

Agricultural Economics
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**Microcredit, Production System and Technical Efficiency of Smallholder
Rice Production in Northern Ghana**

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ACADEMIC DISSERTATION

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Abstract

The purpose of the study was to evaluate technical efficiency in smallholder rice production and how it relates to the production system and participation in agricultural microcredit in Northern Ghana. Smallholder farmers play an important role in agricultural production in Ghana and account for about 80 percent of domestic food production. However, smallholders continue to face challenges concerning access to and utilization of production resources thus constraining their productivity and efficiency. Research has shown that raising the productivity and efficiency of smallholder farmers requires an improvement in access to and utilization of agricultural inputs particularly microcredit, fertilizer and irrigation.

Available statistics show that while global food production is on the increase, many developing countries particularly in Sub-Saharan Africa continue to face the challenge of inadequate food production. The critical factors limiting agricultural production in most of these countries include resource constraints, over-reliance on rainfall, low uptake of improved technologies, weak and poorly developed input and output markets, weak extension service and inadequate government support for agriculture.

This thesis, based on four articles, used data from a farm household survey conducted in 2014 involving 300 smallholder rice-producing households in Northern Ghana. The empirical analysis used both parametric and non-parametric frontier approaches to estimate efficiency. The study also used propensity score matching to account for self-selection arising from non-randomness in assignment of participants into irrigation and microcredit. Probit analysis was used as the selection model to estimate participation in microcredit and irrigation.

In article I, the study estimated technical efficiency and its determinants using an extended Cobb-Douglas stochastic frontier production function. Mean technical efficiency was 63.8 percent, indicating considerable scope for improving the efficiency of production at the current level of technology and input use. Irrigation technology and double-cropping were associated with higher productivity. The study also revealed regional variation in productivity among the producers.

In article II, the study evaluated technical efficiency of microcredit users and non-users using a Cobb-Douglas stochastic frontier production function. The study addressed self-selection into microcredit using propensity score matching. The empirical results showed a non-significant association between microcredit and technical efficiency. The result may be due to the small loan sizes. The study also revealed regional variation in farmers' participation in microcredit.

In article III, the study compared the technical efficiency of irrigators and non-irrigators using a Cobb-Douglas stochastic frontier production function which incorporated an inefficiency effects model. Self-selection into irrigation was addressed using propensity score matching. Based on a heterogeneous production technology assumption, irrigators were found to be 9.2 percentage points more efficient than rain-fed producers. The difference in efficiency was however larger when selection bias was ignored and the wrong technology type was assumed.

In article IV, the study investigated scale efficiency of smallholder rice farmers in northern Ghana using a two-stage data envelopment analysis (DEA). The DEA scores from the first stage were regressed on farm and farmer characteristics using truncated regression with bootstrap to overcome the limitations associated with the standard Tobit model in two-stage DEA models. Smallholder farmers in the study area had a scale efficiency of 69.5 percent. Larger farms were found to be more scale efficient justifying the need for smaller farms to expand their scale of operation. The study also

identified socio-economic factors associated with the scale efficiency of smallholder rice production in the study area.

The results of the study highlight considerable inefficiency in production implying that there is scope for enhancing farmers' level of efficiency. The use of agricultural microcredit by smallholders remains a critical challenge in the study area. Irrigation technology had a positively significant relationship with efficiency and productivity of the farmers while participation in farmer-based organizations was positively related to efficiency of production. Farmer groups are important to smallholder producers because they are effective conduits for extension delivery, access to inputs, agricultural microcredit, among others. Incentivizing these farmer groups will therefore enable them to continue to offer such services to their members.

Keywords: Technical efficiency, irrigation, microcredit, smallholder farmers, Northern Ghana, stochastic frontier analysis, propensity score matching, probit model, selection bias.

