct effect on the quality of precision farming

(Kaivosoja, 2009). Zhou et al. (2014) have indicated that, varying field slopes have visible effects on the precision of yield monitors.

On political challenges, Lattus (2014) has observed that lack of political will by developing countries to enforce innovations has been found to hinder technology adoption. Mcbratney et al. (2005) observed that some potential adopters consider the adoption of PA to be dangerous in developing countries. Their reason is that adoption of PA may enhance the control of multinational farming corporations on developing countries.

Differences in scientists' and cocoa extension Agents' perceived challenges anticipated in PA development in cocoa production in Ghana

Results in Table 12 show Independent sample t-test between scientists and CEAs perceived challenges in PA development and implementation in cocoa production. Table 12 shows that both scientists' ($\bar{X}$=3.63, SD=.61) and CEAs' ($\bar{X}$=3.54, SD=.69) perceived that the overall challenges in PA development is "substantial". This implies that the prospects are rather low towards the development and implementation of PA in cocoa industry in Ghana. The independent sample t-test form the original sample (n=72) in Table 12 shows that there were no significant (sig=0.66) difference (df, =71,MD=.095) between scientists and CEAs mean perceived challenges in PA at 0.05 alpha level.

Table 12

Independent Sample t-test between Scientists' and Cocoa Extension Agents' Perceived Challenges Anticipated in PA Development in Cocoa Production in Ghana

Original sample (n=72)							
Stakeholder	n	$\bar{X}$	MD	SE	t	Sig	CI (95%)
Scientists	11	3.63	.098	.223	.437	.664	-0.348 – 0.543
CEAs	62	3.54					
Bootstrap sample (n=1000)							
	n	Bias	MD	SE	t	Sig	BCA-CI (95%)
Scientists	11	-.001	.098	.193	.437	.624	-0.259 – 0.454
CEAs	62						

$p < 0.05$. Levene's statistics (F=.114; sig=.737 NS), CI = Confidence interval Scale:5=High, 4= Substantial; 3=Moderate, 2= Low, 1=Negligible

Source: Field Survey, Bosompem (2015)

A bootstrap of 1000 samples also showed no significant (sig=0.62) difference between the perceived challenges of scientists and CEAs in PA at 0.05 alpha level. This is further confirmed by the bootstrapped confidence interval of the mean difference which ranges from -0.259 to 0.454. This confidence interval implies that the difference between means (MD =.098) in the population could be negative, positive or even zero since the interval ranges from a negative value to a positive). In other words, it is possible that the true difference between means is zero since the null hypothesis tests that the true difference between means is zero. Therefore, the bootstrap confidence interval confirms the conclusion from the original samples that there is no significant difference between scientists' and CEAs' perceived challenges in PA.

The study, therefore, fails to reject (accept) the third (3) null hypothesis that stated that 'there are no significant differences between experts' (scientists') and Cocoa Extension Agents' perceived challenges/prospects anticipated in PA technology development in cocoa production in Ghana.

This shows that both major stakeholders (scientists and CEAs) whose jobs are critical for development and implementation of PATs in cocoa sector in Ghana believe that a lot need to done before PATs become a reality in Ghana. Many PA advocates (including scientists) had been sceptical about whether PA would be feasible for developing countries because of a number of factors including small scale nature of agriculture in developing countries including Asian countries. Shibusawa (1999) had contended that whether PA was feasible was a leading issue that PA scientists and politicians in Japan had debated in the late 90s. It stands to reason that, despite the assessment by scientists and CEAs on the reality of challenges that need to be tackled before PATs development becomes a reality in cocoa industry in Ghana, the situation is not hopeless since, Shibusawa (1999) proved over a decade and half ago that PAT development and implementation were feasible even in small scale farming once the main fundamental principle of PA (site specific application of inputs through Variable Rate Technology) was developed and applied.

Attributes (Technology Characteristics) of Precision Agriculture Technologies (PATS) Development as Perceived by Major Stakeholders in Cocoa Industry in Ghana

The fourth objective was to compare the perceived technology characteristics (attributes) of PATs by major stakeholders in cocoa industry (cocoa farmers, scientists and Cocoa Extension Agents).

Table 13 presents attributes of Precision Agriculture in cocoa production in Ghana as perceived by major stakeholders (Cocoa Farmers, CEAs and Scientists) in the cocoa industry. Perceived Technology characteristics (attributes) in the Table 13 have been arranged in decreasing order of importance of means. The six (6) main attributes of PATs studied were: (a) relative advantage (usefulness), (b) compatibility, (c) complexity (ease of Use), (d) trialability, and (e) observability, and (f) voluntariness.

Table 13

Stakeholders' Perceived attributes (Technology Characteristics) of PATs development in Cocoa Industry in Ghana

Technology Characteristics PA	Cocoa Farmers (n=416)		CEAs (n=62)		Scientists (n= 11)		All Stakeholders (n=490)	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Relative Advantage	4.31	.88	3.39	.92	3.65	.70	4.12	.94
Voluntariness	3.57	.99	3.06	.83	2.94	.66	3.48	.99
Observability	3.40	1.07	2.77	.91	3.00	.65	3.31	1.08
Compatibility	3.35	.98	3.01	.94	3.41	.67	3.30	.98
Ease of Use	3.45	1.33	2.26	1.09	2.83	.97	3.30	1.35
Trialability	3.13	1.17	3.14	1.04	3.32	.81	3.14	1.14
Overall PA Technology characteristics	3.65	.67	2.96	.84	3.58	.79	3.56	.73

Scale on levels of Agreement (1= Very Low, 2=Low, 3= moderate, 4= High, 5=very high). Source: Field Survey, Bosompem (2015)

Table 13 shows that whereas all stakeholders (cocoa farmers, CEAs, and scientists) had perceived ‘high agreement’ (mean approximately 4) that PA has relative advantage over cocoa farmers’ current practices in Ghana, they ‘moderately agreed’ (means approximately 3) on the other five (5) attributes or technology characteristics **(**compatibility, complexity, trialability, and observability and Voluntariness). This implies that all the stakeholders have high expectation that PATs implementation in cocoa industry would be advantageous over cocoa farmers’ existing technologies, they are generally not too sure whether the other five (5) aforementioned attributes of PA innovation could be a reality in Cocoa industry in Ghana based on the available cocoa technologies and current practices of cocoa farmers in Ghana.

Relative advantage of PATs in cocoa production

The stakeholders generally perceived “high agreement” ($\bar{X}$=4.12, SD=.94) that the PA has relative advantage over the existing technologies of cocoa farmers. This implies that all stakeholders perceived PA to have the potentials of (a) being more profitable than the existing cocoa technologies, (b) improving cocoa farmers’ Social prestige, (c) being most effective means of achieving optimum productivity and (d) being environmentally sustainable compared to current practices of cocoa farmers (see Appendix I**).** However, whiles respondents cocoa farmers ($\bar{X}$=4.31, SD=.88) and scientists ($\bar{X}$=3.65, SD=.7) perceived ‘high agreement’ that PATs have relative advantage over the existing technologies of cocoa farmers; CEAs ($\bar{X}$=3.39, SD=.92) ‘moderately agreed’ on the same issue.

The generally ‘high agreement’ expressed by all stakeholders on the potentials of PA having relative advantage over current practices of cocoa farmers in Ghana is noteworthy since the degree of relative advantage has been expressed mostly on economic profitability (Rogers, 2003). Moreover, perceived usefulness or relative advantage had been found to have a positive significant impact on farm operators decision to adopt PAT among farmers in Quebec (Canada) who adopted PATs such as GPS, GIS, yield monitors, yield maps, remote sensing, VRA and navigation systems (Aubert et al., 2012).

Voluntariness of PATs in cocoa production

Voluntariness has been defined as the “degree to which the use of the an innovation is perceived as being voluntary, or of free will" (Moore & Benbasat,1991, p.195). Results in Table 13 again show that all stakeholders ‘highly agreed’ ($\bar{X}$=3.48, SD=.99) that PA should be introduced to cocoa farmers on a voluntarily basis (i.e optional to farmers) for easy adoption among cocoa farmers. They, however, “moderately agreed” that government and other stakeholders (LBCs, NGOs, etc.) must enact or enforce laws to regulate or mandate farmers’ activities if PA would be successful in the cocoa industry. It is noteworthy that cocoa farmers ($\bar{X}$=3.4, SD=.99) themselves agreed more than scientists ($\bar{X}$=2.4, SD=.9) and CEAs ($\bar{X}$=2.4, SD=1.3) on the statement “cocoa farmers would accept PATs when mandated by law from government” (see Appendix I). This implies that while scientists and CEAs perceived that the adoption of PATs by cocoa farmers must be relatively free from governmental influences; cocoa farmers themselves think that an amount of governmental enforcement is needed before adoption of PATs in the cocoa industry in Ghana. This is not surprising because government has vested interest in cocoa and has intervened in the past to sustain cocoa industry.

Cocoa farmers' perception on the need for governmental enforcement towards adoption of PATs in the cocoa industry is in line with other empirical studies. For example, perceived voluntariness has been found to have negative impacts on its potential adopters (Agarwal & Prasad, 1997; Aubert et al., 2012). The reason is that, the more potential adopters perceived an innovation to be voluntary or of free will, the less pressure it put on them for acceptance of information technology, hence, the less likelihood for its adoption especially since PA is relatively new in most sub-Saharan Africa including Ghana and more so in cocoa industry.

Observability, compatibility, and complexity (ease of use) of PATs in cocoa production

Stakeholders 'moderately agreed' that PA would be observable ($\bar{X}$=3.31, SD=1.08); and compatible ($\bar{X}$=3.3, SD=.89) with cocoa farmers existing technologies. Also, in terms of "ease of use" stakeholders "moderately agreed" ($\bar{X}$=3.30, SD=1.35) on that. In other words, PATs would be quite complex for cocoa farmers to apply (Table 13).

In terms of Observability of PA to cocoa farmers, individual stakeholders [Cocoa farmers ($\bar{X}$=3.40, SD=1.07, CEAs ($\bar{X}$=2.77, SD=.91) and Scientists ($\bar{X}$=3.00, SD=.65)] 'moderately agreed' that PA includes Physical and material objects that farmers could easily observe. This implies that respondents were not too sure the degree to which the results of PA would be visible to other cocoa farmers. This observation by all stakeholders is quite understandable since certain aspects of PA can be easily observed and communicated to other cocoa farmers whereas in other aspects it may not be easy to do that.

For example, of the three (3) main components of PA (a) (b) information/data base, (b) technology/tools, and (c) management), it would be easier to observe the results and the use of the 'technology/tool component' compared to the information/data base and management components (Mandal & Maity, 2013). The technology/tool component includes tools of hardware and equipment such as GPS receivers, GIS, VRAs, yield monitors and combine harvesters whose work on farms could be easily observed by other farmers when they are in use whereas it would be difficult to observe and understand the Information/data base component which includes the data base of the soil, crop and climatic properties such as soil texture, soil structure, physical condition, soil moisture, soil nutrients, crop tissue, nutrient status, crop stress, weeds patches (weed type and intensity), pest infestation (species and intensity), crop yield, harvest swath width, temperature, humidity, rainfall, solar radiation and wind velocity, in-soil related variability etc. Rogers (2003) had, however, opined that observability of a technology as perceived by potential adopters has a positive impact on its adoption. Hence, the stakeholders' mixed feelings on the observability of PA to cocoa farmers may have negative implications to the adoption of PATs when they are available for cocoa farmers.

On compatibility of PATs to current cocoa farmers' practices, individual stakeholders again [Cocoa farmers ($\bar{X}$=3.35, SD=.98, CEAs ($\bar{X}$=3.01, SD=.94) and scientists ($\bar{X}$=3.41, SD=.67)] 'moderately agreed' that PATs would be compatible with most farmers' socio-cultural values and beliefs, fit with their current needs, less compatible with previously introduced cocoa technologies and their current practices in their cocoa farms (see Appendix J). Respondent cocoa farmers 'highly agreeing' that PATs would be compatible with their socio-cultural values and beliefs ($\bar{X}$=4.09, SD=1.1, see Appendix J) indicates a positive prospects towards adoption of PA. This is because Rogers (2003) had observed that, the more an innovation is incompatible with existing deeply embedded cultural values, the less its adoption. Hence, even if PATs had been perceived to have relatively advantages and more profitable compared to farmers existing practices but perceived to be incompatible with socio-cultural values and beliefs of farmers, the prospects of its adoption would have been very bleak among cocoa farmers in Ghana**.** Again, cocoa farmers' responses implied that PATs would be relatively less compatible with previously introduced cocoa technologies ($\bar{X}$=3.0, SD=1.5) and their current practices in their cocoa farms ($\bar{X}$=2.87, SD=1.5) (see Appendix J). Rogers (2003) had opined that old and existing ideas are the main mental tools that clients use to assess new ideas and give them meaning. Hence, previous practices serve as standards or benchmarks against which an innovation is interpreted.

Ease of use (Complexity) is the degree to which a farmer believes that the use of PATs would be free from effort (Pierpaoli et al., 2013). Even though all stakeholders "moderately agreed" ($\bar{X}$=3.30, SD=1.35) that they could easily understand PA practices and practice the technology if it is available, CEAs perceived low agreement ($\bar{X}$=2.26, SD=1.09) on the Ease of use of PATs among cocoa farmers (Table 13).

This implies that CEAs felt that it would be relatively difficult for cocoa farmers to apply PATs even though Cocoa farmers themselves ($\bar{X}$=3.45, SD=1.33) and Scientists ($\bar{X}$=2.83, SD=.98) were quite optimistic on cocoa farmers ability to apply PATs. CEAs observations on cocoa farmers ability to apply PATs is noteworthy since they serve as conduit for transfer of cocoa innovation from researchers to farmers and are also on the field or ground to observe current practices of cocoa farmers. It should be noted that the high standard deviations (above 1), show that respondents, especially cocoa farmers and CEAs, were inconsistent in their level of agreements on the ease of use of PATs among cocoa farmers.

The ease of use of an innovation has been found to be important for adoption in computer-based innovation and computer self-efficacy or personal skills (Pierpaoli et al., 2013; Rogers, 2003). It stands to reason that since PATs are computer and ICT based, the perceived ease of use of PATs farmers is very crucial for future development and adoption of PATs among cocoa farmers.

Trialability of PATs among Cocoa farmers

Trialability is the degree to which an innovation may be experimented or tried on a limited basis (Rogers, 2003). In general, all stakeholders 'moderately agreed' ($\bar{X}$=3.14, SD=1.14) that PATs could be experimented on limited bases under current context and conditions of the cocoa farmers, however, stakeholders were inconsistent in their views as shown by relatively high standard deviation of more than 1 even among individual stakeholders (see Table 13). Trailability also happens to be the least agreed among the six (6) attributes or characteristics of PA innovations studied. The 'moderate agreement' of stakeholders means that stakeholders feel that to be able to try PATs, the equipment and tools, as well as farmers themselves and their farms are quite ready to experiment PATs on smaller bases before its adoption. Innovations that can be tried on the limited basis are likely to be adopted more rapidly than innovations that are not (Rogers, 2003).

Overall Technology characteristics as perceived by stakeholders

Results in Table 13 again shows that all stakeholders 'highly agreed' ($\bar{X}$=3.56, SD =.73) on the overall (6) attributes/characteristics of PATs needed for future development and adoption of PATs in cocoa production in Ghana. The positive perceptions (high agreement) of stakeholders especially cocoa farmers ($\bar{X}$=3.65, SD =.67) and Scientists ($\bar{X}$=3.58, SD =.79) on the attributes of PA innovation in cocoa industry is likely to have positive effect on the likelihoods of its adoption among cocoa farmers in Ghana. Again, it should be noted that CEAs were moderate ($\bar{X}$=2.96, SD =.84) in their agreement on the overall attributes or technology characteristics of PA innovation development and adoption in the cocoa industry in Ghana.

Differences in perceived attributes (technology characteristics) of PATs among stakeholders in Cocoa industry

Table 14 shows the results of a one way ANOVA used to determine whether statistically significant differences existed among the overall attributes of PATs innovations as perceived by major stakeholders.

Table 14

ANOVA of stakeholders' Perceived Technology Characteristics (attributes) of PA

Stakeholder	n	$\bar{X}$	SD	F	Sig
Scientists	12	3.58	.77	27.40	.000*
Cocoa Extension Agents	63	2.96	.84		
Cocoa Farmers	416	3.65	.67		

n=491 , p< 0.05. Eta-squared = .101. Scale on levels of Agreement (1= Very Low, 2=Low, 3=Moderate, 4= High, 5=Very high).

Source: Field Survey, Bosompem (2015)

Results from Table 14 showed that there were statistically significant- $F(2,487)=27.403; p=0.000$-differences among stakeholders perceived attributes of PA innovation development in cocoa industries at 0.05alpha level.

The study, therefore, failed to accept the 4th null hypothesis that stated that 'There are no significant differences among major stakeholders' (cocoa farmers, scientists and CEAs) perceived technology characteristics (attributes) of PATs". The alternative hypothesis which stated that "there significant differences among major stakeholders' (cocoa farmers, scientists and CEAs) perceived technology characteristics (attributes) of PATs" is accepted. Table 14 again showed the effect size, calculated using eta squared, to show the magnitude of the significance was 0.101 indicating a moderate to large effect using Cohen's convention as described by Cohen (1988). According to Cohen's classification, 0.01= small effect, .06= medium effect and .14 = large effect. Hence, the effect size shows that, the actual difference in mean scores among the stakeholders perceived attributes of PAT innovation is substantial and should not be ignored.