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Authors' contribution

The thesis comprises four related articles that investigate technical efficiency and how it is related to the use of agricultural microcredit and irrigation technology. The author is mostly responsible for the conception of the research ideas, the formulation of the research questions, the design of the questionnaire, developing the theoretical framework, empirical work, data collection, and the writing of the manuscript.

In article I, the model was fitted by the first author, Benjamin Tetteh Anang who also suggested the research question. All the authors participated in the construction of the variables for the model. The data analysis was carried out by Benjamin Tetteh Anang with the guidance of the co-authors. Benjamin Tetteh Anang did the writing of the manuscript with the guidance of the co-authors and was the corresponding author for the article. All the authors read through the final draft.

In article II, the first author Benjamin Tetteh Anang suggested the research question, fitted the model and wrote the manuscript with the guidance of the co-authors. All authors constructed the variables for the model. Timo Sipiläinen proposed the propensity score matching approach and provided literature and references on the methodology. The co-authors provided guidance with the application of the propensity score matching. All the authors read and revised the final manuscript. Benjamin Tetteh Anang was responsible mostly for the texts and analysis and was the corresponding author for the article.

In article III, Benjamin Tetteh Anang suggested the research question, performed the analysis and writing of the manuscript with the guidance of the co-authors. Antonios Rezitis and Stefan Bäckman edited the manuscript. All authors constructed the variables for the model and read the final draft. Benjamin Tetteh Anang was the corresponding author for the article.

In article IV, Benjamin Tetteh Anang suggested the research question and conducted the empirical work for the paper including fitting the model, reporting and interpreting the results. All the authors

constructed the variables for the model. Antonios Reztis proposed the Simar and Wilson approach for the analysis. The authors jointly contributed in writing and editing the paper. However, Benjamin Tetteh Anang was responsible mostly for the texts and analysis and was the corresponding author for the article.

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1. Introduction

The measurement of efficiency in smallholder agriculture in developing countries has gained much attention following the seminal work by Schultz (1964) who hypothesized that small-scale farmers are “poor-but-efficient”. Schultz’s hypothesis suggested that smallholder farmers are rational and through learning will make optimal adjustment of their input and output combinations. In the opinion of Schultz, allocation of resources in small-scale farming is characterized by relatively insignificant inefficiency, adding that there are few or no possibilities to increase small-scale agricultural production with current resources except through the introduction of new technologies. Schultz’s hypothesis greatly influenced development thinking at the time and played a critical role in the Green Revolution that brought significant transformation to agriculture particularly in Asia.

However, following the failure of Schultz’s hypothesis, considerable attention has been given to the efficient use of resources as a way of improving productivity and efficiency rather than the introduction of new technologies. Authors such as Herdt and Mandac (1981), Ghatak and Ingersent (1984) and Xu and Jeffrey (1998) identified the cost of new technologies, the unwillingness on the part of small-scale producers to fully adjust input levels due to cultural and institutional constraints as well as farmers’ adaptation to traditional practices as some of the reasons that invalidate Schultz’s hypothesis.

Ghanaian agricultural producers are mainly small-scale farmers who are resource-poor. Furthermore, adoption of new production technologies remains low among Ghanaian smallholders. Empirical investigations of technical efficiency are therefore very relevant in the context of Ghanaian smallholder agriculture in order to ascertain the current level of technology use and the measures to enhance farm productivity by improving the efficiency with existing resources and technologies.

There are different measures of efficiency in the empirical economic literature. Technical efficiency is defined as the attainment of maximum output from a given set of inputs using the existing technology. Alternatively, it is the attainment of a given output using minimum level of inputs. From an input-orientation, technical efficiency describes the situation whereby given a firm’s existing technology, it is unable to produce the same output with less of one or more inputs without increasing the level of other inputs. Technical efficiency is a physical notion and does not take into account price information or the behavioral objectives of the producers. Hence, the avoidance of waste of resources is considered the main objective. Allocative efficiency takes into account the price of inputs as well as the behavioral objective of the producer. Allocative efficiency is defined as the ability of a producer to allocate resources (inputs) in the cost minimizing way, given the respective input prices. Allocative efficiency (from an input-orientation) occurs when the producer uses an input at the point where the price is equal to the marginal cost of production. Economic efficiency is a product of technical and allocative efficiency, and occurs when goods are produced using the least possible combination of inputs (to produce maximum output) and at the least possible cost (to achieve maximum revenue) (Chukwuji et al., 2006).