Table 15 shows Levene's test of homogeneity of variances among the three (3) major stakeholders. Levene's test was used to determine the appropriate post hoc multiple comparison to be used to determine where significant differences actually existed among the three (3) major stakeholders perceived attributes of PAT innovation since F-test showed significant differences in Table 14.

Table 15

Levene's Test of Homogeneity of Variances among major stakeholders

Levene's Statistics	Sig.
4.112	.017

$p < 0.05$ (Scientists: n=12;CEAs:n=63; Cocoa farmers: n=416)

Source: Field Survey, Bosompem (2015)

Table 15 reveals that variances that existed among the groups were significant (df =2, 487; p = .017) at 0.05 alpha level. The result is understandable since variances are greatly affected by the sample (n), and as noted earlier, the sample size for each of the three (3) major stakeholders (scientists: n=12; CEAs: n=63 and cocoa farmers: n=416) were varied (Pallant, 2013 and Tabachnick & Fidell, 2013). Tamhane's T2 was chosen as appropriate post hoc multiple comparison technique since equal variances were not assumed, and also it is more robust (Field, 2013). Hence, Tamhane's T2 was chosen for the multiple comparisons of mean differences among the major stakeholders based on the Levene's test.

Table 16

Tamhene's T2 Post Hoc Multiple comparison of stakeholders' perceived technology characteristics of PATs

Stakeholders		MD	Original Samples (n=491)		
A	B	A-B	Std. Error	Sig.	CI (95%)
Scientists	CEAs	.622	.260	.090	-0.800 – 1.324
	Cocoa Farmers	-.074	.240	.987	-0.754 – 0.606
CEAs	Cocoa Farmers	-.696*	.111	.000	-0.966 – -0.425
Bootstrapped samples (n=1000)					
Stakeholders		A-B	Std. Error	Bias	BCa-CI (95%)
Scientists	CEAs	.622*	.258	.000	0.080 – 1.124
	Cocoa Farmers	-.074	.237	-.001	-0.595 - 0.382
CEAs	Cocoa Farmers	-.696*	.112	-.002	-0.924 – -0.471

n=491, p< 0.05* MD=Mean Difference, CI = Confidence interval

Source: Field Survey, Bosompem (2015)

Table 16 shows a multiple comparison of mean perceived attributes of PAT for the three (3) major stakeholders using both the original samples and bootstrap samples of 1000. Table 16 revealed that in the original sample (n=491), there were statistically significant (sig=.000) differences between cocoa farmers' ($\bar{X}$=3.65, SD =.67) and CEAs' ($\bar{X}$=2.96, SD =.77) overall mean perceived attributes of PA at 0.05 alpha level. However, there were no statistically significant differences between scientists' ($\bar{X}$=3.58, SD =.79) and CEAs' ($\bar{X}$=2.96, SD =.84) – sig =0.09 - and between scientists' ($\bar{X}$=3.58, SD =.79) and cocoa farmers' ($\bar{X}$=3.65, SD =.67) - sig = 098 - overall mean perceived attributes of PA at 0.05 alpha level.

However, the bootstrapped sample of 1000 showed that statistically significant difference existed between scientists' ($\bar{X}$=3.58., SD =.79) and CEAs' ($\bar{X}$=2.96., SD =.84) perceived attributes of the PA at 0.05 alpha level (in addition to the difference observed in the original sample) even though the original sample showed no significant difference (*p*=.090) at 0.05 alpha level. This is because the bootstrapped confidence interval (BCa-CI (95%) of the mean difference (MD= -.696) ranges from -0.924 to -0.471. Since both the lower (-0.924) and the upper (-0.471) confidence interval are negative, it implies that the difference between means in the population could never cross the zero value i.e the bootstrapped sample does not include the value of zero effect (Field, 2013; du Prel, Hommel, Röhrig, & Blettner, 2009). In other words, it is not possible that the true difference between means is zero, since the null hypothesis tests that the true difference between means is zero. It is concluded, therefore that there is a statistically significant difference between scientists' and CEAs.

The results imply that cocoa farmers actually differed greatly (positive) on their perceived attributes of PAT development and implementation among cocoa farmers in Ghana from that of CEAs and that scientists also differed (more positive) about the attribute of the PA innovation from CEAs . The high agreement of cocoa farmers shows a positive prospect for development of PA and general acceptance of PA by cocoa farmers since about 50- 80% adoption decision or intension is driven by the attributes of innovation discussed earlier (Rogers, 1983, 1995; Moore & Benbasat, 1991).

The CEAs' moderate agreement also shows that even though cocoa farmers have high hopes and expectations on the feasibility of developing PA in cocoa, they are quite measured on their expectations so far as development of PATs in the industry is concerned.

Relationship between Farmers' Willingness to Adopt PA Technology and their Demographic, Farm-related Characteristics, Perceived Technology Characteristics of PA, and Awareness level in PA

The fifth objective was to assess the relationships between cocoa farmers' willingness to adopt PATs and their demographic, farm-related, technology-related characteristics and awareness level. However, before the relationships are discussed, Tables 17 and 18 provide the summary of the demographic and farm related characteristics respectively. The summary of the other two main independent variables- awareness level and perceived technology–related characteristics- of PA had been discussed in Tables 5 and 13 respectively.

Summary of demographic characteristics of cocoa farmers

Table 17 provides the descriptive statistics of the respondent cocoa farmers' demographic characteristics: sex, educational background, marital status, age, experience in cocoa farming and household size. It shows that the majority (about 76%) of the respondents cocoa farmers were males and about 78% have some form of formal education; however, their level of education was low since about 65% had received basic education. Moreover, about 84% of the respondents were married and with more than half (56.5%) of the respondents above 50 years ($\bar{X}$= 52 ± 13.6 years) were very experienced ($\bar{X}$= 21 ± 10.2 years) in cocoa farming. The mean household size was approximately 6 members with about 55% having more than 5 dependents.

The results on sex distribution (76% males) show that males still dominate the cocoa production in Ghana and this have been so for the past two decades. For example, a survey by Cocoa Research Institute of Ghana (CRIG) (1995) in Ashanti and Eastern regions of Ghana showed about 71% were males. Bosompem and Nunoo (2009) reported 72% male and 28% female cocoa farmers in the Brong- Ahafo region of Ghana. Anang et al. (2011) worked on Farmers' Management Practices and the Quality of Cocoa Beans in the Upper Denkyira District of Central Region, Ghana also reported 79% male and 21% female cocoa farmers, Bosompem and Mensah (2012) found 71% of 160 cocoa farmers sampled in Birim South district in the Eastern region to be males and results from Okorley et al. (2014) showed about 76% of the 140 cocoa farmers sampled in Mpohor Wassa East District in the Western region of Ghana to be males.

Table 17

Descriptive Statistics of the Demographic Characteristics of Cocoa Farmers

Variables	Categories	f	%	$\bar{X}$	SD
Sex (n=416)	Male	317	76.2		
	Female	99	23.8		
Educational Level (n=413)	No Formal	92	22.3		
	Basic	268	64.9		
	Secondary	38	9.2		
	Tertiary	15	3.6		
Marital Status	Married	349	83.9		
	Not Married	67	16.1		
Age (Years) (n=412,	<30	14	3.4	51.8	13.6
Min=22 Max=94)	30 – 39	69	16.8		
	40 – 49	96	23.3		
	50 -59	113	27.4		
	60 – 69	75	18.2		
	≥70	45	10.9		
Experience (Years n=407)	1-10	76	18.7	21.0	10.2
Min= 3, Max=54	11 -20	156	38.7		
	21-30	117	28.7		
	>30	58	14.3		
Household size (n=409)	None	4	1	6.4	3.9
	1-5	181	44.2		
	6 -10	173	42.3		
	11-15	43	10.5		
	> 15	8	2		

n= 416.

Source: Field Survey, Bosompem (2015)

The result on the educational level (78% having formal education) is almost similar to the findings of Bosompem et al. (2011b) who reported about 80% of sampled cocoa farmers in Eastern region of Ghana had formal education. Okorley et al. (2014) also found 78% of cocoa farmers in Western region had formal education even though their level of education was low (67%) having basic education (i.e. up to Junior High or Middle School level). The results also show that there have been improvement in the educational level of farmers who have formal education entering into cocoa farming over a decade ago. For example, Aryeetey (2004) reported that in the rural areas where the majority are farmers, only 29.3% of the people sampled had formal education. Dankwa (2002) and Kumi (2003) also reported that 50-55% of cocoa farmers have been found to have no formal education in the Ashanti and Eastern regions of Ghana. However, the low level of education in this study (65% with basic education) may have negative implications for potential adoption of PA among cocoa farmers (Byrness & Byrness, 1978, Gamble & Gamble, 2002)

The results on the age of farmers ($\bar{X}$=52±14 years) show that cocoa farmers are still aged with few (20%) youths (below 40 years) in the sector. Marcella (2007) also reported that most cocoa farmers in Ashanti and Brong-Ahafo regions of Ghana were aged (65-70 years). Bosompem and Mensah (2012) also found 72% of the cocoa farmers were above forty (40) years old while 26% were 40 years or below (20-40). Okorley et al. (2014) also reported a mean age of 50 years of cocoa farmers with most (79%) of them between 41 to 80 years.

Results on the farming experience of cocoa farmers ($\bar{X}$=21±10.2) clearly portray that most cocoa farmers in Ghana have adequate experience in cocoa production. The study confirms results from other studies. Bosompem et al. (2011b) reported that the mean experience of cocoa farmers was 24 years. Anang et al. (2011) also found that about 25.5% of their respondents were experienced cocoa farmers with more than 21 years in cocoa production in Central Region of Ghana. Bosompem and Mensah (2012) reported more than half of the respondents (58%) had more than 20 years cocoa farming experience and Okorley et al. (2014) found a mean of 18 years of farming experience with most (64%) of them with experience ranging between 11 to 50 years.

The mean household size of 6.4 is similar to that of Aryeetey (2004) who reported that, the mean household size in rural forest in Ghana was 6.9 a decade ago. The result is a little bit lower than the results of Bosompem (2006) who found the mean household size of nine (9) in Eastern Region of Ghana. Household size has implication for availability of labour since family labour has been found to be the most prevalent labour type in cocoa farming in West Africa and about 87 percent of the permanent labour used in cocoa farming comes from the family (IITA, 2002).

Summary of farm-related characteristics of cocoa farmers

Table 18 presents the summary of the farm-related characteristics of cocoa farmers namely: farm size under cocoa production, farm size fertilized, land ownership, land rights, row planting, quantity of fertilizer used and yield per acrea.

Table 18

Descriptive Statistics of Farm-Related Characteristics of Cocoa Farmers

Variables	Categories	f	%	$\bar{X}$	SD
Farm size under cocoa (Acres) (n=401, min=0.50, Max= 100)	≤ 5	83	20.7	12.8	13.2
	5.1 -10	162	40.4		
	10.1-15	66	16.5		
	Above 15	90	22.4		
Number of cocoa farms (n=413) min-=1, max=15	1-2	234	56.7	2.6	1.6
	3-4	140	33.9		
	≥5	39	9.4		
Farm size fertilized (Acres) (n=380, min=0.25, Max= 99)	≤ 5	182	48.3	7.8	9.9
	5.1 -10	130	34.5		
	10.1-15	42	11.1		
	>15	23	6.1		
Age of fertilized farm (years) (n=362), min= 4, Max.50)	Lessthan 10	70	19.3	18.3	8.4
	11-20	187	51.7		
	21-30	81	22.4		
	>30	24	6.6		
Amount of Fertilizer applied (bags) n=338	1-10	142	42.0	19.0	24.5
	11-20	93	27.5		
	21-30	52	15.4		
	>30	51	15.1		
Land Rights of fertilized land (n=370)	Sell out right	150	40.5		
	Otherwise	220	59.5		
Land ownership (n=403)	Inherited	266	66.0		
	Otherwise	137	34.0		
Row planting (n=399)	Yes	82	20.6		
	No	317	79.4		
Table 18, continued					
Access road to farm (n= 399)	Yes	231	57.9		
	No	168	42.1		
Access to credit (414)	Yes	103	24.9		
	No	311	75.1		
Access to credit from financial institution (n=103)	Yes	53	51.5		
	No	50	48.5		
Main source of labour (n=404)	Hired	204	51.5		
	Other sources	200	48.5		

Table 18 *continued*	Categories	f	%	$\bar{X}$	SD
Have mobile phone (n=404)	Yes	315	78		
	No	89	22		
Frequency of contact with Extension Agents (n=337)	At least once Monthly	181	53		
	Less than once month	156	47		
Current Yield of fertilized farm (bags/acre)				4.6	6.7

n= 416

Source: Field Survey, Bosompem (2015)

Land size, number of farms and age of cocoa trees

Table 18 also shows that a majority of the farmers (61%) had 10 (4.0 ha) or less acres of cocoa farm with a mean farm size of 12.8 ± 13.2 acres (5.2 ha.). However, a mean of 7.8 acres (3.2 ha) cocoa farms were fertilized even though a majority (83%) of the farmers had farm size of about 10 or less acres fertilized. Also, a little over half of the farmers (56%) had 2 cocoa farms. The mean age of the cocoa farms fertilized was approximately 18 years with about 52% of the farms aged between 11 to 20 years. The age of cocoa farms was closer to that results of Edwin and Masters (2003) who found that of the 192 farms surveyed in Ashanti and Western Regions, the mean age of cocoa trees was 20 years with a minimum and a maximum 3 and 56 years respectively. The findings of the age of cocoa trees (mean age =18 years), however, differs from that of Bosompem (2006) who reported a mean age of cocoa trees to be 24 years in the Eastern Region and about 30% of respondent cocoa farmers having trees more than 30 years. The yield of cocoa had been found to decline with age of cocoa trees even when fertilizer is applied and yields of cocoa farms are highest when trees were between 8 to 15 years old for both hybrids and traditional varieties (Edwin & Masters, 2003).

Land tenure and Access roads to cocoa farms

Most farmers (66%) inherited their land from a family member and the other 34% of the respondents either bought the land, or acquired it through sharecropping (abunu and abusa), hence, about 41% had the right to sell their land outright to others. The majority of the farmers (58%) had access roads to their farms hence farm machinery and inputs like fertilizers were conveyed easily to the farms. However, only 21% of the farmers had their cocoa trees planted in recommended rows and planting distance and anything contrary to that can retard the movements of farm machineries (e.g. tractors) and Precision Agriculture tools (e.g. VRA and Yield monitors) to those farms planted haphazardly.

Since about (66%) inherited their land and 41% of the respondents can sell their land outright, it stands to reason that they are likely to have better land rights. Antolini et al. (2015) noticed that farmers are more likely to manage their own land in a more favorable way than rented lands and have more chances to enjoy the advantages. Therefore, if farmers have highest land rights (for example if they buy or inherited), they are more likely to adopt PAT since they have the advantages of enjoying their own farm management practices and investments.

Access to credit, labour and extension services

Of the 414 respondents, only 103 representing 25% had access to credit either in kind (inputs) or in cash, hence the majority (75%) used their own resources or cash to finance their farming activities. Fifty-three (53) out of 103 respondents who had access to credit representing about 52% had the credit from financial institutions such as the rural banks and the micro finance, the rest (48%) had the credit from either LBCs , moneylenders and other family members and friends. A little over half of the respondents (52%) used hired labour in their farms but the rest used either their own, family or through "nnoboa" (cooperative) labour. About 78% of the respondents had mobile phones which were mostly analog. About 181 respondents representing 53% of the respondents had contact with cocoa extension agents at least once a month. The rest (47%) had less than one contact to the extension agents i.e. quarterly, once per six months or once per year.

In Ghana, famers in general lack access to credit including cocoa farmers. The results, however, showed that access to credit among cocoa farmers (25%) is relatively better than farmers in other crops such as cassava, maize, oil palm. For example only 2% of the farmers surveyed in West Akim district in Ghana had access to credit (Baidoo & Amoatey, 2012).

About 53% of the farmers having contact with CEAs at least once a month is quite encouraging since information on agricultural practices (including PATs) is provided by either extension services or consultants. Adopters of PATs was found to be higher among those who received information from trained extension agents or those who hired consultants (Larson et al., 2008).

The results from the study of about 52% of the cocoa farmers using hired-labour is quite similar to that of Baidoo and Amoatey (2012) who reported about 55% used hired labour on their farms. The use of hired labour has been found to have significant influence on the likely of adoption of fertilizer (Degu et al., 2000). However, since farmers pay for hired labour, if access to credit is low or not existing , adoption of PA is likely to suffer (Dormon et al., 2004).

Fertilizer application and yield of cocoa farmers

A total mean of 19 ±24 bags of fertilizer were applied with a mean of 2.5±1.9 bags/acre instead of the recommended 3 bags/acre. The yield was also 4.7 bags /acre relatively lower compared to the expected 10 bags/acre or more expected from the programme (Appiah, 2004). However, the result is similar to the findings of Bosompem et al. (2011b) who found a mean yield increase from 448.9 kg/ha (2.85 bags/acre) to 768.5kg/ha (4.9 bags/acre) from cocoa farmers 3 years (2002-2005) after the adoption of fertilizer application in the Eastern region of Ghana. Edwin and Masters (2003) had reported a relatively lower average yield (294.8 kg/ha) of farmers in the Ashanti and Western regions of Ghana.

Cocoa farmers' willingness to adopt precision agriculture in cocoa production

The results in Table 19 show that the majority (83%) of the respondent cocoa farmers were willing to adopt future PATs development in Ghana which is an indication of bright prospects of any future PATs development in Ghana since willingness to adopt or farmers intensions to adopt has been found to have a positive actual future adoption of PATs (Aubert et al., 2012)

Table 19

Cocoa Farmers Willingness to Adopt Precision Agriculture in Cocoa Production

Willingness	f	%
Willing	344	83
Not willing	70	17
Total	414	100

n=416.

Sources: Field Survey, Bosompem (2015)

Relationships between farmers' willingness to adopt PATs and their demographic and farm-related characteristics

Table 20 shows the relationship between the farmers' willingness to adopt PA technology and demographic and farm-related characteristics. The type of correlation coefficients used depended on the scale of measurement of the items or characteristics as shown in the Table 20

Table 20 shows that five (5) of the demographic and farm-related characteristics had positive and significant relationships with cocoa farmers' willingness to adopt Precision Agriculture at 0.05 alpha level. These were educational level (r_{rbi} = 0.440**), household size (rbi=.100*), access to credit (r_{φ} =.112*) , row planting (r_{φ} =.168*), access to mobile phone (r_{φ} =-.107*).

Table 20

Correlation Coefficients of Respondent Farmers' Willingness to Adopt PA Technology and their Demographic and Farm-related Characteristics

Demographic/Farm-Related Variables	Coefficient	P value	Type of Correlation
Sex (1=Male, 0=otherwise)	.093	.058	Phi (r_{φ})
Marital status (1=Married , 0=otherwise)	.082	.096	Phi (r_{φ})
Age at last birth day (Years)	-.091	.065	Biserial (r_{bi})
Educational Level	.440**	.001	Rank Biserial (r_{rbi})
Farming Experience (years)	-.062	.213	Biserial (r_{bi})
Household size/Dependents	.100*	.042	Biserial(r_{bi})
Size of land under (Acres)	-.022	.669	Biserial(r_{bi})
Land size where fertilizer applied (Acres)	-.002	.975	Biserial (r_{bi})
Access to Credit (1=yes, 0=otherwise)	.112*	.023	Phi (r_{φ})
Access to credit from financial institution	.010	.837	Phi(r_{φ})
Row planting (1=yes, 0=otherwise)	.168*	.046	Phi (r_{φ})
Access road to farm (1=yes, 0=otherwise)	.072	.154	Phi(r_{φ})
Land Ownership (1=Inherited , otherwise)	.074	.038	Phi(r_{φ})
Land Rights (1=Sell out right, 0 =otherwise)	-.0209	.000	Phi(r_{φ})
Main source of labour (1=hired, 0=otherwise)	.042	.397	Phi(r_{φ})
Amount of fertilizer applied/ acrea (bags)	-.004	.931	Biserial(r_{bi})
Yield (bags)	.007	.905	Biserial(r_{bi})
Have mobile phone (1=yes, 0=otherwise)	-.107*	.032	

n= 416 p<0.05*; p<0.01**

Sources: Field Survey, Bosompem (2015)

The positive significant relationship between willingness to adopt PATs and educational level (r_{rbi} =0.440) implies that the higher the educational level of cocoa farmers the more likely they would adopt PATs. The results agree with hypothetical and actual relationship between educational level and intension to adopt technologies (Rogers, 2003; Tey & Brindal, 2012). For example, Aubert et al. (2012) reported a positively significant relationship between formal education and adoption of precision agriculture technologies by farm operators in Canada. Walton et al. (2008) also found a positive and significant relationship between education and adoption of precision soil sampling among cotton farmers in 11 southern states of USA. Larson et al. (2008) also reported a positive significant relationship between the educational level of farmers and adoption of PA. Educational level was also found to have a positive influence on farmers' intension to adopt PATs (Adrian et al., 2005).

The results also implied that cocoa farmers who have access to credit are more likely to adopt PATs than those who do not have access to credit. Similar to the results from this study, credit availability and access have been found to have a positive relationship with adoption of PATs since PA is capital intensive (Antolini et al., 2015). Access to credit (among other factors such as farming experience, membership of farm group and output) was also found to be a significant positive predictor of the use of insecticides among cocoa farmers in the Ashanti region (Asare, 2011).

The results also implied that cocoa farmers who have relatively larger household size are more likely to adopt PATs. Household size has been found to have implication for availability of labour because family labour is the most prevalent source of labour in cocoa farming in West Africa (IITA, 2002). However, technologies that require less use of human effort (eg PATs) are likely to require less household labour and therefore, negative relationship was expected.

Again, cocoa farmers who had planted their farms in rows with the recommended planting distance are likely to adopt the PA technology than those who have not planted in rows. It would be easier to use machinery and equipment such as plough, tractors, power tillers as well as PA tools like VRAs, yield monitors, planters on farms planted on rows using the requisite planting distance (CRIG, 2010). However, there were negative relationship between cocoa farmers' willingness to adopt PATs and their access to mobile phone (r_{φ} = -.107*). This means that farmers who have mobile phone are less likely to adopt PATs apparently because the mobile receptions are relatively bad in the cocoa farms.

Relationship between cocoa farmers' willingness to adopt PATs, and their perceived technology characteristics and Awareness level of PATs

Table 21 presents the relationship between cocoa farmers' willingness to adopt PATs and their perceived attributes and awareness level of the PATs.

Table 21

Correlation Coefficients of the Relationship between Cocoa Farmers Willingness to Adopt PATs, and their Perceived Technology characteristics and Awareness level in PATs

Variables	Coefficient	P -value	Type of Correlation
Relative Advantage	.320**	.000	Biserial(r_{bi})
Compatibility	.254**	.000	Biserial(r_{bi})
Complexity (Ease of Use)	.327**	.000	Biserial(r_{bi})
Trialability	.260**	.000	Biserial(r_{bi})
Observability	.379**	.000	Biserial(r_{bi})
Voluntariness	.160**	.004	Biserial(r_{bi})
Awareness of PA information/Data	-033	.566	Biserial(r_{bi})
Awareness of PA Technology /Tools	-.149*	.046	Biserial(r_{bi})
Awareness of Management of info.	.123	.773	Biserial(r_{bi})

n= 416 p<0.05*; p<0.01**

Sources: Field Survey, Bosompem (2015)

Results from Table 21 show that cocoa farmers' willingness to adopt PATs had positive and significant relationships with all the six (6) perceived attributes/ technology characteristics of PATs of innovation at even 0.01 alpha level.

The relationship with the three (3) of the attributes- Relative Advantage (r_{bi}=.320), Ease of Use (r_{bi} =.327) and observability (r_{bi} =379**) -was moderate while that with the other three (3) - Compatibility (r_{bi},=.254), Trialability (r_{bi} = .260) and Voluntariness (r_{bi} .160)-was low using Davis' convention.

Relationship between relative advantage and willingness to adopt PATs

The positive and significant relationship between cocoa farmers' willingness to adopt PATs and relative advantage (r_{bi}=.320) means that cocoa farmers who perceived that the PATs have relative advantage over their current practice were more willing to adopt PATs than those who do not.

The findings agree with the theorized relationship between relative advantage and willingness to adopt innovation in general and also in empirical studies in PATs (Rogers, 2003). For example, perceived usefulness (relative advantage) had been found to have a positive significant relationship with decision to adopt PATs among cereal farmers in Quebec, Canada (Aubert et al., 2012). A positive relationship was also reported between perceived usefulness and intension to use mobile wireless technology adoption which is integral part of PATs adoption (Kim & Garrison, 2009). Although Walton et al. (2008) found a positive but no significant relationship between adoption and income of farmers, perceived profitability (a measure of relative advantage) was a significant predictor of adoption of PATs.

Relationship between compatibility and willingness to adopt PATs

The positive significant relationship between willingness to adopt PATs and compatibility (r_{bi},=.254), means that cocoa farmers who perceived that PATs would be more compatible with their current technologies are more likely to adopt PATs than those who do not.

The results again agree with the theorized relationship between willingness to adopt innovation in general and empirical studies in PATs. According to Rogers (2003), the more an innovation meets the felt needs of potential adopters, the faster its rate of adoption. Compatibility has been found to be a positive and significant predictor of perceived usefulness (relative advantage) of PAT and by extension with intension to adopt PATs (Aubert et al., 2012).

Relationship between ease of use and willingness to adopt PATs

The positive and significant relationship between cocoa farmers' willingness to adopt PATs and ease of use (r_{bi} =.327) means that cocoa farmers who perceived that the PATs are relatively free from effort would be more likely to adopt PATs than those who do not. Conversely, cocoa farmers who perceived PATs as complex are less likely to adopt future PATs.

The results agree with the theorized l relationship between willingness to adopt innovation in general and empirical studies in PATs (Rogers, 2003). This is important to PATs development in cocoa industry in Ghana since ease of use of an innovation has been found to be important for adoption in computer-based innovation and computer self-efficacy or personal skills like PA (Pierpaoli et al., 2013; Rogers, 2003).

Aubert et al. (2012) reported the perceived ease of use had direct relationship with the adoption of PATs among farmers in Canada. Perceived ease of use has also been found to have indirect relationship with intension to adopt PAT, mediated by perceived net adoption (Adrian et al., 2005). Perceived ease of use can be influenced by other factors such as education level of farmers, farmers' previous experience with PA tools, availability of technical support or presence of experts, and possibility of trial period with PAT by farmers and these also have positive relationship with intension to adopt (Pierpaoli et al., 2013).

Relationship between trialability and observability and, willingness to adopt PATs

Both trialability and observability had positive relationship with willingness to adopt PATs. As expected in both cases, trialability of an innovation, as perceived by the farmers, is positively related to its rate of adoption. However, trying an innovation may result in re-inventing – customizing it more closely to the individual's adopter needs which can be positive or negative to the adoption and use of the original technology (Rogers, 2003). Trialability was negatively related to adoption of PATs among farmers in Canada (Aubert et al., 2012). According to Rogers (2003), the observability of an innovation, as perceived by potential adopters, is positively related to its rate of adoption and the findings are in line with Rogers' (2003) assertion.

Relationship between voluntariness and willingness to Adopt PATs

The positive and significant relationship between cocoa farmers' willingness to adopt PATs and Voluntariness ($r_{bi} = .160$) means that cocoa farmers who perceived that the PATs application among cocoa farmers must be less free from will, the more likely they would be willing to adopt PATs and vice versa. The result from the study is contrary to theorized and empirical relationship between intention to adopt and level of voluntariness which is expected to have negative relationship with willingness to adopt ICT (Agarwal & Prasad, 1997) since perceived voluntariness has been found to reduce the pressure of acceptance of innovation. Empirically, Aubert et al. (2012), confirmed that voluntariness had a negative and significant relationship with adoption of PATs among farmers in Quebec, Canada.

Relationship between awareness level and willingness to adopt PATs

The last three rows in Table 21 show the relationship between cocoa farmers' awareness level in the three (3) main components of PA -information or data base, technology or tools and management - and their willingness to adopt PATs. Of the three (3) main components, only their awareness level in the technology or tool component ($r_{bi} = -.149$*) of PA that had significant and negative relationship with their willingness to adopt PATs at 0.05 alpha level.

The negative relationship implies that the cocoa farmers who were more aware of the technology or tool component of PA are less likely to adopt future PATs.

This is contrary to the expectation since farmers' awareness level is expected to have a positive relationship with their willingness to adopt PATs PA (Watkins et al., 2008; Morgan & Ess, 2003; Forouzanmehr & Loghavi, 2012). Since the technology or tools component includes relatively sophisticated equipment such as GPS receivers, GIS, VRAs (which can be aircraft-based), yield monitors etc., it stands to reason that the more the farmers are aware of these tools, the less they may think that the use of these tools are feasible in their cocoa farms and the less likely they may be willing to adopt the PATs. In other words, those farmers who are aware of such tools may be sceptical about the feasibility of using those equipments on their farms. This is not surprising because even some advocates (including researchers and scientists) were sceptical about whether PA would be feasible for small scale farmers despite the proven empirical evidence that PATs are feasible even among small scale farmers in a number of Asian countries (Shibusawa, 1999 ; Mandal & Maity, 2013).

Summary of the correlations

In all 12 out of the 28 independent variables had some significant relationship with cocoa farmers' willingness to adopt PATs. The study therefore, fails to accept the 5th null hypothesis that stated that 'There is no significant relationships between demographic, farm-related, technology related factors, and awareness level of cocoa farmers and their willingness to adopt

PATs. The alternative hypothesis is therefore accepted since at least 12 of the independent variables had significant relationship with willingness to adopt PATs.

Multicollinearity Diagnostic Test

Multicollinearity diagnostic test was done to see if there is a strong correlation between two or more predictors which could bias the regression estimates. Tolerance and Variance Inflation Factor (VIF) was used. Both tests show whether a predictor has a strong linear relationship with the other predictor or predictors (Field, 2013**)**.

Results in Table 22 show the minimum and maximum tolerance and VIF observed in estimate (see Appendix K for individual values of VIF and Tolerance for all 28 predictors).

Table 22

Collinearity Diagnostics Test showing VIF and Tolerance values

Measure	Minimum	Maximum
VIF	1.003	3.536
Tolerance	0.283	0.998

n=417. *p*>0.05. *Factor (VIF) =Variance Inflation Factor*

Source: Field Survey, Bosompem (2015)

Both the VIF and Tolerance values in Table 22 show that there is no significant multicollinearity that could bias the subsequent regression estimates.

The minimum and the maximum tolerance value were 0.283 and 0.988 respectively is more than 0.10. Tolerance value less than 0.10 indicates possibility of multicollinearity. The minimum and the maximum VIF values of 1.0 and 3.5 respectively is far less than 10 indicating no significant multicollinearity since VIF greater than 10 shows significant concern for multicollinearity (Pallant, 2011; Field, 2013).

Best Predictor(s) of Cocoa Farmers' Willingness to Adopt PATs in Ghana

Specific objective six (6) was to identify that best predictor(s) cocoa farmers' willingness to adopt PATs from the following independent variable Binary logistic regression was performed to assess the impact of a number of factors on the likelihood that respondent cocoa farmers would adopt any future PATs introduced in cocoa production in Ghana. The model contained about 28 independent variables.

The results of the Hosmer-Lemeshow Goodness of Fit Test and the chi-square of the Omnibus tests of model coefficients was statistically significant (p=0.000), even at .001 alpha level indicating that the model was able to distinguish between respondents who are willing to adopt and those who are not willing to adopt any future PATs introduced in cocoa production (Table 23).

Table 23

Binary Logistic Regression Showing the Best Predictors of Cocoa Farmers' Willingness to Adopt PATs in Ghana

Predictors	B	S.E.	Wald	Sig.	Odds Ratio	95% C.I. for odd Ratio
Constant	-5.542	3.313	2.798	.094	.004	
Educational Level	-3.994	1.860	4.61	.032	.018	.00 - .71
Credit from financial institution	2.899	1.327	2.06	.047	1.38	.10 -18.66
Row planting	3.995	1.636	5.96	.015	54.30	2.20 -134.5
Relative Advantage	1.176	.423	7.73	.005	3.242	1.42 - 7.43
Ease of Use	.787	.294	7.16	.007	2.196	1.23 - 3.91

Model Summary

	Value	Sig	-2 Log likelihood
Cox Snell R- Square	0.375		81.96
Nagelkerke R- Square	0.604		
Omnibus test of model Chi- square	77.052	0.000	
Hosmer and Lemeshow Test	2.195	.974	

n=417. *p*>0.05. CI=Confident interval

Source: Field Survey, Bosompem (2015)

The model summary in Table 23 shows that the model as a whole (with 28 variables) explained between 37.5% (Cox and Snell R square) and 60.4% (Nagelkerke R squared) of the variances in cocoa farmers' willingness to adopt any future PATs (see Appendix L for the model containing all the 28 predictors). Of the 28 predictors in the equation, only five (5) of them made a unique statistically significant contribution to the model at 0.05 alpha level as shown in Table 23. These best predictors were (a) educational level of cocoa farmers, (b) row planting, (c) credit from financial institution, (d) relative advantage of PATs, and (e) the perceived ease of use (complexity) of PATs.

Educational level as a predictor of cocoa farmers' willingness to adopt PATs

Educational Level was the only demographic characteristics found to be significant but negative predictor (β= -3.994) of cocoa farmers' willingness to adopt PATs. This implies that farmers who had higher level of education are less likely to adopt PATs in Cocoa production. In other words, the lower the educational level of respondents, the more likely they were willing to adopt any future PATs. The odds ratio of 0.02 (less than 1) also indicate that for every additional level of education, respondents were .02 times less likely to adopt future PATs.

The result from the study is contrary to the theorized expectations and almost all the adoption studies in PATs reviewed. For example, Aubert et al. (2012) found formal education as a positive predictor of PATs in Canada. Walton et al. (2008) also found a positive and significant relationship between education and adoption of precision soil sampling among cotton farmers in 11 southern states in USA. Adrian et al. (2005) also found educational level as a positive predictor of farmer's intension to adopt PAT. This negative relationship observed may be as a result of how educated farmers perceived the enormous challenges that need to be surmounted before PA become a reality in Ghana. This is possible because, Gamble and Gamble (2002), opined that sometimes, high level of education can become a barrier rather than a facilitator or aid to communication and by extension adoption since educated farmers may be skeptical about the feasibility of PATs development in Ghana. Many PA advocates (researchers with higher level of education) are even sceptical about whether PA is feasible for small scale farmers despite the proven empirical evidence that PATs are feasible even among small scale farmers in a number of Asian countries (Shibusawa, 1999 ; Mandal & Maity, 2013).