Producers may also have the objectives of revenue or profit maximization. Hence, the estimation of revenue efficiency (e.g. Bader et al., 2008; Best et al., 2015) and profit efficiency (e.g. Kumbhakar, 1994; Rahman, 2003; Islam, Sipiläinen and Sumelius, 2011) are also common in the economic literature.

Another important measure of efficiency is scale efficiency which measures the effect of scale of operation on efficiency. A farm can be technically efficient but scale inefficient (under variable

returns to scale assumption but not constant returns to scale). Hence, a farm may be using best practices without taking advantage of economies of scale. Smallholders usually operate small farm holdings and the concept of scale efficiency can provide important insight into the ways to ensure efficiency gains from adjusting the scale of production.

There are several methods for analyzing efficiency namely parametric, semi-parametric and non-parametric approaches. The parametric approach typically assumes a functional form and attributes deviations from the production frontier to inefficiency and random noise. The non-parametric approach typically does not require a functional form and attributes all deviations from the frontier to inefficiency (stochastic DEA models now exist that account for the stochastic nature of production). The semi-parametric approach combines some aspects of the parametric and non-parametric approaches. An example of a semi-parametric efficiency analysis in agriculture includes Sipiläinen et al. (2009). The parametric efficiency approach typically employs a stochastic frontier analysis (SFA) (Aigner et al., 1977; Meeusen and van den Broeck, 1977) while the non-parametric approach mainly uses data envelopment analysis (DEA) (Charnes et al., 1978; Banker et al., 1984; Färe et al., 1994). Both the SFA and DEA approaches have been widely used in agriculture to analyze the efficiency of production. In agricultural production there typically is some stochastic variation. In that sense, models that include a stochastic element could be preferable. For that reason, most of the articles comprising the dissertation leaned towards the stochastic approach.

The analysis of efficiency usually involves determination of the level of inefficiency and the factors contributing to inefficiency. The determination of the sources of inefficiency is useful in prescribing policy options to address socio-economic and institutional factors related to inefficiency. In the SFA framework, inefficiency is usually modeled as a function of socio-economic and institutional factors that are regarded to influence efficiency of production. The procedure can be implemented in one stage or in two stages. However, authors such as Kumbhakar et al. (1991), Battese and Coelli (1995) and Wang and Schmidt (2002) have criticized the parametric two-step analysis due to its theoretical inconsistency. Hence, the one-step procedure is employed in this study as in Battese and Coelli (1995). In terms of DEA, the two step procedure has similarly been criticized by authors such as Simar and Wilson (2007) and McDonald (2009). Truncated regression with bootstrap has been suggested by Simar and Wilson for modelling the second stage regression to determine the factors associated with inefficiency.

A common problem in impact evaluation studies is the presence of sample selectivity bias due to the non-randomness in the assignment of participants into participating and non-participating categories. The estimation of the effect¹ of an intervention in the presence of selection bias will lead to biased estimates of the impact so there is a need to account for the selection bias. Heckman's (1979) selection model has been found to be unsuitable in non-linear models by Greene (2010). One commonly used method to account for selection bias in impact evaluation studies is propensity score matching (PSM). The propensity score is the conditional probability of receiving treatment given observed pre-treatment characteristics (Rosenbaum and Rubin, 1983). The propensity score matching technique reduces selection bias by comparing the outcomes for the treated and control groups that are as similar as possible thus eliminating the effects of confounding factors. In the present study, nearest neighbor matching was used to select comparable farm groups according to their participation status in microcredit and irrigation. The PSM subsample was then used in the estimation of efficiency.