Row planting as a predictor of cocoa farmers' willingness to adopt PATs

Row planting was one of the two farm-related factors that was found to be significant (positive) predictor (β=3.995) of cocoa farmers' willingness to adopt precision agriculture (Table 23). This implies that farmers who had planted cocoa trees in rows are likely to adopt future PATs in Cocoa production in Ghana. The odds ratio showed that the strongest predictor of farmers' willingness to adopt any future PATs was "row planting" (odd ratio= 54.30). The odd ratio of 54.30 indicate that respondents who had planted their cocoa trees in rows are over 54 times more willing to adopt any future PATs in cocoa production in Ghana, controlling for all other factors (predictors) in the model. This gives an indication that farmers who had already planted in rows are more likely to adopt PA technology than those who had not yet done so. However, most farms in Ghana are not generally planted in rows using the recommended planting distance of 3m x 3m (10ft x 10 ft) spacing (CRIG, 2010). Only about 21% of respondent cocoa farmers (see Table 18) reported that they planted in rows. This has implication for movement of PA machinery and equipment such as tractors and VRAs.

Source of credit as a predictor of cocoa farmers' willingness to adopt PATs

Another farm-related factor that was found to be a significant (positive) predictor (β=2.899) of respondents' willingness to adopt precision agriculture was cocoa farmers access to credit from financial institutions. The odd ratio of 1.38 indicate that respondents who had credit from financial institutions (eg. banks, MFIs etc.) are about one and a half times more likely to adopt any future PATs in cocoa production in Ghana than those who received credit elsewhere (e.g friends, family, moneylenders and even own source), controlling for all other factors (predictors) in the model. It is noteworthy however that, whether farmers had "access to credit or not" itself was not a significant predictor of their willingness to adopt. Hence, for those who have access to credit, if the source is from financial institutions then they are likely to adopt future PATs in cocoa production.

The findings are contrary to assertions of Swinton and Lowenberg-Deboer (2001) that availability of financial capital irrespective from the source (either from farmers' own resources or credit from other sources) is expected to have positive impact on adoption. A tentative explanation to the source of credit (in this case from financial institutions) being important determinant of future adoption of PATs is that because PA is capital intensive, credit or finance from financial institutions could provide adequate funding for successful implementation of PA than other sources from friends, money lenders and even farmers' own source since the later source may not be able to provide adequate funding to support PAT development. Nevertheless, credit availability and access have been found to have a positive relationship with adoption of PATs since PA is capital intensive (Antolini et al., 2015).

Relative advantage as a predictor of cocoa farmers' willingness to adopt PATs

Relative advantage **(p**erceived usefulness) of PATs was one of the two technology-related factors that was positive (β=1.176) and significant predictor of cocoa farmer' willingness to adopt precision PATs with the odds ratio of 3.242. This implies that respondent cocoa farmers perceived PATs as being better than their previous technologies and they are likely to adopt future PATs in Cocoa production in Ghana. This result is significant for the prospects of PAT development and adoption of cocoa in Ghana since the degree of relative advantage has been expressed in economic profitability and social prestige (Rogers, 2003).

The results also agree with other research findings. For example, perceived usefulness or relative advantage had been found to have a positive significant impact on farm operators' decision to adopt PAT among cereal farmers who adopted GPS,GIS, yield monitors, yield maps, remote sensing ,VRA and navigation systems in Quebec (Aubert et al., 2012). Also Kim and Garrison (2009) reported a positive relationship between perceived usefulness and intension to use mobile wireless technology adoption which is an integral part of PATs adoption (Kim & Garrison, 2009). Walton et al. (2008) also found that perceived profitability (relative advantage) was a positive significant predictor of adoption of PATs.

Ease of use and cocoa farmers' willingness to adopt PATs

The perceived ease of use (complexity) of PATs was the other technology-related factor that was positive (β=.776) and significant predictor of cocoa farmers' willingness to adopt future PATs with the odds ratio of 2.196. This implies that respondent cocoa farmers who perceived PATs as being easier than their previous technologies are more likely to adopt future PATs in cocoa production in Ghana. The findings are at par with other findings. For example, Aubert et al. (2012) reported that 'perceived ease of use' was a significant and positive predictor of the adoption of PATs among farmers in Canada. Also 'perceived ease of use' has also be found to have indirect relationship with intension to adopt PATs, mediated by perceived net adoption (Adrian et al., 2005).

Since respondent cocoa farmers viewed the PATs to be "moderately complex", it is likely to affect the rate of its adoption when even implemented in cocoa production in Ghana. Secondly, since ease of use (complexity) of an innovation has been found to be important for adoption in computer-based innovation and computer self-efficacy (Pierpaoli et al., 2013; Rogers, 2003) like PATs, it stands to reason that adoption of PATs by cocoa farmers' may also largely depend on their self-efficacy as far as their abilities to use computer and its related peripherals are concerned.

It is noteworthy that the two (2) of the six (6) technology characteristics that significantly predicted willingness or intension to adopt PATs, i.e. Relative advantage (Perceived Usefulness) and Complexity (Perceived Ease of Use) were also the same significant two factors that the Technology Acceptance Model (TAM) by Davis (1989) posited as significant for intension to adopt and final adoption of Information technology (IT) innovations.

Unique Observation of Changes of Signs of Two (2) Independent Variables during the Correlation and Regression Analysis

Table 24 shows unusual changes of the sign of two independent variables during the correlation and regression analysis. Table 24 shows that the relationship between willingness to adopt PATs (dependent variable) and each of these two variables (educational level, and perceived voluntariness) was positive (+) during correlation analysis. However, during the regression analysis, the beta coefficients of these two independent variables changed to negative (-).

Table 24

Positive Correlation but Negative Beta Coefficient in Regression

Independent Variable	Correlation		Regression	
	Coefficient	Sign	Beta	Sign
Educational level	.440**	+	-3.994*	-
Voluntariness	.160**	+	-.220	-

n=417. *p*>0.05* *p*>0.01**

Source: Field Survey, Bosompem (2015)

This observation is unusual because in most cases the sign of the relationship between the dependent variable and an independent variable observed during correlation analysis does not change during regression analysis. Even though the situation is unusual, it is possible. According to Pearl (2014), Edward H. Simpson first addressed this phenomenon (later called Simpson Paradox) in a technical paper in 1951, even though Karl Pearson in 1899 and Udny Yule 1903 had mention these phenomenon earlier. In these three instances, the reported associations disappeared rather than reversing sign. According to Pearl (2014), sign reversal was first noted by Cohen and Nagel in 1934 but it was Blyth in 1972 who labeled the reversal “paradox” because the surprise at that time seems paradoxical. Simpson’s Paradox refers to “a phenomenon whereby the association between a pair of variables (X,Y) reverses sign upon condition of a third variable , Z, regardless of the value taken by Z" (Pearl, 2014, p 1).

One of the reasons attribute to the reversal is that regression gives coefficients while controlling for the other independent variables. However, simple correlation coefficients do not control for the other variables and, therefore, the signs could change. Also, other independent variable can suppress others – a situation known as "Suppression" (Darmawan & Keeves, 2006). Accordingly, Pearl (2014) proved that the reversal could be attributed to causal interpretation of the regression models and that correlations do not mean causation. Hence, in such situations, the signs of the regression are trusted more than that of the correlation because of the causal power of regression.

The results from Table 24 suggest that the negative signs of educational level and voluntariness in the regressions analysis actually show negative impacts of these two variables on cocoa farmers' willingness to adopt PATs in cocoa production. The implications of the negative impact of educational level on farmers' willingness to adopt PATs have already been discussed in the logistic regression analysis in Table 23. However, that of voluntariness was not discussed because it was not a significant predictor. Though not significant, the reversal sign of negative in the regression analysis agrees with the theoretical and empirical relationship between adoption and voluntariness which have been found to be negative (Agarwal & Prasad, 1997; Aubert et al., 2012). The reason for the negative relationship has been attributed to the fact that perceived voluntariness reduces the pressure of acceptance of innovation, hence its subsequent adoption.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter presents the summary, conclusions and recommendations of the study. Summary of the results and conclusions have been organized based on the specific objectives and the hypotheses of the study. This section also presents suggested areas for further research.

Summary

Concerns of climate change and environmental sustainability have resulted in the general consensus among many agricultural development practitioners worldwide that, agricultural goals must not focus on increase in productivity alone but also prevent soil erosion, reduce pesticide and fertilizer contamination, protect biodiversity, and preserve natural resources and other relevant climatic indicators in order to improve well-being. One of the major emphases in cocoa production in Africa and especially in Ghana recently is to mitigate and adapt to the harmful effects of agrochemical residuals in cocoa production as well as produce quality cocoa to meet international regulations and legislations. Studies have shown that the climate change impact on future cocoa production in West Africa including Ghana would be significant and worse; hence there is the need to develop new technologies among others to minimize these predicted impacts. Precision Agriculture (PA) has been identified as one of the emerging technologies to have the potentials of addressing two major problems: (a) increase agricultural productivity and (b) mitigate and adapt to some climate change effects on cocoa production.

Precision Agriculture is a highly mechanized and information and technologically based agriculture production system that emphases site- specific application of inputs to achieve high and optimum productivity as well as environmental sustainability though judicious use of inputs. To achieve these, PA combines innovations such as geographic information system ***(***GIS), global positioning system (GPS), variable rate application (VRA) and yield monitors among others in farming.

Because of the aforesaid benefits and potentials, farmers in developed countries have been using PA technologies for over two decades now. However, their use is limited in Sub-Saharan Africa including Ghana even though the use of GPS, which is the cornerstone of PA, is readily available in almost all the countries in Africa. Moreover, the potentials for developing and implementing PATs and practices have not been fully assessed in major crops (including cocoa) in Ghana. Also, the identified major areas of challenges that PA must address before it can be successfully developed and implemented have not been fully assessed in the major crops including cocoa in Ghana. Again, some critical factors (e.g. stakeholders' level of awareness, knowledge level, and perceived attributes of PATs) necessary for future development and adoption of PATs among cocoa farmers in Ghana have not been fully examined.

The general objective of the study was to examine the prospects and challenges of developing and implementing PATs in cocoa production in Ghana. Specifically, the study sought to : (a) compare the awareness level of major stakeholders in cocoa production of PATs, (b) compare the perceived level of knowledge of scientists and CEAs on PA technologies, principles and practices, (c) identify scientists' and CEAs' perceived challenges and prospects anticipated in PA development in cocoa production in Ghana, (d) compare perceived attributes of PATs as perceived by major stakeholders in cocoa industry, (e) explore the relationships between independent variables and cocoa farmers' willingness to adopt PATs, and (f) identify best predict(s) of cocoa farmers' willingness to adopt PATs.

Correlational research design was used for the study. There were three (3) main sets of target population: (a) all cocoa farmers (N=143546) who adopted the CHTP since 2014 in the seven (7) cocoa growing regions, (b) all CEAs the cocoa regions in Ghana (N=200), and (c) all researchers (scientists) involved in cocoa researches (N=35) from GRIG. A multistage sampling was employed to sample 422 and 140 cocoa farmers and extension officers respectively; however, a census of all the scientists was taken. Content validated questionnaires (for scientists and CEAs) and structured interview schedule (for cocoa farmers) were used for data collection. Results were analyzed using measures of central tendency and dispersion, frequencies and percentage distributions, one way ANOVA, post-hoc multiple comparison, independent sample t-tests, correlation coefficients, and logistic regression. The summary of major findings in relation to the specific objectives of the study is as follows:

Awareness level of major stakeholders of precision agriculture

Stakeholders' awareness levels were assessed based on the three (3) main components of PA namely, (a) Information or data base, (b) Technology or tools, and (c) Management components. The level of awareness of the scientists on the information or data component was high, that of CEAs was fair, and that of cocoa farmers was low. Scientists perceived that their level of awareness of the technology or tools component was high, but that of both CEAs and cocoa farmers was fair. There was an exception of one of the sub-components of the technology or tool component (GPS receiver) that all stakeholders were much aware of its use. On the management component, both scientists and CEAs perceived that their levels of awareness were fair while that of cocoa farmers was low.

Scientists perceived that their overall awareness level in PA was high; that of CEAs was fair, while that of cocoa farmers was low. A one way ANOVA conducted to determine any significant difference among the stakeholders' awareness of the PA innovations revealed that there were statistically significant differences between their awareness levels. The effect size showed that the magnitude of the significance among stakeholders' awareness levels was moderate. A bootstrapped post hoc multiple comparison revealed that statistical significant differences actually existed between the awareness level of scientists and CEAs, scientists and farmers, and CEAs and farmers. This implied that the level of awareness of scientists was high followed by that of CEAs, and cocoa farmers being the least aware of PA innovations.

Knowledge level of scientists and cocoa extension agents in PA

The knowledge levels of scientists and CEAs were assessed based on the three (3) main components of PA namely (a) Information or data base, (b) Technology or tools, and (c) Management components. Both scientists and CEAs perceived that they have fair knowledge in both the information or data and the technology or tools components of PA. However, their levels of knowledge in the use of GPS receivers – a sub component of – technology or tools component – was good and relatively higher than all the subcomponents. The level of knowledge in the third component (the management and decision support from implementing PA in cocoa) was perceived by both scientists and CEAs to be poor or low. However, the overall perceived knowledge levels of scientists and CEAs in PA innovations was fair.

An independent t-test confirmed that there were no significant differences between the knowledge level of scientists and CEAs in the cocoa sector in PA innovations. Hence, their knowledge levels in PATs are the same.

Challenges and prospects anticipated in PATs development in cocoa industry in Ghana

Eight (8) main challenges to PAT development and implementation examined were economic, time, educational/training, technical, data quality, farmer/operator demographics, environmental, and political/governmental challenges. Generally, both scientists and CEAs perceived that five (5) of the challenges (farmer demographic characteristics, economic, educational, environmental and technical) would be substantial in militating against any future development of PATs in cocoa industries in Ghana, whereas three (3) of the challenges (time, data quality, and political) would be moderate. However, the greatest perceived challenge to PAT development and implementation was farmer demographic characteristics. This was followed by environmental, educational, economic and technical challenge. The perceived challenges in these five areas (farmer demographic characteristics, economic, educational, and environmental) being substantial imply that the prospects of developing PA in these areas is low. Conversely, they perceived moderate challenges in these three (3) areas (time, data quality and political) were moderate which also implied that the prospects are moderate.

The most important farmer demographic characteristics perceived to pose greatest challenge to PATs development and adoption in cocoa industry were, age of farmers, farmers' low level of education, farmers' lack of computer knowledge, and subsistence farmers with low income.

The most important environmental challenges reported to pose substantial challenge to PAT development and adoption were lack of accessible road to farms, vegetation (mostly forest/trees) posing a challenge to the movement PA tools, and undulating nature of topography of cocoa lands.

Educational challenges perceived to pose substantial challenges to PAT development and implementation in Ghana were: lack of farmers awareness and basic knowledge of PATs, lack of effective advisory service, lack of local experts on PA, lack of extension personnel knowledgeable in PATs, lack of PA topic consideration in educational institution, and lack of adequate training resources.

The most important economic challenges perceived to pose a challenge to PA were high initial cost of investments, very expensive PA equipment, and accessibility of funds, high consultancy and rental fees, and uncertainty of PA's returns on investments. Moreover, lack of PA research centre in Ghana, low mechniasation level on cocoa farms, and unreliable internet connectivity were the most important technical challenges, perceived to pose substantial challenge to PA development.

Scientists' and CEAs' perceived that the overall challenges to PATs development and implementation would be substantial and there were no significant difference between their perceived challenges anticipated in the development and implementation of PATs in cocoa industry in Ghana. This means that the overall prospect is rather low.

Attributes (technology characteristics) of PATs development as perceived by major stakeholders in cocoa industry in Ghana

The major stakeholders (cocoa farmers, CEAs, and scientists) had high conviction that PA would have relative advantage over cocoa farmers' current practices in Ghana, however**,** they moderately agreed that the other five (5) attributes or technology characteristics (compatibility, complexity, trialability, and observability and voluntariness) of the PA innovation.

Cocoa farmers and scientists highly agreed on the overall attributes of the PA innovations whiles CEAs moderately agreed on the technology characteristics. A one way ANOVA confirmed that there were significant differences between their perceived attributes of innovation studied. A post hoc multiple comparison revealed that the significant differences existed between scientists' and CEAs', farmers and CEAs but not between scientists and cocoa farmers.

Relationship between cocoa farmers' willingness to adopt PATs and their demographic, farm-related characteristics, perceived technology characteristics of PA, and awareness level in PA

The majority (83%) of the sampled cocoa farmers were willing to adopt future PATs.

Two demographic characteristics of farmers had significant (positive) relationships with cocoa farmers' willingness to adopt precision agriculture. These were educational level (r_{rbi} = 0.440**) and household size (rbi=.100*) of cocoa farmers.

Access to credit (r_{φ} =.112*) and row planting (r_{φ} =.168*) were two (2) farm-related characteristics that had significant and positive relationship with cocoa farmers' willingness to adopt future PAT development in Ghana. However, there were negative relationships between cocoa farmers' willingness to adopt PATs and their access to mobile phone (r_{φ} = -.107*) and awareness (r_{bi} = -.149*) level of the technology or tool component of PA.

Cocoa farmers' willingness to adopt PATs had positive and significant relationship with each of the six (6) perceived attributes of PATs innovation [(relative advantage (r_{bi}=.320), ease of use (r_{bi} =.327) and observability (r_{bi} =379**), compatibility (r_{bi} =.254), trialability (r_{bi} = .260) and voluntariness (r_{bi} =.160)].

Best predictor(s) of cocoa farmers' willingness to adopt PATs in Ghana

Only five (5) of the 28 predictors were statistically significant to cocoa farmers' willingness to adopt future PATs. These were educational level of cocoa farmers, row planting, and credit from financial institutions, relative advantage of PATs, and the perceived ease of use of PATs. However, the model as a whole (with 28 variables) explained between 37.5% and 60.4% of the variances in cocoa farmers' willingness to adopt any future PAT development.