¹ The term "effect" as used in the individual articles that constitute this dissertation does not necessarily imply causal relationship (causality).

Several studies have shown the important role of microcredit in agricultural production and technical efficiency of small farm households in developing countries (Hazarika and Alwang, 2003; Dorfman and Koop, 2005). Availability of credit relaxes the liquidity constraint of the farm household and enhances household risk-taking and investment decisions. The lack of credit however sets constraints to adoption of productivity-enhancing technologies. As noted by Chaovanapoonphol et al. (2005), microcredit enhances the technical and allocative efficiency of farmers. In Ghana, credit has been identified as the primary concern of smallholder farmers (Dittoh, 2006). Farmers may have access to credit but may not borrow for various reasons. Hence, the study distinguishes between participation in credit and access to credit, where access means the ability to borrow whereas participation refers to actual uptake of loan. Factors limiting participation in credit may include exclusion factors and refusal to borrow for various reasons including risk aversion.

Several authors have also shown the key role of irrigation in enhancing the productivity and efficiency of small-scale farmers (Lemoalle and de Condappa, 2010; Bhattarai and Narayanamoorthy, 2011; You et al., 2011; Xie et al., 2014). Ghana's rice ecology is divided into irrigated and rain-fed systems. The current study therefore divided the rice production system into irrigated and rain-fed systems. Irrigation infrastructure in Ghana is, however, not well developed and this limits participation of small-scale farmers in irrigation. Diao (2010) reported that only 3 percent of cultivated land is currently under irrigation in Ghana. The current study therefore investigated the efficiency differences between irrigators and non-irrigators, by accounting for selection bias using propensity score matching. The findings from this research will be helpful to guide irrigation policy in Ghana.

The basic motivation for this study arises from the paucity of research on the relationship between microcredit and irrigation, and technical efficiency of small farm households particularly in northern Ghana. The study sought to make a detailed empirical comparison between microcredit borrowers and non-borrowers on the one hand, and irrigators and non-irrigators on the other hand. In addition, the study sought to assess how technical efficiency is related to smallholders' participation in microcredit as well as irrigation. The study was based on the assumption that microcredit and irrigation both enhance technical efficiency – through productive investments by borrowers and regular water supply for rice production by irrigators. The topic of the study is relevant to agriculture in Ghana where smallholder farmers' participation in microcredit and irrigation remains a critical concern. Ghana has a huge irrigation potential that is currently untapped. This study will therefore provide empirical evidence necessary to guide irrigation policy in the country. This is particularly important because rice has been identified by the Government of Ghana as a crop to be promoted to achieve national food self-sufficiency. The study will also help policymakers to formulate policies on agricultural credit and lending to support smallholder farmers in the country. The study also examined the scale efficiency of farms to understand the association between farm size and efficiency. This objective was motivated by the variation in farm sizes among the respondents due to differences in resource endowments including control over agricultural land by farm households. The findings from the study will help to formulate land policies to promote agricultural development in Ghana.

The thesis is organized as follows: section two presents the background information on agriculture and rice production in Ghana. The section also covers the role of microcredit and irrigation in smallholder rice production. The core concepts of microcredit, efficiency, and productivity are also discussed in this section. Section three is devoted to the objectives of the study. Section four covers the data and methods used in the study. This section contains the description of the study area, description of the data collection methods as well as the modeling procedures. Section five presents the results of the study and discussion of the key findings. Section six is devoted to the concluding remarks and suggestions for further research.

2. General Background

2.1 The contribution of agriculture to Ghana's economic development

Agriculture is central to economic development in most developing countries (Diao et al., 2007) and Ghana is no exception. The agricultural sector in Ghana plays a key role in the country's socio-economic development through its contribution to gross domestic product (GDP), employment creation, food security, rural development, among others. Historically, Ghana's economy has relied heavily on the export of cocoa as the main agricultural product and gold as the main mineral resource. The recent discovery of oil has boosted the contribution of the mineral sector to economic development, while the manufacturing and service sectors continue to play important roles in the country's socio-economic development.

Ghana's post-independence era has been characterized by a high dependence on agriculture for economic development. For example, agriculture contributed about 40% to GDP in the late 1990s and even though the contribution of agriculture kept declining with time, it remained above 35% until 2007. Agriculture's contribution to GDP fell to 23% in 2012, declining to 22% in 2013 (GSS, 2014). Estimates for 2014 showed a further decline to 19 percent (GSS, 2015). The decline in the share of agriculture to GDP has been attributed to the faster growth in the service sector (Diao, 2010) as well as growth in the manufacturing sector.

Authors like Timmer (1988), Byerlee et al. (2009), and Cervantes and Brooks (2008) associate a decline in agriculture's share of GDP and employment to economic progress, arguing that this is the result of higher income elasticities of demand for non-agricultural goods and services. The basic explanation is that an increase in income leads to a more than proportionate increase in the consumption of manufactured goods and services relative to the consumption of food.

In the agricultural sector, crops constitute the most important product category with a share of 16.9% of GDP. Cocoa is the most important cash crop providing about 30% of the export revenue (Ashitey, 2012). The agricultural sector has also both forward and backward linkages with other sectors of the economy thus generating additional benefits to the economy in terms of employment creation and income generation. The agricultural sector employs about 50.6% of the Ghanaian labor force and was the largest contributor to foreign exchange earnings in 2010 (MoFA, 2010a).

Ghana's agricultural sector, like in most developing countries, is characterized by smallholder production units, with farm sizes averaging about 2 hectares. According to the Ministry of Food and Agriculture, smallholders constitute more than 90 percent of the farming population in Ghana (MoFA, 2010b). These farm households reside in rural areas where poverty is more common than in urban centers. Since poverty is higher in rural areas where agriculture is the main economic activity, emphasizing agricultural development seems to be the best way out of poverty for rural dwellers. The World Bank in its 2008 Report on Agriculture for Development stated that: "Growth in the agricultural sector contributes proportionately more to poverty reduction than growth in any other sector" (World Bank, 2008, p.1). Growth in agriculture triggers growth in other sectors of the economy leading to poverty reduction. Agricultural growth is therefore regarded as 'pro-poor' (Meijerink and Roza, 2007, p.1).

Some authors have linked growth in the agricultural sector to economic growth (Kuznets, 1959; Kiminori, 1992). According to Tiffin and Irz (2006) growth in agriculture is the main source of

economic growth. Efforts to promote economic development in developing countries such as Ghana therefore require the promotion of agriculture.

Diao (2010) has called for a broad-based agricultural development in Ghana and the acceleration of agricultural growth to raise the country to the status of a middle-income country. She further called for a reduction in yield gaps and the lowering of domestic staple prices through productivity-led growth to enable local products to be able to compete with imports. The author found the possibility of import-substitution for rice, for which domestic production is about 30 percent even though the country was once a net exporter of rice three to four decades ago.

Despite the contribution of agriculture to economic development, the sector is still faced with many challenges that impede its growth (see Diao, 2010). These challenges include low yields due to reliance on natural rainfall and low adoption of improved production technologies. There are also challenges of low product prices, high input prices, and suboptimal use of production inputs, which are disincentives to production. Other challenges include weak institutional support, in the form of weak extension service and credit markets, inadequate supply of irrigation infrastructure, among others. These challenges have direct and indirect effects on the technical efficiency and productivity of Ghanaian smallholder farmers. Addressing these problems, particularly the issues of low yield and inefficiency in resource use will therefore spur growth in the agricultural sector and hence contribute to the socio-economic development of Ghana.

2.2 Rice production in Ghana

Rice production in Ghana is an important economic activity for food security and income generation among smallholders. Rice is one of the major cash crops because of its market value. The country has a long history of rice production and was once a net exporter of the crop in the 1970s and 1980s.