Educational level of cocoa farmers emerged as a negative significant predictor of cocoa farmers' willingness to adopt PATs whereas the other four (4) significant predictors (row planting, and credit from financial institutions, relative advantage of PATs, and the perceived ease of use) were positive.

Row planting emerged as the overall best predictor of cocoa farmers' willingness to adopt PATs and farmers who planted in roles were over fifty-four (54) times more likely to adopt any future PATs.

The study also observed unusual change of signs of two independent variables (educational level and perceived voluntariness) from positive during correlation analysis to negative during regression analysis.

Conclusions

The following conclusions were drawn from the findings based on the specific objectives and the findings:

The awareness level of scientists in each of the three (3) main components of the PA (information or data base, technology or tools, management components) as well as the PA innovation as a whole was, highest followed by that of CEAs with cocoa farmers being least aware of PATs among the three major stakeholders in the cocoa industry in Ghana.

Scientists and CEAs have fair knowledge in both the information or data and the technology or tools components of PA, but poor knowledge in management and decision support component necessary for development and implementation of PA innovations in cocoa industry in Ghana. An exception was the use of GPS receivers – a cornerstone of PATs development and implementation - where their knowledge level was high. Both scientists and CEAs have fair knowledge in PA innovations as whole.

The five (5) most important challenges expected to have significant impact against any future development of PATs in cocoa industry in Ghana are (a) farmer demographic characteristics, (b) economic, (c) educational, (d) environmental, and (e) technical, with farmers' demographic characteristics expected to be the greatest. The farmers' demographic factors expected to militate against the PATs adoption in cocoa industry are age of cocoa farmers, farmers' low level of education, farmers' lack of computer knowledge, and subsistence nature of farms. Both scientists and CEAs believe that the challenges to future precision agricultural technologies development and implementation in cocoa production in Ghana would be substantial; hence the prospects would be rather low.

Lack of accessible road to farms, undulating nature of topography, and vegetation (mostly forest/trees) of cocoa lands are the most important environmental challenges that must be addressed in the quest to make PA reality. Lack of cocoa farmers' awareness and basic knowledge of PATs, lack of effective advisory service, lack of local experts in PA, lack of extension personnel knowledgeable in PATs, and lack of PA topic consideration in educational institution are significant educational challenges that must be addressed to make PATs development in Ghana a reality. Economic challenges to future PATs development and implementation in cocoa industry in Ghana are high initial cost of investments, very expensive PA equipment, and accessibility of funds, high consultancy and rental fees, and uncertainty of PA's returns on investments. Moreover, lack of PA research centre in Ghana, low mechnisation level on cocoa farms, and unreliable internet connectivity are the technical challenges.

Stakeholders (scientists, CEAs and cocoa farmers) are highly confident that PATs development in cocoa industry would be advantageous over cocoa farmers existing technologies, however, they are not too sure whether the other five (5) attributes (compatibility, complexity, trialability, and observability and voluntariness) of PA innovation could be a reality in cocoa industry in Ghana as a results relatively low current mechanization practices of cocoa farmers in Ghana.

All the stakeholders have high conviction that PATs would (a) be more profitable than the existing cocoa technologies, (b) improve cocoa farmers' social prestige, (c) be most effective means of achieving optimum productivity and environmental sustainability compared to current practices of cocoa farmers in Ghana. Scientists and cocoa farmers have high confidence of the potential of attributes of PATs innovations development in cocoa industries in Ghana whiles CEAs are not too sure of PA potentials. Hence, scientists and cocoa farmers differ significantly from the CEAs perceived attributes (technology characteristics) of PA.

The majority of cocoa farmers (83%) were willing to adopt PATs indicating rather positive prospects for PATs development from cocoa farmers' perspectives. Cocoa farmers with higher educational level and have relatively larger household, who have access to credit are more likely to adopt future PATs than those who do not. Also, cocoa farmers who had planted their farms in rows with the recommended planting distance are more likely to adopt the PATs than those who have not since it would be easier to use PA tools in their farms. However, cocoa farmers who have access to mobile phones are not likely to adopt PATs since the network receptions are rather poor in cocoa growing areas. On the other hand, cocoa farmers who are more aware of the technology or tools component of PA are less likely to adopt PATs as the results of the sophisticated nature of PA tools. Cocoa farmers who perceived that PATs have relative advantage over their currently practice are more likely to adopt PATs than those who do not and vice versa. Cocoa farmers who perceived that PATs to be more compatible with their currently technologies are more likely to adopt PATs than those who do not and vice versa. Cocoa farmers who perceived PATs as more complexity are less likely to adopt any future PATs. Cocoa farmers who perceived the PATs are triable and observable are more likely or willing to adopt PATs than those who do not and vice versa.

The best predictors of cocoa farmers' willingness to adopt any future development of PATs are educational level of cocoa farmers, row planting, and credit from financial institutions, relative advantage of PATs, and the perceived ease of use of PATs. These predictors significantly explained between 38% to 60% variances in cocoa farmers' willingness to adopt any future PATs development. Row planting was the overall best predictor of cocoa farmers' willingness to adopt any future PATs development. Educational level has negative impact on any future adoption of PATs, as a result, of the reality of challenges they perceived in PATs development in Ghana. Cocoa farmers' access to credit from financial institutions would facilitate their adoption of PATs among farmers. Perceived relative advantage (perceived usefulness) and ease of use of PATs have positive impact on cocoa farmers willingness to adopt PATs. The study does confirm the Technology Acceptance Model (TAM) by Davis (1989) that posited that only these two (2) attributes are significant predictors of adoption of IT-related innovations.

The study also observed unusual change of signs of two independent variables (educational level and perceived voluntariness) from positive during correlation analysis to negative during regression analysis. This unusual but possible observation could be attributed to 'Simpson paradox' and 'suppression' emphasizing the need to trust the signs of regression coefficient more than that of the correlation. Hence, the study concluded that perceived voluntariness has negative impact on cocoa farmers' willingness to adopt PATs as opposed to the positive relationship observed in the correlation analysis.

Recommendations

Based on the conclusions of the study, the following recommendations were made for consideration to make PA innovation development in cocoa industry in Ghana a reality:

1. Cocoa research institute of Ghana (CRIG), in collaboration with cocoa health and extension division (CHED) of Ghana and private GIS operators in Ghana (e.g. Syecomp Business Services Ltd), should create awareness among farmers and CEAs on PA tools and practices. The focus should not be restricted to the use of GPS receivers and its use in measuring farms but also on other uses of these receivers as well as data and information necessary for PA to be a reality in the cocoa industry in Ghana.
2. CRIG should set up a unit for PA research to champion research into PA technology and practice in cocoa industry. Such researches should take into consideration the environmental factors such as soil type, vegetation and

topography of arable cocoa lands in Ghana. On-station trials of PATs should begin with these units and later on-farm trials replicated on farmers' farm. The unit can also take the lead in organizing workshop, seminar, and conferences to create awareness, and a forum for interaction among research scientists and other major stakeholders in the industries to improve the acceptability of PATs among scientists and other stakeholders.

3. On-farm trials of PATs should begin with farmers who practise row planting and have access to roads to their farms. Such farms could demonstrate to cocoa farmers the relative advantage (usefulness) and the ease of use of PAT principles and practices.
4. For the proposed PA research unit establishment at CRIG to function well, potential researchers and scientists in the proposed units need to be trained or receive specialized education in PATs and practices in countries where PA is well established such as Canada, US, Japan, Germany and Germany.
5. COCOBOD should alert the major stakeholders (e.g. Government, LBCs, WCF, ICCO and Banks) on the potentials and challenges of PA development in Ghana. Such collaboration is necessary because of the potentially high cost of investments as a result of very expensive equipment and consultancy fees.
6. Institutions of higher learning (universities and polytechnics) specializing in agricultural and related disciplines (especially in engineering, crop science, soil science, ICT and geographic information systems) should collaborate to introduce precision agriculture topics, courses and subsequently curricula to introduce and teach undergraduates in PA. Alternatively, PA topics can be mainstreamed into the curriculum of aforementioned agriculture and related

institutions. These would provide adequate knowledge and practical skills necessary to jumpstart precision farming and research among these young future farmers and researchers.

7. PATs development must target farmers with higher level of education who can fully comprehend and apply features of PA since PA is highly knowledge based. These farmers when well informed could be trained and be provided with necessary incentives to take up the technologies involved in precision agriculture. Moreover, farmers with relatively low educational level must be given requisite training necessary to accept the technology.
8. COCOBOD should also strengthen the Research-Extension-Farmer linkages in cocoa production. This would go a long way to reinforce the training and education of farmers who are the ultimate implementers of the technology. If the Research-Extension-Farmer linkage becomes stronger, farmers who are aware of all the aspects PA but have inadequate knowledge in its application could locate and consult CEAs, researchers and other private advisory services for advice and assistance in applying PA technologies.
9. Current training by CEAs must focus, among others; the relevant and fundamental cultural practices required to jumpstart PA adoption most importantly, row planting and improvement in the use of mechanization among cocoa farmers. These training must focus on farmers who are cultivating new farms and those who would be doing replanting after cutting down aged cocoa trees.
10. The internet service providers in the cocoa regions of Ghana should improve their network services in order to facilitate the information and data base

components of PA since some PA tools require fast internet connectivity to work.

11. Stakeholders (CRIG, LBCs, and ICCO and Financial institutions) should set up a regulatory body to regulate any research and future implementation of PATs in Ghana.

Suggestions for Further Research

1. The study should be extended to other cocoa farmers aside the cocoa farmers under the Cocoa High Technology Programme (CHTP).
2. Further studies should also focus on the challenges as perceived by cocoa farmers.
3. Future research should extend the population to other researchers and academicians in universities and other research institutes whose research focus is either in cocoa or other significant crops in Ghana.
4. Future research should single out and further investigate these two attributes of innovation –relative advantages and ease of use - and its significance in future PA adoption cocoa in Ghana.
5. Studies should also be conducted in the prospects and challenges of PA in other significant crops in Ghana.

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APPENDICES

Appendix A: Awareness Level of Stakeholders on the Information or Data Base Sub-Component of Precision Agriculture

Information or Data base component	Scientists (12)			Cocoa Extension Agents (63)			Cocoa Farmers (416)			
	Yes	$\bar{X}$	SD	Yes	$\bar{X}$	SD	Yes	$\bar{X}$	SD	n
Soil texture data	12(100)	4.2	.8	52(82.5)	3.6	1.2	100(24.9)	1.44	1.4	401
Soil structure data	12(100)	4.2	.8	51(82.3)	3.6	1.2	100 (24.9)	1.39	1.4	402
Use of Soil moisture data	12(100)	4.4	.7	49(80.3)	3.3	1.3	102(25.4)	1.36	1.36	402
Use of Soil nutrients data	12(100)	4.5	.7	50(82.0)	3.4	1.2	94 (23.4)	1.49	1.29	402
Plant population	12(100)	4.3	.8	53(86.9)	3.8	1.2	90 (22.6)	1.63	1.46	399
Crop tissue	12(100)	3.3	1.4	46(75.4)	2.9	1.4	40 (10.1)	1.64	1.32	398
Crop stress	12(100)	3.4	1.5	48(78.7)	3.1	1.3	54 (13.7)	1.88	1.41	395

Weed patches (weed type	10(83.3)	3.7	1.1	50(83.3)	3.4	1.2 1.3	242 (60.5)	2.59	1.01	400
Weed patches (intensity)	10(83.3)	3.8	1.3	46(80.7)	3.2	1.2	220 (55.7)	2.25	1.23	395
Determining various species of Pest infestation in cocoa	12(100)	3.7	1.6	51(86.4)	3.8	1.2	250 (62.2)	2.79	1.15	402
Measuring pest intensity	11(100)	4.0	1.1	49(83.1)	3.4	1.2	168(42.2)	2.26	1.59	398
Measuring Crop yield	11(100)	4.2	1.0	54(88.5)	3.8	1.1	197 (50)	2.86	1.26	394
Use of Temperature Data	12(100)	4.0	1.3	51(85.0)	2.9	1.1	186(46.4)	2.62	1.13	401
Humidity Data	12(100)	3.9	1.4	49(83.1)	2.9	1.1	184 (46.0)	2.64	1.11	400
Rainfall Data	12(100)	4.5	.7	50(86.2)	3.2	1.1	181 (45.1)	2.72	1.05	401
Solar radiation Data	12(100)	3.0	1.4	44(75.9)	2.8	1.2	179 (44.5)	2.65	1.03	402
Wind velocity Data	11(91.7)	3.6	1.3	45(78.9)	2.7	1.2	175 (43.6)	2.67	1.00	401

APPENDIX B: Awareness Level of Stakeholders in Technology and Management Sub-Components of Precision Agriculture

PA Technologies/Tools and Management	Scientists (11)			Cocoa Extension Agents (63)			Cocoa Farmers (416)			
PA Technologies/Tools	YES	$\bar{X}$	SD	YES	$\bar{X}$	SD	Yes	$\bar{X}$	SD	n
Global Positioning System (GPS) Receiver	12(100)	4.1	1.3	62(98.4)	4.5	.8	323 (77.6)	3.07	1.06	416
Differential Global Positioning System (DGPS)	11(9.17)	3.4	1.4	52(85.2)	2.8	1.3	76 (18.4)	2.53	1.18	414
Geographic information systems (GIS)	12(100)	3.7	1.3	54(88.5)	3.1	1.3	70 (16.8)	2.47	1.10	416
Aircraft- based Remote Sensors	10(90.9)	3.4	1.4	44(71.0)	2.5	1.4	47 (11.4)	2.03	1.06	414
Satellite-based Remote Sensors	12(100)	3.5	1.6	49(79.0)	2.7	1.4	57 (13.7)	2.06	.94	416
Simple hand-held Remote Sensors	11(100)	3.7	1.5	47(78.3)	2.5	1.4	63 (15.1)	2.92	1.12	416
Uniform Rate Applicators (URA)	9(81.8)	4.3	1.0	25(45.5)	2.5	1.4	44 (10.6)	1.95	.98	416
Map-based Variable Rate Applicator (VRA)	10(83.3)	3.9	1.5	34(55.7)	2.5	1.4	38 (9.2)	1.76	1.03	415
Sensor-based Variable Rate Applicators (VRA)	10(83.3)	3.3	1.1	35(58.3)	2.3	1.4	39 (9.4)	1.43	1.0	415
Chlorophyll Meter	11(9.17)	4.6	.7	45(76.3)	2.3	1.3	33 (8.0)	1.77	.91	415
Yield monitors	12(100)	3.4	1.4	46(80.7)	2.5	1.2	34 (8.2)	1.64	1.07	414
Combine harvesters	12(100)	4.5	.7	54(91.5)	3.8	1.4	181 (44.0)	3.11	1.52	411
Planter							159 (38.8)	2.72	1.50	410

PA Management	YES	$\bar{X}$	SD	YES	$\bar{X}$	SD	YES	$\bar{X}$	SD	n
PA information management	11(97.1)	3.2	1.2	46(76.7)	2.6	1.3	50 (12.0)	1.64	.86	409
PA Decision support system (DSS)	11(97.7)	3.2	1.3	39(66.1)	2.3	1.3	49 (12.0)	1.51	.79	408
Precision agriculture service providers in Ghana or elsewhere	7(63.6)	2.8	.8	40(64.5)	3.0	1.4	66 (16.1)	1.57	.77	409

APPENDIX C: Perceived Knowledge Level of Scientists and CEAs in the Information or Data Base Sub-Component

Information or Data base components	Scientists (12)			Cocoa Extension Agents (63)		
	Yes	$\bar{X}$	SD	Yes	$\bar{X}$	SD
Soil texture data	12(100)	3.5	1.4	48(80.0)	3.5	.9
Soil structure data	12(100)	3.6	1.3	48(81.4)	3.5	1.0
Use of Soil moisture data	12(100)	3.7	1.3	48(81.4)	3.4	1.0
Use of Soil nutrients data	12(100)	3.7	1.3	46(80.7)	3.3	1
Plant population	12(100)	3.8	1.2	49(84.5)	3.6	1.1
Crop tissue	11(97.1)	3.0	.9	44(78.6)	2.9	1.1
Crop stress	11(100)	3.5	.8	45(78.9)	3.1	1.1
Weed patches (weed type	10(83.3)	3.3	1.1	46(82.1)	3.2	1.1
Weed patches (intensity)	10(83.3)	3.2	1.0	44(80.0)	3.0	1.1
Determining various species of Pest infestation in cocoa	11(97.1)	3.3	1.3	45(84.9)	3.6	1.1
Measuring pest intensity	11(97.1)	2.9	1.4	46(80.7)	3.5	1.0
Measuring Crop yield	11(97.1)	3.7	1.7	50(86.2)	3.8	1
Use of Temperature Data	12(100)	3.7	1.6	46(79.3)	3.0	1.0
Humidity Data	12(100)	3.6	1.4	47(81.0)	3.0	1.1

Rainfall Data	12(100)	4.4	.9	43(78.2)	3.3	.9
Solar radiation Data	11(97.1)	3.2	1.2	41(74.5)	2.7	1.2
Wind velocity Data	11(97.1)	3.0	1.4	39(73.6)	2.8	1.0

APPENDIX D: Perceived Knowledge Level of Scientists and CEAs on PA Technology/Tools and Management Sub – component.