The Government of Ghana has identified rice as a major food and cash crop grown by smallholders. Under the Food and Agricultural Sector Development Policy (FASDEP), rice is considered an important crop for national food self-sufficiency. Several national policies and projects are also targeted at domestic rice production in order to improve domestic cultivation of the crop, reduce the rice import bill, create employment and income of farmers as well as enhance the efficiency of production through the provision of services and production inputs to farmers. For example, the National Rice Development Strategy (NRDS) seeks to double domestic cultivation of the crop to achieve food self-sufficiency. The objective of the Inland Valley Rice Development Project is to increase the production of good quality rice to enhance food security, reduce rice importation and increase incomes of smallholder rice farmers, marketers and processors. The Rice Sector Support Project on its part seeks to improve livelihood of poor rice farmers especially in northern Ghana by transforming rice production into a sustainable economic activity. The project is targeted at lowland rice production. Furthermore, the Sustainable Development of Rain-fed Lowland Rice Production Project was implemented between 2009 and 2014 to improve productivity and profitability of rice farmers in the project areas (Northern and Ashanti Regions). Other measures to improve domestic rice cultivation are a national fertilizer input subsidy for cereal producers, investments in irrigation infrastructures, and provision of agricultural mechanization and extension services to producers across the country.

Northern Ghana is important for domestic rice production in Ghana. Reporting on data from the Statistical, Research and Information Directorate (SRID) of Ghana's Ministry of Food and

Agriculture (MoFA), Angelucci et al. (2013) showed that northern Ghana, comprising the Upper East, Upper West and Northern Regions jointly produced 67.8% of the rice produced in Ghana in 2010.

Rice production is estimated to provide 10% of Ghanaian households with employment (MoFA, 2009). About 295,000 Ghanaian households are engaged in rice cultivation for food and income security. Rice production in Ghana can be classified by the agro-ecology. Irrigated rice comprises 16% of domestic rice production, rain-fed lowland rice production accounts for 78%, while rain-fed upland system constitutes 6%. In 2008, the total area cropped to rice was 118,000 hectares and the average household rice land holding stood at 0.4 hectares. According to FAO (2005), the yield of irrigated rice is between 3.5 and 7.0 tons, which gives an average yield of about 4.6 tons/ha. Yield under uncontrolled water conditions is however between 1.0 and 1.5 tons/ha, while sawah rice without fertilizer application gives an average yield of 2 – 2.5 tons/ha.

Ghana's gross production of paddy in 2012/2013 was estimated at 481,010 tons while the gross production of milled rice for the same period was estimated at 331,897 tons. Rice yield remains low at 2.5 tons/ha. The achievable yield is however estimated at 6.5 tons/ha. This means that Ghana's average rice yield represents only 38.5% of the achievable yield.

2.3 The role of irrigation and credit in smallholder rice production

Improving the productivity and efficiency of agricultural production is seen as an important route out of poverty and food insecurity in many parts of the developing world including Ghana. Following the success of the Green Revolution in Asia, many researchers have envisaged similar productivity growth in Sub-Saharan Africa where yield levels remain low compared to other parts of the world.

The drivers of productivity and efficiency growth in smallholder agriculture have been shown to include factors such as irrigation, credit and extension services, improved crop variety adoption, among others (Bhasin, 2002; Makombe et al., 2007; Omonona et al., 2010; Reyes et al., 2012). These studies highlight the need to improve access to and utilization of these services and factors of production in order to enhance agricultural productivity among smallholders who are typically resource-poor.

Agricultural credit has been shown to influence farmers' efficiency of production (Hazarika and Alwang, 2003; Dorfman and Koop, 2005). Microcredit can enhance technical and allocative efficiency of farmers as shown by Chaovanapoonphol et al. (2005). Credit can also enhance agricultural productivity and efficiency of production by allowing farm households to hire-in labor, acquire and use production inputs in optimal quantities and at the right time. On the other hand, farmers who are credit-constrained are more likely to misallocate resources and under invest in production. Provision of microcredit therefore affords households facing cash constraints the opportunity to borrow to finance important farm operations.