PA Technologies and Managements components	Scientists (12)			Cocoa Extension Agents (63)		
PA Technologies/Tools	Yes	$\bar{X}$	SD	Yes	$\bar{X}$	SD
Global Positioning System (GPS) Receiver	11(91.7)	4.0	1.2	58(98.3)	3.9	1.0
Differential Global Positioning System (DGPS)	10(83.3)	2.6	1.0	43(72.9)	2.7	1.4
Geographic information systems (GIS)	10(83.3)	2.9	.6	50(83.3)	2.6	1.3
Aircraft- based Remote Sensors	9(75.0)	2.5	.8	34(58.6)	2.1	1.2
Satellite-based Remote Sensors	9(75.0)	2.1	1.0	37(62.7)	2.3	1.4
Simple hand-held Remote Sensors	10(83.3)	2.6	1.2	38(66.7)	2.2	1.2
Uniform Rate Applicators (URA)	6(60)	3.1	1.3	16(34.0)	2.3	1.5
Map-based Variable Rate Applicator (VRA)	8(66.7)	2.6	1.3	28(50.0)	2.3	1.5
Sensor-based Variable Rate Applicators (VRA)	8(66.7)	2.6	1.4	30(53.6)	2.0	1.5
Chlorophyll Meter	10(83.3)	4.3	.9	39(67.2)	2.4	1.4
Yield monitors	10(83.3)	3.0	1.2	42(73.7)	2.5	1.2

Combine harvesters	11(91.7)	3.7	1.3	50(87.7)	3.2	1.2
PA Management	Yes	$\bar{X}$	SD	Yes	$\bar{X}$	SD
PA information management	10(83.3)	2.4	1.0	40(72.7)	2.5	1.3
PA Decision support system (DSS)	11(91.7)	2.2	.9	33(61.1)	2.4	1.3
Precision agriculture service providers in Ghana or elsewhere	11(91.7)	2.6	.9	33(58.9)	2.8	1.4

APPENDIX E: Farmer Demographic Characteristics and Environmental Challenges of Scientists and CEAs on PATs.

Farmer Demographics challengers	Scientists (12)			Cocoa Extension Agents (63)		
	n	$\bar{X}$	SD	Yes	$\bar{X}$	SD
Aged farmers	10	4.4	.7	61	3.9	1.3
Farmer's low educational level	10	4.6	.5	61	3.9	1.2
Lack of computer knowledge	10	4.5	1.3	60	4.3	1.2
Negative attitude towards new technologies	10	3.7	.9	61	3.8	1.2
Farmers resistance to change	10	3.7	1.2	60	3.6	1.2
Risk averse	10	3.7	1.1	58	3.5	1.2
Subsistence farmers with low income	10	4	1.4	61	4.0	1.1
Low farming experience	9	3	1.3	60	2.6	1.5
Land ownership /tenure systems problems	9	3.8	1.6	61	3.6	1.4
Overall challenges-Demographic		4.0	.6		4.0	.8
Environmental Challenges	n	$\bar{X}$	**SD**	**Yes**	$\bar{X}$	**SD**
Undulating (sloppy) topography	10	3.8	1.4	60	3.8	1.2
Vegetation mostly (Forest /Trees) will make access of machinery to farms difficult	10	4.0	1.1	61	3.9	1.1

Marshy areas of land will prevent movement of PA Equipment to cocoa farms	10	3.3	.9	62	3.4	1.5
Rivers/streams will pose problems for movements of PA equipment.	9	3.4	1.1	62	3.4	1.4
Lack of accessible roads to farms	10	4.2	.6	54	3.6	1.3

APPENDIX F: Education and Economic Challenges of Scientists and CEAs on PATs

Education challenges	Scientists (12)			Cocoa Extension Agents (63)		
PA Technologies/Tools	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Lack of effective advisory services	11	3.5	1.4	61	3.3	1.3
Lack of local experts on PA	11	3.5	1.1	62	3.7	1.4
Lack of research personnel knowledgeable in PA technologies	11	3.2	1.3	60	3.3	1.5
Lack of extension personnel knowledgeable in PA technologies	11	3.8	.9	58	3.4	1.6
Lack of farmers awareness of PA technologies	10	4	1.2	60	3.5	1.5
Lack of experts awareness of PA technologies	11	3.5	1.3	61	3.4	1.4
Farmers Lack of basic knowledge in PA	11	4.1	1.0	60	3.8	1.2
Lack of consideration of PA topics in various educational institutions	10	3.7	.9	58	3.7	1.3
Lack of adequate training resources	10	3.8	.9	58	3.7	1.2

Lack of Knowledge in PA software and hardware applications	10	3.8	.8	60	4.0	1.2
Overall challenges-Education		3.7	.8		3.7	.9
Economic	n	$\bar{X}$	SD	n	$\bar{X}$	SD
High Initial cost of Investment	11	4.5	.8	60	4.1	1
Very Expensive equipment	11	4.4	.7	60	3.9	1.1
High Consultancy and Rental fees	10	4.1	1	60	3.5	1.2
High Training and learning costs to use equipment	10	3.7	1.3	59	3.4	1.2
High interest rate of borrowed capitals	10	4	1.1	60	3.6	1.3
Availability of fund for investment	11	4	1	57	3.6	1.5
Accessibility of funds for investment	11	4.2	.8	60	3.8	1.2
Obsolesce Potential of hardware	10	3.9	.7	61	3.1	1.3
Uncertainty of PA's return on investment	11	3.8	1.3	61	3.1	1.3
Overall Challenges-Economic		4.0	.6		3.6	.8

APPENDIX G: Perceived Technical Challenges of Scientists and CEAs on PATs

Challenges	Scientists (12)			Cocoa Extension Agents (63)		
Technical	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Difficulty of quantifying PA profitability	10	3.6	1.2	61	3.6	1.2
Lack of PA research centre in Ghana	10	4.1	.9	60	3.9	1.1
Incompatibility of machines of different manufacturers	10	2.8	.4	62	3.5	1.1
Unreliable equipment (eg sensors, GPS)	10	2.7	1.2	61	3.3	1.2
Unreliable internet connectivity	10	3.4	1.3	60	3.7	1.1
Unreliable technician to service the equipment	9	3.6	1.4	61	3.5	1.4
Lack of access road to farms that inhibits movement of PA equipment	10	4.2	.8	59	3.8	1.3
Low mechanization level on cocoa farms	9	3.9	1.5	59	4.1	1.1
Smaller farms would make PA technology not viable	9	4.1	.9	59	3.5	1.1
Lack of standardization in manufacturing of PA tools	10	3.3	1.2	61	3.3	1.3
Overall challenges-Technical		3.6	.8		3.7	.8

APPENDIX H: Perceived Time, Data Quality, and Political Challenges of Scientists and CEAs on PATs

Time	Scientist (12)			Cocoa Extension Agents (63)		
Time	n	$\bar{X}$	SD	n	$\bar{X}$	SD
It takes lengthy time to introduce the PA Technologies	10	3.2	1.1	62	3.5	1.0
It takes lengthy time to learn how to use the Equipment	10	3.3	1.1	60	3.2	1.4
It takes lengthy of time to experience any return on the producer's investment.	10	3.6	1.1	57	3.2	1.3
Overall challenges-Time		3.4	1.0		3.3	1.0
Data quality						
Difficulty in maintaining quality	10	3	1.2	58	3.6	1.2
Difficulty in storing and retrieving data with different formats,	10	2.7	1.6	61	3.5	1.3
Difficulty in analyzing data to understand yield limiting factors	9	2.8	1.3	62	3.4	1.3
Difficulty of data transfer to external sources for analysis	9	2.8	1.2	61	3.3	1.3
Difficulty of data interpretation	10	2.7	1.4	61	3.1	1.3
Lack of appropriate measurement and analysis techniques for agronomical important factors	10	2.8	.9	59	3.2	1.1
Difficulties in managing large amount of data	10	2.4	1.1	62	3.3	1.2
Incompatibility of software packages.	10	3.0	1.4	61	3.2	1.3
Inaccuracy of data concerns	10	3.1	1.0	60	3.3	1.1

Political Challenges	n	$\bar{X}$	SD	n	$\bar{X}$	SD
PA technology is not compatible with current government policies in Agriculture and Cocoa in Ghana	10	3.1	1.5	61	3.1	1.6
Inadequate funds from government (COCOBOD) to develop and implement PA technologies	10	3.4	1.0	61	3.5	1.3
Less political will to start PA even if funds are available because PA principles and practice may not appeal to politicians/government of Ghana	10	3.7	1.6	62	3.3	1.4
Precision Agriculture not a priority of COCOBOD /government of Ghana	9	2.7	1.5	60	3.0	1.4

APPENDIX I: Perceived Technology Characteristics of PA in Cocoa Production (Relative Advantage and Voluntariness)

PA Characteristics	Scientists (12)			Cocoa Extension Agents (63)		
Relative advantage	n	$\bar{X}$	SD	n	$\bar{X}$	SD
PA technologies would be more profitable than existing Cocoa technologies	11	3.8		61	3.3	1.1
PA technologies would improve the Social prestige of cocoa farmers	11	3.1	1.3	61	3.5	1.1
PA is the most effective means of achieving optimum productivity	11	3.8	.8	60	3.3	1.0
PA is the most effective means of achieving optimum environmental sustainability	11	3.8	.8	61	3.3	1.1
Voluntariness	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Cocoa farmers would accept PA technologies when they are mandated by law from government	9	2.4	.9	62	2.5	1.3
Cocoa farmers would accept PA technologies when they are mandated by industrial partners (eg. Licensed Buying companies/ cooperatives /NGOs)	10	2.8	1.0	62	2.5	1.3
Even though PA technologies might be helpful their use should be optional for cocoa farmers	11	3.5	1.2	62	3.5	1.3

APPENDIX J: Perceived Technology Characteristics of PA in Cocoa Production (Observability, Compatibility, Complexity, and Triability).

PA Characteristics	Scientists (12)			Cocoa Extension Agents (63)		
Compatibility	n	$\bar{X}$	SD	n	$\bar{X}$	SD
PA technologies would be compatible with most socio-cultural values and beliefs of cocoa farmers	11	3.0	.9	62	3.0	1.1
PA would be compatible with previously introduced technologies by researchers	11	3.6	1.0	60	3.2	1.2
PA technologies would fit with the current practices of most cocoa farmers	10	3.7	.9	61	2.9	1.2
PA technologies would be compatible with cocoa farmers felt current needs	10	3.4	1.1	61	2.9	1.2
Observability	n	$\bar{X}$	SD	n	$\bar{X}$	SD
PA technologies and facilities include physical and material objects that are easy to observe by cocoa farmers	11	3.3	.6	61	2.8	1.2
PA technologies and facilities include physical and material objects that are easy to observe by cocoa farmers	11	3.1	.8	62	2.8	1.2
PA technologies and facilities include physical and material objects that are easy to observe by cocoa farmers	11	2.6	.9	60	2.6	1.1
Overall PA Characteristics-Observability		3.0	.6		2.8	.9

Complexity(ease of use)	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Cocoa farmers can easily understand Precision Agricultural practices	9	3.0	1.2	60	2.0	1.4
Cocoa farmers can easily practise Precision Agricultural Technologies	9	2.7	.9	58	1.8	1.3
Trialability	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Cocoa farmers can easily use PA technologies on trial bases before they decide to use it full scale	11	3.3	.8	61	2.8	1.3
Cocoa farmers can easily use PA technologies on trial bases before they decide to use it full scale	11	3.4	1.2	60	3.3	1.2

APPENDIX K: Collinearity Statistics

Variables	Collinearity Statistics	
	Tolerance	VIF
(Constant)		
Age at last birthday	.343	2.915
Highest Educational Level	.618	1.619
Experience in Farming	.357	2.801
Number in Households/Dependent	.656	1.524
Land size_under_High_Tech	.361	2.770
Age of the farm _ under hitech	.565	1.771
How Many cocoa farms do you have	.664	1.506
Amount of fert in bags 2014/2015	.283	3.536
How often did extension officer visit you and group past year	.685	1.460
Yield under High / bags	.347	2.881
Sex	.796	1.256
Marital	.718	1.394
Credit access	.526	1.901
Credit from Financial Institution	.501	1.997
Row planting	.668	1.496
Access road to farm	.763	1.311
Mobile Phone Access	.774	1.292
Frequency of contact by Extension Agents	.695	1.439
Land rights	.734	1.362
Source of Labour	.504	1.986

Relative Advantage	.644	1.552
Compatibility	.673	1.485
Complexity(Ease)	.535	1.870
Trialability	.515	1.942
Observability	.373	2.680
Voluntariness	.629	1.589
Awareness of data	.998	1.003
Awareness of Technology/tool	.956	1.046
Awareness of Management	.954	1.048

APPENDIX L: Predictors of Cocoa Farmers Willingness to Adopt PATs

Predictors	B	S.E.	Wald	Sig.	Odds Ratio	95% C.I.for odd Ratio	
						Lower	Upper
Constant	-5.542	3.313	2.798	.094	.004		
Demographic							
Sex	.681	.962	.50	.479	1.98	.30	13.0
Educational Level	-3.994	1.860	4.61	.032	.018	.00	.71
Marital status	-.962	1.136	.72	.397	.38	.04	3.5
Age	.006	.035	.03	.874	1.01	.94	1.08
Experience	-.025	.041	.36	.549	.98	.90	1.06
Households size	.074	.142	.271	.603	1.077	.815	1.424
Farm-Related							
Land under cocoa	.005	.029	.03	.868	1.01	.95	1.06
Land Fertilized	-.014	.025	.31	.576	.99	.94	1.03
Land Rights	.189	.875	.047	.829	1.208	.217	6.72
Land ownership	.529	1.602	.109	.741	1.697	.073	39.21
Source of Labour	-.086	1.070	.006	.936	.918	.113	7.478
Access to Credit	-.023	1.116	.00	.984	.98	.11	8.70
Credit from financial institution	2.899	1.327	2.06	.047	1.38	.10	18.66
Row planting	3.995	1.636	5.96	.015	54.30	2.20	1341.5
Access roads to farm	.258	.689	.14	.709	1.294	.34	4.99
Mobile Phone	-1.44	1.023	1.99	.158	.236	.03	1.76
Frequency of contact by Extension Agents	.016	.025	.04	.844	1.11	.94	1.34

Yield/acre	.002	.019	.016	.898	1.002	.966	1.040
Technology -Related	B	S.E.	Wald	Sig.	Odds Ratio	95% C.I.for odd Ratio	
Relative Advantage	1.176	.423	7.73	.005	3.242	1.42	7.43
Compatibility	.115	.352	.11	.744	1.122	.56	2.24
Ease of Use	.787	.294	7.16	.007	2.196	1.23	3.91
Trailability	.453	.368	1.51	.219	1.574	.76	3.24
Observability	.457	.408	1.25	.263	1.579	.71	3.51
Voluntariness	-.220	.405	.30	.586	.802	.36	1.76
Awareness of data	1.051	.883	1.418	.234	2.860	.507	16.132
Awareness of Technology/tool	-1.59	.829	3.713	.054	.203	.040	1.028
Awareness of Management	1.275	1.000	1.623	.203	3.577	.504	25.410

APPENDIX M: Structured Interview Schedule for Cocoa Farmers

University of Cape Coast
Department of Agricultural Economics and Extension

Topic: Prospects and Challenges of Precision Agriculture in Ghana

Structured interview schedule for cocoa farmers

Introduction: Precision Agriculture (PA) is defined as an information and technological-based farm management system to identify, analyse and manage variability within fields for optimum profitability, sustainability and protections of the land resource. Precision Agriculture (PA) uses geographic information system (GIS) and global positioning system (GPS) tools to provide an extensive amount of detailed information on crops so that inputs (e.g. fertilizers, water, pesticides etc.) can be distributed on site-specific basis to maximise long term benefits such as optimum profitability and environmental sustainability.

Goals of the research: This research would be used to develop a model towards the development and implementation of Precision Agriculture technologies and tools in Agriculture especially in the Cocoa Industry in Ghana. In-depth research within Precision Agriculture (PA) is needed to evaluate the challenges and the potentials for development, implementation, adoption, uses and benefits of the PA technology in Ghana. Our goal in this study is to better understand the necessary and sufficient conditions needed to make PA technology development and implementations in Cocoa productions a reality in Ghana.

Confidentiality Statement: The data from you would be treated confidentially. Only the researcher, the supervisors and the enumerators will have access to data. Your personal identity will be kept anonymous and be shielded from any other persons or organizations.