Irrigation is another important factor that promotes agricultural growth, productivity and efficiency among smallholders (Hussain and Hanjra 2003; Hussain and Hanjra 2004; Bhattarai and Narayanamoorthy, 2011). Several authors have highlighted the productivity-enhancing role of irrigation in smallholder agriculture (Lemoalle and de Condappa, 2010; You et al., 2011; You et al., 2014; Xie et al., 2014). Furthermore, improved agricultural production has been recorded in Sub-Saharan Africa countries where irrigation infrastructure is well developed (Adekalu et al., 2009; Lemoalle and de Condappa, 2010).

Provision of irrigation remains very low in Ghana (Kuwornu and Owusu, 2012) which is a drawback to agricultural production (ISSER, 2006). According to Diao (2010), only 3% of total crop area in Ghana is under irrigation. Ghana's rice ecology is classified into irrigated, rain-fed upland and rain-fed lowland production with irrigated rice production accounting for only 16%. Northern Ghana where most of the rice is produced is located in the Guinea Savannah and experiences a single rainfall regime. As a result, farmers without irrigation are unable to cultivate rice during the long dry season that lasts for about seven to eight months.

According to Namara et al. (2011), Ghana's irrigation system may be classified into public systems, small reservoirs and dugouts, river/lake lift private systems, and groundwater systems. Namara et al. (2010) also divide Ghana's irrigation typology into conventional irrigation systems and emerging irrigation systems as shown in Table 1.

Table 1: Typology of irrigation systems in Ghana

Conventional Irrigation Systems	Emerging Irrigation Systems
1. Public Surface Irrigation Systems	Groundwater Irrigation Systems
2. Small Reservoir-based Communal Irrigation Systems	River Lift Irrigation Systems
3. Domestic Wastewater and Storm Water Irrigation	Public-Private Partnership-based Commercial Irrigation Systems
4. Recession Agriculture or Residual Moisture Irrigation	Lowland/Inland Valley Rice Water Capture Systems
5. Traditional Shallow Groundwater Irrigation	Small Reservoirs/Dugout-based Private Irrigation Systems

Source: Namara et al. (2010).

The study covered smallholder rice farmers operating under public surface irrigation systems in northern Ghana. There are about 22 public surface irrigations systems in Ghana managed by the Ghana Irrigation Development Authority (GIDA). Out of the five largest public irrigation systems in the country, three are located in northern Ghana: Tono, Vea and Botanga Irrigation Schemes. These three irrigation schemes comprise 43.3% of total area of developed land and 64.3% of total area of irrigated land in Ghana (Miyoshi and Nagayo, 2006)².

2.4 Core concepts: microcredit, productivity and efficiency

2.4.1 The concept of microcredit

The terms microfinance and microcredit are often used interchangeably even though they do not mean the same thing. Microfinance refers to small loans given to an individual by a lender (usually a lending institution) as well as the provision of other financial services such as savings, insurance and transfers. Microfinance therefore provides a mix of financial services to clients considered too poor to borrow from formal financial institutions. Microcredit on the other hand refers to small amount of money given as loans to an individual (or client) by a lender (e.g. financial institution or individual lender). Agricultural microcredit refers to small loans to farmers to improve their production activities. Microcredit is often targeted at very poor clients and may be offered to individuals or groups, with or without collateral. Group lending aims at overcoming problems associated with information asymmetry and moral hazards in lending.

² The figures represent the author's own calculations from data obtained from the cited source.

Microcredit contrasts with microfinance (MF) mainly in terms of the services involved. Microfinance deals with a mix of products including microcredit and other loans, savings mobilization, insurance, transfers, and other financial services that meet the needs of low-income clients. In many rural areas of developing countries, the microfinance sector is not well-developed. Consequently, the microfinance sector tends to offer limited financial products and services to clients, notably microcredit provision and savings mobilization.