SECTION A
Demographic and Farm related Characteristics of Cocoa Farmers

Name-- Telephone No.------------ -------------------------------

1. a. Cocoa Region----------------------- Cocoa District. ----------------------- -Operational Area____________
   b) Village/Town-----------------------------------
2. Sex: 1. Male [ ] 2. Female [ ]
3. Please indicate your age at your last birthday ---------------- (in years)
4. Kindly indicate your highest educational qualification. Please tick [√]
   1. No formal schooling/education [ ]
   2. Primary Education [ ]
   3. Middle School Leaving Certificate /JSS [ ]

4. Senior Secondary School Certificate [ ]
5. GCE 'O' level [ ]
6 GCE 'A'' level [ ]
7. Tertiary [ ]
8. Others (specify) ---

5 . Please indicate your total number of years of Schooling……………………

6. How long have you been working as a cocoa farmer? -------------- (in years).

7. Marital Status 1. Married [ ] 2. Not Married [ ]

8. Number of children ----------------

9. Number of children who are in school----------------

10. Please indicate the number of dependents (household size) ----------------

11 Total Number of Land under cultivation _Cocoa (Acres)______________Other Crops (Acres)____________

12. How many cocoa farms do you have? ----------------------------------

13. Indicate your total land size under and not under the High Tech

Total Land Size under cocoa cultivation	Acres	Age of Farm
Not Under High Tech		
Under High Tech		

14. Indicate the type of Land ownership and Right you have under Cocoa High Tech (tick as many as Applicable)

Land ownership	tick	Land Rights	tick
1.Bought		1. sell outright	
2.inherited		2. rent out	
3.Abunu		3. Plant trees	
4. Abusa		4.Nominate heir	
5 Gift		5. give as a gift	
6. Rent		Others	

15. Did you plant in Rows on your farm under CHTP 1. Yes [ ] 2. No [ ]

16. Do you have Access road to your farm? 1. Yes [ ] 2. No [ ]

17. Please indicate the Type and Amount of Fertilizer Received under the High Tech Programme

Cocoa season	Type of fertilizer	Amount (Bags)
2014/2015		
2015		

Key

1. Asasewura
2. . Cocofeed
3. Cocoa master 4 Sidalco

18. Please indicate your yield on the land size under the High Tech Programme

Cocoa season	Yield (bags)		Total Yield (Bags)
	Major Season	Minor Season	
2014/2015			
2013/2014			

19. Please indicate your yield in bags of your total matured cocoa farms <u>not under High Tech</u> for past 2 years

Cocoa season	Yield (bags)		Total (Bags)
	Major Season	Minor Season	
2014/2015			
2013/2014			

20. Did you have Access to Credit for the past 2 years? 1. Yes [ ] 2. No [ ]

21. What is your Main Source of funding?

1. Own [ ]
2. Friends [ ]
3. Money Lenders [ ]
4. Family members [ ]
5. Financial institutions [ ]

22. Have you ever had credit from financial institution? 1. Yes [ ] 2. No [ ]

23. If yes, in which form. 1. Cash [ ] 2. Inputs [ ] 3. Both [ ]

24. Indicate your Main Source of Labour

1. own [ ]
2. Hired labour [ ]
3. Family Labour [ ]
4. Nnoboa System [ ]
5. Others (specify) [ ]

25. What input did you own/apply to your farm at the past seasons

Input	Put a Tick		
	Own	Access	Quantity
1.Fertilizer			
2. Pesticides			
4. Fungicides			
5. Weedicides			
6. Tractor			
7. Power tiller			
8. Knapsack Sprayer			
8. Mist blower			
9.Harvesting equipment (sickle)			
10.Prunner			
11.Cutlasses			

26. Have you had access to extension services in the past year? 1. Yes [ ] 2. No [ ]
27. How often did cocoa extension officer contact you in the past year?
    1 Once a week [ ]
    2 once every two weeks [ ]
    3 Once a month [ ]
    4 Once every 3 months [ ]
    5 once every 6 month [ ]
    6 once a year [ ]
    7 others(specify) [ ]
28. Do you have a personal Mobile Phone 1. Yes [ ] 2. No [ ]
29. If yes to q28, what type of phone do you have 1. Analog [ ] 2. Android [ ] 3. Both [ ]
30. Do you have Network Coverage for your mobile phone :
    a. Town/Village 1. Yes [ ] 2. No [ ]
    b. Cocoa farm under Cocoa High Tech programme 1. Yes [ ] 2. No [ ]

SECTION B

PERCEIVED AWARENESS LEVELS OF COCOA FARMERS IN PRECISION AGRICULTURAL TECHNOLOGIES

Please indicate your **awareness level** in the use of each of each of the following components of Precision Agriculture using the following ratings:

Ratings	Awareness Level
0	Not aware
1	Least aware
2	Less aware
3	Fairly aware
4	Much aware
5	Very much aware

	Precision Agriculture Components	Awareness Level					
A	**<u>Information or Data base</u>**	**5**	**4**	**3**	**2**	**1**	**0**
1	Soil texture data						
2	Soil structure data						
3	Use of Soil moisture data						
4	Use of Soil nutrients data						

5	Plant population						
6	Crop tissue						
7	Crop stress						
8	Weed patches (weed type)						
9	Weed patches (intensity)						
10	Determining various species of Pest infestation in cocoa						
11	Measuring pest intensity						
12	Measuring Crop yield						
13	Use of Temperature Data						
14	Use of Humidity Data						
15	Use of Rainfall Data						
16	Use of Solar radiation Data						
17	Use of Wind velocity Data						
B	**Technologies/Tools**	**5**	**4**	**3**	**2**	**1**	**0**
1	Global Positioning System (GPS) Receivers						
2	Differential Global Positioning System (DGPS)						
3	Geographic information systems (GIS)						
4	Aircraft- based Remote Sensors						
5	Satellite-based Remote Sensors						
6	Simple hand-held Remote Sensors						
7	Uniform Rate Applicators (URA)						
8	Map-based Variable Rate Applicator (VRA)						
9	Sensor-based Variable Rate Applicators (VRA)						
10	Chlorophyll Meter						
11	Yield monitors						
12	Combine harvesters						
13	Planter						
C	**Management**	**5**	**4**	**3**	**2**	**1**	**0**
1	PA information management						
2	PA Decision support system (DSS)						
3	Precision agriculture service providers in Ghana or elsewhere						
OV	**How would you rate your overall Awareness of PA**	**5**	**4**	**3**	**2**	**1**	**0**

SECTION C

Perceived Technology Characteristics of Precision Agriculture in Cocoa Production

Please indicate your level of agreement on the following attributes/characteristics of PA technology in Cocoa Production in Ghana.

0=No Agreement
1= Least agree
2=Less Agree
3=Fairly Agree
4= Agree
5=Strongly Agree

	Attributes/Characteristics of PA	**Level of Agreement**					
A	**Relative advantage**	**5**	**4**	**3**	**2**	**1**	**0**
1	PA technologies would be **more profitable** than existing Cocoa technologies						
2	PA technologies would improve my **Social prestige**						
3	PA is the **most effective** means of achieving optimum productivity						
4	PA is the **most effective** means of achieving optimum environmental sustainability						
B	**Compatibility**	**5**	**4**	**3**	**2**	**1**	**0**
1	PA technologies would be compatible with **most of my socio-cultural values and beliefs**						
2	PA would be compatible with **previously introduced technologies** by researchers to me						
3	PA technologies would **fit** with my **current practices** in my cocoa farm						
4	PA technologies would **be compatible with** my **current needs**						
C	**Complexity (Ease of Use)**	**5**	**4**	**3**	**2**	**1**	**0**
1	I can **easily understand** Precision Agricultural practices						
2	I can **easily** practise Precision Agricultural Technologies						
D	**Trialability**	**5**	**4**	**3**	**2**	**1**	**0**
1	I **can easily use** PA technologies **on trial** bases before they decide to use it full scale						
2	I **would easily adopt** PA technologies if they are permitted to use the technology **long enough to see the benefits**.						
E	**Observability.**	**5**	**4**	**3**	**2**	**1**	**0**
1	PA technologies and facilities include physical and material objects that are **easy to observe by** cocoa farmers						

2	PA technologies and facilities include physical and material objects that are **easy to describe** to cocoa farmers						
3	I would **have no difficulty** explaining the pros and cons of PA to other cocoa farmers.						
F	**Voluntariness**	**5**	**4**	**3**	**2**	**1**	**0**
1	I **would accept** PA technologies when I am **mandated by law from government**						
2	I **would accept** PA technologies when I am **mandated by** industrial partners (eg. Licensed Buying companies/ cooperatives /NGOs)						
3	Even though PA technologies might be helpful to me **their use should be optional** to me.						

SECTION D

WILLINGNESS OF COCOA FARMERS TO ADOPT AND PAY FOR PRECISION AGRICULTURAL INNOVATION

1. Would you be willing to adopt the PA Technologies if available? (Please let them know that they would not be penalized if the answer no and that they need to be sincere
   1. Yes [ ] 2. No [ ]

2. Which of the following main components and tools of PA technologies are you **willing** to adopt if available. Rate using the ratings :
   0=Not Sure (NS)
   1= Strongly Disagree (SD)
   2= Disagree (D)
   3= Somewhat Agree (SWA)
   4= Agree (A)
   5= Strongly Agree (SA)

	STATEMENT	**Level of Agreement**					
		SA	**A**	**SWA**	**D**	**SD**	**NS**
		5	**4**	**3**	**2**	**1**	**0**
1	Global Positioning System (GPS) Receivers						
2	Differential Global Positioning System (DGPS)						
3	Geographic information systems (GIS)						
4	Aircraft/Satellite- based Remote Sensors						
5	Simple hand-held Remote Sensors						
6	Yield Monitors						

7	Map-based Variable Rate Applicator (VRA)						
8	Sensor-based Variable Rate Applicators (VRA)						
9	Grid soil sampling and mapping						
10	Crop scouting						

3. Looking at my Overall Impression of PA technologies, I would **be willing** to adopt it if it is available. Please answer this using the following ratings:

0 .Not Sure (NS) [ ]
1= Strongly Disagree (SD) [ ]
2= Disagree (D) [ ]
3= Somewhat Agree (SWA) [ ]
4= Agree (A) [ ]
5= Strongly Agree (SA) [ ]

Thank you very Much for your time and effort

APPENDIX N: Questionnaire for Cocoa Extension Officers

University of Cape Coast
Department of Agricultural Economics and Extension

Topic: <u>Prospects and Challenges of Precision Agriculture in Ghana</u>

questionnaire FOR COCOA EXTENSION officers

<u>Introduction:</u> Precision Agriculture (PA) is defined as an information and technological-based farm management system to identify, analyse and manage variability within fields for optimum profitability, sustainability and protections of the land resource. Precision Agriculture (PA) uses geographic information system (GIS) and global positioning system (GPS) tools to provide an extensive amount of detailed information on crops so that inputs (eg. fertilizers, water, pesticides etc.) can be distributed on site-specific basis to maximise long term benefits such as optimum profitability and environmental sustainability.

Goals of the research: This research would be used to develop a model towards the development and implementation of Precision Agriculture technologies and tools in Agriculture especially in the Cocoa Industry in Ghana. In-depth research within Precision Agriculture (PA) is needed to evaluate the challenges and the potentials for development, implementation, adoption, uses and benefits of the PA technology in Ghana. Our goal in this study is to better understand the necessary and sufficient conditions needed to make PA technology development and implementations in Cocoa productions a reality in Ghana.

Confidentiality Statement: The data from you would be treated confidentially. Only the researcher, the supervisors and the enumerators will have access to data. Your personal identity will be kept anonymous and be shielded from any other persons or organizations.

SECTION A
Demographic Characteristics of Scientists

Name (Optional) : ……………………. …………Telephone number **(optional)**:……………...

1. Cocoa Region …………… Cocoa District…………………….. Operational Area………………
2. Sex: 1 Male [ ] 2 Female [ ]
3. Please, indicate your age at your last birthday? ----------------(in years)
4.. Indicate your highest educational qualification. Please tick [√]
    1. Certificate in General Agriculture [ ]
    2. Diploma [ ]
    3. Degree (Bachelors) [ ]
    4. Post Graduate Diploma [ ]

5. Masters [ ]
4. Others (specify) [ ]

5. How long have you worked with Cocoa Health and Extension Division?…………………..(years).

6. What is the Estimated of the number of cocoa farmers in your operational Area…………………

7. **What is the** Estimated of the number of farmers in your operational area **under the cocoa high tech** programme………………

8. How often do you visit cocoa High Tech farmers- in a month?

8 Twice A weak [ ]
9 Once a week [ ]
10 once every two weeks [ ]
11 Once Every Three weeks[ ]
12 Once a month [ ]

9 Which Extension teaching methods do you mostly use?…………

10 Mode of contact with Cocoa farmers………………………

SECTION B

PERCEIVED AWARENESS AND KNOWLEDGE LEVELS OF RESPONDENTS IN PRECISION AGRICULTURE TECHNOLOGIES.

Please indicate your **awareness and knowledge levels** in the use of each of the following components/Tools of Precision Agriculture using the following ratings:

Ratings	Awareness Level	Knowledge Level
0	Not aware **(NA)**	0 No knowledge **(NK)**
1	Least aware **(LtA)**	1 Very poor knowledge **(VPN)**
2	Less aware **(LsA)**	2 Poor knowledge **(PK)**
3	Fairly aware **(FA)**	3 Fair knowledge **(FK)**
4	Much aware **(MA)**	4 Good knowledge (**GK)**
5	Very much aware **(VMA)**	5 Very good knowledge **(VGK)**

	Precision Agriculture Components	**Awareness Level**							**Knowledge Level**					
														NA
A	**Information or Data base**	**5**	**4**	**3**	**2**	**1**	**0**		**5**	**4**	**3**	**2**	**1**	**0**
1	Soil texture data													
2	Soil structure data													
3	Use of Soil moisture data													
4	Use of Soil nutrients data													

5	Plant population													
6	Crop tissue													
7	Crop stress													
8	Weed patches (weed type)													
9	Weed patches (intensity)													
10	Determining various species of Pest infestation in cocoa													
11	Measuring pest intensity													
12	Measuring Crop yield													
13	Use of Temperature Data													
14	Use of Humidity Data													
15	Use of Rainfall Data													
16	Use of Solar radiation Data													
17	Use of Wind velocity Data													
B	**Technologies/Tools**	**5**	**4**	**3**	**2**	**1**	**0**		**5**	**4**	**3**	**2**	**1**	**0**
1	Global Positioning System (GPS) Receivers													
2	Differential Global Positioning System (DGPS)													
3	Geographic information systems (GIS)													
4	Aircraft- based Remote Sensors													
5	Satellite-based Remote Sensors													
6	Simple hand-held Remote Sensors													
7	Uniform Rate Applicators (URA)	**5**	**4**	**3**	**2**	**1**	**0**		**5**	**4**	**3**	**2**	**1**	**0**
8	Map-based Variable Rate Applicator (VRA)													
9	Sensor-based Variable Rate Applicators (VRA)													
10	Chlorophyll Meter													

11	Yield monitors													
12	Combine harvesters													
C	**Management**													
1	PA information management													
2	PA Decision support system (DSS)													
3	Precision agriculture service providers in Ghana or elsewhere													
OV	Rate your overall **Awareness and /Knowledge levels** of PA	**5**	**4**	**3**	**2**	**1**	**0**		**5**	**4**	**3**	**2**	**1**	**0**

SECTION C
CHALLENGES TO PRECISION AGRICULTURAL DEVELOPMENT AND IMPLEMENTATION IN COCOA PRODUCTION IN GHANA

Please indicate in your opinion the challenges that are likely to hinder PA development and implementation in Cocoa production in Ghana by using the following ratings**: (Please note that your rating of low challenge implies high prospect in this study)**

0=No challenge
1= Negligible challenge = High Prospect
2=Low challenge = Substantial prospect
3= Moderate Challenge = Moderate Prospect
4= Substantial Challenge = Low prospect
5= High Challenge = Negligible prospect

	CATEGORY OF CHALLENGE	5	4	3	2	1	0
A	**Economic challenges**						
1	High Initial cost of Investment						
2	Very Expensive equipment						
3	High Consultancy and Rental fees						
4	High Training and learning costs to use equipment						
5	High interest rate of borrowed capitals						
6	Availability of fund for investment						
7	Accessibility of funds for investment						
8	Obsolesce Potential of hardware						
9	Uncertainty of PA's return on investment						

B	**Educational/Training Challenge**	**5**	**4**	**3**	**2**	**1**	**0**
1	Lack of effective advisory services						
2	Lack of local experts on PA						
3	Lack of research personnel knowledgeable in PA technologies						
4	Lack of extension personnel knowledgeable in PA technologies	**5**	**4**	**3**	**2**	**1**	**0**
5	Lack of farmers awareness of PA technologies						
6	Lack of experts awareness of PA technologies						
7	Farmers Lack of basic knowledge in PA						
8	Lack of consideration of PA topics in various educational institutions						
9	Lack of adequate training resources						
10	Lack of Knowledge in PA software and hardware applications						
C	**Technical challenge**	**5**	**4**	**3**	**2**	**1**	**0**
1	Difficulty of quantifying PA profitability						
2	Lack of PA research centre in Ghana						
3	Incompatibility of machines of different manufacturers						
4	Unreliable equipment (eg sensors, GPS)						
5	Unreliable internet connectivity						
6	Unreliable technician to service the equipment						
7	Lack of access road to farms that inhibits movement of PA equipment						
8	Low mechanization level on cocoa farms						
9	Smaller farms would make PA technology not viable						
10	Lack of standardization in manufacturing of PA tools						
D	**Time Challenge**	**5**	**4**	**3**	**2**	**1**	**0**

1	It takes lengthy time to introduce the PA Technologies						
2	It takes lengthy time to learn how to use the Equipment						
3	It takes lengthy of time to experience any return on the producer's investment.						
E	**Data quality challenges**	**5**	**4**	**3**	**2**	**1**	**0**
1	Difficulty in maintaining quality						
2	Difficulty in storing and retrieving data with different formats,						
3	Difficulty in analyzing data to understand yield limiting factors						
4	Difficulty of data transfer to external sources for analysis						
5	Difficulty of data interpretation						
6	Lack of appropriate measurement and analysis techniques for agronomical important factors						
7	Difficulties in managing large amount of data						
8	Incompatibility of software packages.						
9	Inaccuracy of data concerns						
F	**Farmer/Operator demographic Challenges**	**5**	**4**	**3**	**2**	**1**	**0**
1	Aged farmers						
2	Farmer's low educational level						
3	Lack of computer knowledge						
4	Negative attitude towards new technologies						
5	Farmers resistance to change						
6	Risk averse						
7	Subsistence farmers with low income						
8	Low farming experience						
9	Land ownership /tenure systems problems						
G	**Environmental/abiotic challenges**	**5**	**4**	**3**	**2**	**1**	**0**
1	Undulating (sloppy) topography						
2	Vegetation (mostly Forest /Trees) will make access of machinery to farms difficult						

3	Marshy areas of land will prevent movement of PA Equipment to cocoa farms						
4	Rivers/streams will pose problems for movements of PA equipment.						
5	Lack of accessible roads to farms						
H	**Political /Governmental Challenge**	**5**	**4**	**3**	**2**	**1**	**0**
1	PA technology is not compatible with current government policies in Agriculture and Cocoa in Ghana						
2	Inadequate funds from government (COCOBOD) to develop and implement PA technologies						
3	Less political will to start PA even if funds are available because PA principles and practice may not appeal to politicians/government of Ghana						
4	Precision Agriculture not a priority of COCOBOD /government of Ghana						

Please indicate any other challenges or prospects you think can affect the development and implementation of PA in Cocoa in Ghana.
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SECTIONS D

Perceived Technology Characteristics of Precision Agriculture in Cocoa Production

Please indicate your level of agreement on the following attributes/characteristics of PA technology in Cocoa Production in Ghana.

0=No Agreement
1= Least agree
2=Less Agree
3=Fairly Agree
4= Agree
5=Strongly Agree

	Attributes/Characteristics of PA	**Level of Agreement**					
A	**Relative advantage**	**5**	**4**	**3**	**2**	**1**	**0**
1	PA technologies would be **more profitable** than existing Cocoa technologies						
2	PA technologies would improve the **Social prestige** of cocoa farmers						
3	PA is the **most effective** means of achieving optimum productivity						
4	PA is the **most effective** means of achieving optimum environmental sustainability						
B	**Compatibility**	**5**	**4**	**3**	**2**	**1**	**0**
1	PA technologies would be compatible with **most socio-cultural values and beliefs** of cocoa farmers						
2	PA would be compatible with **previously introduced technologies** by researchers						
3	PA technologies would **fit** with the **current practices** of most cocoa farmers						
4	PA technologies would **be compatible with current needs** of cocoa farmers						
C	**Complexity (Ease of Use)**	**5**	**4**	**3**	**2**	**1**	**0**
1	Cocoa farmers can **easily understand** Precision Agricultural practices						
2	Cocoa farmers can **easily** practise Precision Agricultural Technologies						
D	**Trialability**	**5**	**4**	**3**	**2**	**1**	**0**
1	Cocoa farmers **can easily use** PA technologies **on trial** bases before they decide to use it full scale						
2	Cocoa farmers **would easily adopt** PA technologies if they are permitted to use the technology **long enough to see the benefits**.						
E	**Observability.**	**5**	**4**	**3**	**2**	**1**	**0**

1	PA technologies and facilities include physical and material objects that are **easy to observe by** cocoa farmers						
2	PA technologies and facilities include physical and material objects that are **easy to describe** to cocoa farmers						
3	Cocoa farmers would **have no difficulty** explaining the pros and cons of PA to other cocoa farmers.						
F	**Voluntariness**	**5**	**4**	**3**	**2**	**1**	**0**
1	Cocoa farmers **would accept** PA technologies when they **are mandated by law from government**						
2	Cocoa farmers **would accept** PA technologies when they **are mandated by** industrial partners (eg. Licensed Buying companies/ cooperatives /NGOs)						
3	Even though PA technologies might be helpful **their use should be optional** for cocoa farmers						

SECTION E

WILLINGNESS OF COCOA FARMERS TO ADOPT AND PAY FOR PRECISION AGRICULTURAL INNOVATION

Based on your dealings with cocoa farmers throughout Ghana and their attitude towards cocoa innovation, kindly offer your opinion as to their willingness to adopt PA technologies if available to cocoa farmers.

4. Do you think cocoa farmers would be willing to adopt the PA Technologies if it is available?
   a. Yes [ ] b. No [ ]

5. Which of the following main components and tools of PA technologies do you think cocoa farmers would be **willing** to adopt if available. Rate using the ratings
   0=Not Sure (NS)
   1= Strongly Disagree (SD)
   2= Disagree (D)
   3= Somewhat Agree (SWA)
   4= Agree (A)
   5= Strongly Agree (SA)

	STATEMENT	Level of Agreement					
		SA	A	SWA	D	SD	NS
		5	4	3	2	1	0
1	Global Positioning System (GPS) Receivers						
2	Differential Global Positioning System (DGPS)						
3	Geographic information systems (GIS)						
4	Aircraft/Satellite- based Remote Sensors						
5	Simple hand-held Remote Sensors						
6	Yield Monitors						
7	Map-based Variable Rate Applicator (VRA)						
8	Sensor-based Variable Rate Applicators (VRA)						
9	Grid soil sampling and mapping						
10	Crop scouting						

6. Looking at my Overall Impression of Precision Agriculture technologies, I think cocoa farmers would adopt it if it is available. Please answer this using the following ratings:

0 .Not Sure (NS) [ ]
1= Strongly Disagree (SD) [ ]
2= Disagree (D) [ ]
3= Somewhat Agree (SWA) [ ]
4= Agree (A) [ ]
5= Strongly Agree (SA) [ ]

Thank you very Much for your time and effort

APPENDIX O: Questionnaires for Scientists/ Experts in Cocoa Production

University of Cape Coast
Department of Agricultural Economics and Extension

Topic: <u>Prospects and Challenges of Precision Agriculture in Ghana</u>

questionnaires FOR SCIENTISTs/ experts in cocoa production

Introduction: Precision Agriculture (PA) is defined as an information and technological based farm management system to identify, analyse and manage variability within fields for optimum profitability, sustainability and protections of the land resource. The main goal of PA is to manage and distribute inputs, such us fertilizers, on site-specific basis to maximise long term benefits such as optimum profitability and environmental sustainability. It involves the use of GIS GPS

Goals of the research: This research would be used to develop a model towards the development and implementation of Precision Agriculture technologies and tools in Agriculture especially in the Cocoa Industry in Ghana. In-depth research within Precision Agriculture (PA) is needed to evaluate the challenges and the potentials for development, implementation, adoption, uses and benefits of the PA technology in Ghana. Our goal in this study is to better understand the necessary and sufficient conditions needed to make PA technology development and implementations in Cocoa productions a reality in Ghana.

Confidentiality Statement: The data from you would be treated confidentially. Only the researcher, the supervisors and the enumerators will have access to data. Your personal identity will be kept anonymous and be shielded from any other persons or organizations.

SECTION A
Demographic Characteristics of Scientists

Name (Optional) : ……………………. …………Telephone number **(optional)**:……………...

1. Sex: a) Male [ ] b) Female [ ]
2. Please, indicate your age at your last birthday? ----------------(in years)
3. Indicate your highest educational qualification. Please tick [√]
   6. Masters [ ]
   7. PhD [ ]
   8. Post Doctorate [ ]
   4. Others (specify) [ ]…………

4. Area of Specialization. 1. Agronomy [ ]
2. Plant Breeding [ ]
3. Plant Pathology [ ]
4. Entomology [ ]
5. Plant Physiology [ ]
6. Biochemistry [ ]
7. Soil Science [ ]
8. Others Specify [ ] -------------------------------
-

5. Rank : 1. Research Scientist [ ]
2. Senior Research Scientist [ ]
3. Principal Research Scientist [ ]
4. Chief Research Scientist [ ]
5. Others (specify) [ ]

6. Department/Division (please Specify): ………………
7. Position held in the Department/Division: ……………………………
8. How long have you worked with **CRIG? ……………(in years)**

SECTION B

PERCEIVED AWARENESS AND KNOWLEDGE LEVELS OF RESPONDENTS IN PRECISION AGRICULTURAL TECHNOLOGIES.

Please indicate your **awareness and knowledge levels** in the use of each of the following components/Tools of Precision Agriculture using the following ratings:

Ratings	**Awareness Level**	**Knowledge Level**
0	Not aware **(NA)**	No knowledge **(NK)**
1	Least aware **(LtA)**	Very poor knowledge **(VPN)**
2	Less aware **(LsA)**	Poor knowledge **(PK)**
3	Fairly aware **(FA)**	Fair knowledge **(FK)**
4	Much aware **(MA)**	Good knowledge **(GK)**
5	Very much aware **(VMA)**	Very good knowledge **(VGK)**

	Precision Agriculture Components	**Awareness Level**							**Knowledge Level**					
														NA
A	**Information or Data base**	**5**	**4**	**3**	**2**	**1**	**0**		**5**	**4**	**3**	**2**	**1**	**0**
1	Soil texture data													
2	Soil structure data													
3	Use of Soil moisture data													
4	Use of Soil nutrients data													
5	Plant population													

6	Crop tissue													
7	Crop stress													
8	Weed patches (weed type)													
9	Weed patches (intensity)													
10	Determining various species of Pest infestation in cocoa													
11	Measuring pest intensity													
12	Measuring Crop yield													
13	Use of Temperature Data													
14	Use of Humidity Data													
15	Use of Rainfall Data													
16	Use of Solar radiation Data													
17	Use of Wind velocity Data													
B	**Technologies/Tools**	**5**	**4**	**3**	**2**	**1**	**0**		**5**	**4**	**3**	**2**	**1**	**0**
1	Global Positioning System (GPS) Receivers													
2	Differential Global Positioning System (DGPS)													
3	Geographic information systems (GIS)													
4	Aircraft- based Remote Sensors													
5	Satellite-based Remote Sensors													
6	Simple hand-held Remote Sensors													
7	Uniform Rate Applicators (URA)	**5**	**4**	**3**	**2**	**1**	**0**		**5**	**4**	**3**	**2**	**1**	**0**
8	Map-based Variable Rate Applicator (VRA)													
9	Sensor-based Variable Rate Applicators (VRA)													
10	Chlorophyll Meter													
11	Yield monitors													
12	Combine harvesters													

C	Management	5	4	3	2	1	0		5	4	3	2	1	0
1	PA information management													
2	PA Decision support system (DSS)													
3	Precision agriculture service providers in Ghana or elsewhere													

SECTIONS C

Perceived Technology Characteristics of Precision Agriculture in Cocoa Production

Please indicate your level of agreement on the following attributes/characteristics of PA technology in Cocoa Production in Ghana.

0=No Agreement
1= Least agree
2=Less Agree
3=Fairly Agree
4= Agree
5=Strongly Agree

	Attributes/Characteristics of PA	**Level of Agreement**					
A	**Relative advantage**	**5**	**4**	**3**	**2**	**1**	**0**
1	PA technologies would be **more profitable** than existing Cocoa technologies						
2	PA technologies would improve the **Social prestige** of cocoa farmers						
3	PA is the **most effective** means of achieving optimum productivity						
4	PA is the **most effective** means of achieving optimum environmental sustainability						
B	**Compatibility**	**5**	**4**	**3**	**2**	**1**	**0**
1	PA technologies would be compatible with **most socio-cultural values and beliefs** of cocoa farmers						
2	PA would be compatible with **previously introduced technologies** by researchers						
3	PA technologies would **fit** with the **current practices** of most cocoa farmers						
4	PA technologies would **be compatible with current needs** of cocoa farmers						
C	**Complexity (Ease of Use)**	**5**	**4**	**3**	**2**	**1**	**0**
1	Cocoa farmers can **easily understand** Precision Agricultural practices						
2	Cocoa farmers can **easily** practise Precision Agricultural Technologies						

D	Trialability	5	4	3	2	1	0
1	Cocoa farmers **can easily use** PA technologies **on trial** bases before they decide to use it full scale						
2	Cocoa farmers **would easily adopt** PA technologies if they are permitted to use the technology **long enough to see the benefits**.						
E	**Observability.**	**5**	**4**	**3**	**2**	**1**	**0**
1	PA technologies and facilities include physical and material objects that are **easy to observe by** cocoa farmers						
2	PA technologies and facilities include physical and material objects that are **easy to describe** to cocoa farmers						
3	Cocoa farmers would **have no difficulty** explaining the pros and cons of PA to other cocoa farmers.						
F	**Voluntariness**	**5**	**4**	**3**	**2**	**1**	**0**
1	Cocoa farmers **would accept** PA technologies when they **are mandated by law from government**						
2	Cocoa farmers **would accept** PA technologies when they **are mandated by** industrial partners (eg. Licensed Buying companies/ cooperatives /NGOs)						
3	Even though PA technologies might be helpful **their use should be optional** for cocoa farmers						

SECTION D
CHALLENGES TO PRECISION AGRICULTURAL DEVELOPMENT AND IMPLEMENTATION IN COCOA PRODUCTION IN GHANA

Please indicate in your opinion the challenges that are likely to hinder PA development and implementation in Cocoa production in Ghana by using the following ratings**: (Please note that your rating of low challenge implies high prospect in this study)**

0=No challenge
1= Negligible challenge = High Prospect
2=Low challenge = Substantial prospect
3= Moderate Challenge = Moderate Prospect
4= Substantial Challenge = Low prospect
5= High Challenge = Negligible prospect

	CATEGORY OF CHALLENGE	5	4	3	2	1	0
A	**Economic challenges**						
1	High Initial cost of Investment						
2	Very Expensive equipment						
3	High Consultancy and Rental fees						
4	High Training and learning costs to use equipment						
5	High interest rate of borrowed capitals						
6	Availability of fund for investment						
7	Accessibility of funds for investment						
8	Obsolesce Potential of hardware						
9	Uncertainty of PA's return on investment						
B	**Educational/Training Challenge**	**5**	**4**	**3**	**2**	**1**	**0**
1	Lack of effective advisory services						
2	Lack of local experts on PA						
3	Lack of research personnel knowledgeable in PA technologies						
4	Lack of extension personnel knowledgeable in PA technologies						
5	Lack of farmers awareness of PA technologies	5	4	3	2	1	0
6	Lack of experts awareness of PA technologies						
7	Farmers Lack of basic knowledge in PA						
8	Lack of consideration of PA topics in various educational institutions						
9	Lack of adequate training resources						
10	Lack of Knowledge in PA software and hardware applications						
C	**Technical challenge**	**5**	**4**	**3**	**2**	**1**	**0**
1	Difficulty of quantifying PA profitability						
2	Lack of PA research centre in Ghana						
3	Incompatibility of machines of different manufacturers						
4	Unreliable equipment (eg sensors, GPS)						
5	Unreliable internet connectivity						

6	Unreliable technician to service the equipment						
7	Lack of access road to farms that inhibits movement of PA equipment						
8	Low mechanization level on cocoa farms						
9	Smaller farms would make PA technology not viable						
10	Lack of standardization in manufacturing of PA tools						
D	**Time Challenge**	**5**	**4**	**3**	**2**	**1**	**0**
1	It takes lengthy time to introduce the PA Technologies						
2	It takes lengthy time to learn how to use the Equipment						
3	It takes lengthy of time to experience any return on the producer's investment.						
E	**Data quality challenges**	**5**	**4**	**3**	**2**	**1**	**0**
1	Difficulty in maintaining quality						
2	Difficulty in storing and retrieving data with different formats,						
3	Difficulty in analyzing data to understand yield limiting factors						
4	Difficulty of data transfer to external sources for analysis						
5	Difficulty of data interpretation						
6	Lack of appropriate measurement and analysis techniques for agronomical important factors						
7	Difficulties in managing large amount of data						
8	Incompatibility of software packages.						
9	Inaccuracy of data concerns						
F	**Farmer/Operator demographic Challenges**	**5**	**4**	**3**	**2**	**1**	**0**
1	Aged farmers						
2	Farmer's low educational level						
3	Lack of computer knowledge						

4	Negative attitude towards new technologies						
5	Farmers resistance to change						
6	Risk averse						
7	Subsistence farmers with low income						
8	Low farming experience						
9	Land ownership /tenure systems problems						
G	**Environmental/abiotic challenges**	**5**	**4**	**3**	**2**	**1**	**0**
1	Undulating (sloppy) topography						
2	Vegetation (mostly Forest /Trees) will make access of machinery to farms difficult						
3	Marshy areas of land will prevent movement of PA Equipment to cocoa farms						
4	Rivers/streams will pose problems for movements of PA equipment.						
5	Lack of accessible roads to farms						
H	**Political /Governmental Challenge**	**5**	**4**	**3**	**2**	**1**	**0**
1	PA technology is not compatible with current government policies in Agriculture and Cocoa in Ghana						
2	Inadequate funds from government (COCOBOD) to develop and implement PA technologies						
3	Less political will to start PA even if funds are available because PA principles and practice may not appeal to politicians/government of Ghana						
4	Precision Agriculture not a priority of COCOBOD /government of Ghana						

Please indicate any other challenge or prospect you think can affect development and implementation of PA in Cocoa in Ghana.
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SECTION E

WILLINGNESS OF COCOA FARMERS TO ADOPT AND PAY FOR PRECISION AGRICULTURAL INNOVATION

Based on your dealings with cocoa farmers throughout Ghana and their attitude towards cocoa innovation, kindly offer your opinion as to their willingness to adopt PA technologies if available to cocoa farmers.

7. Do you think cocoa farmers would be willing to adopt the PA Technologies if it is available?
   b. Yes [ ] b. No [ ]

8. Which of the following main components and tools of PA technologies do you think cocoa farmers would be **willing** to adopt if available. Rate using the ratings
   0=Not Sure (NS)
   1= Strongly Disagree (SD)
   2= Disagree (D)
   3= Somewhat Agree (SWA)
   4= Agree (A)
   5= Strongly Agree (SA)

	STATEMENT	Level of Agreement					
		SA	A	SWA	D	SD	NS
		5	4	3	2	1	0
1	Global Positioning System (GPS) Receivers						
2	Differential Global Positioning System (DGPS)						
3	Geographic information systems (GIS)						
4	Aircraft/Satellite- based Remote Sensors						
5	Simple hand-held Remote Sensors						
6	Yield Monitors						
7	Map-based Variable Rate Applicator (VRA)						
8	Sensor-based Variable Rate Applicators (VRA)						
9	Grid soil sampling and mapping						
10	Crop scouting						

Thank you very Much for your time and effort