Agricultural microcredit is an important component of financial services. The importance of microcredit (and microfinance in general) to agricultural development in developing countries has been acknowledged by many authors (Omonona et al. 2008; Owusu-Antwi, 2010; Islam, Sipiläinen and Sumelius, 2011; Boniphace et al., 2015). Other studies include Rezitis et al. (2003) who explored the factors influencing the technical efficiency of participants in farm credit programs in Greece as well as Rada and Valdes (2012) who studied rural credit and the efficiency of Brazilian agriculture. Microcredit enables capital acquisition and adoption of improved production technologies by farmers. Microcredit is also used as consumption loan to finance household consumption in times of adversity.

The provision of credit is one of the most important concerns of farm households in northern Ghana where agriculture is the main economic activity (Dittoh, 2006). Improving the provision of microcredit to farmers could therefore enhance agricultural production by small farm households in northern Ghana.

2.4.2 The concepts of efficiency and productivity

Production functions have been traditionally used to model the relationship between physical inputs and outputs of a firm and the underlying production technology. Conventional econometrics use production, cost and profit functions with the assumption that producers efficiently use their resources and produce maximum output given the production technology (Kumbhakar and Lovell, 2000). Traditional production approach assumes that producers are successful in solving their optimization problems. Any departure from the production (or cost, profit, etc.) function is attributed to randomly distributed statistical noise. Kumbhakar and Lovell (2000) have highlighted the limitations of the traditional approach in modeling production performance and hence many econometricians have moved towards frontiers approach. As indicated by Kumbhakar and Lovell (2000), producers are not always successful in solving their optimization problems. The development of frontier analysis can be traced to Koopmans (1951) who stated that a production unit is efficient 'if, and only if, it is impossible to produce more of any output without producing less of some other output or using more of some input'. Debreu (1951) and Shephard (1953) took a cue from Koopmans' work to develop models which linked the distance function to technical efficiency. Farrell (1957) became the first to employ this approach to measure technical efficiency in agriculture. Aigner et al. (1977) and Meeusen and van den Broeck (1977) independently proposed the stochastic frontier production function with a composite error term thus allowing the production frontier to be stochastic. Charnes et al. (1978) subsequently developed data envelopment analysis (DEA) as another frontier analysis method. Many variants of DEA models have been developed since Charnes et al. (1978).

Total factor productivity is defined as the ratio of a firm's output quantity to its input quantity (Lovell, 1993) and includes all input variables used in the production of one output. Partial productivity however relates output quantity to a given input quantity (as opposed to a set of input quantities). The concept of productivity therefore relates how much output is produced from a given input or set of inputs. A producer who is able to produce more output from a given input or set of inputs than another producer is said to be more productive.

The efficiency of a production unit is a relative concept that compares observed and optimal values of the firm's output and input (Lovell, 1993). The concept of technical efficiency compares the ratio of observed to maximum attainable output from a given input quantity. Alternatively, it may compare the ratio of minimum to observed input needed to produce the given output. A technically efficient firm produces at the maximum output, given the quantities of inputs and the available technology (Amaza and Maurice, 2005). Alternatively, a technically efficient firm produces a given output with minimum inputs. A producer who produces in such a way to minimize total production cost is said to be allocatively efficient (Field, 1997). Allocative efficiency "measures a firm success in choosing an optimal set of inputs with a given set of input prices" (Daraio and Simar, 2007, p.15). Allocative efficiency is attained at the point where the producer equates the price of the input to the marginal value product of the input (or the marginal rate of technical substitution equals the price ratio). Economic (overall) efficiency is the product of technical and allocative efficiency and occurs when a firm combines its inputs in the least possible combination (to produce maximum output) and at least possible cost (to achieve maximum revenue) (Chukwuji et al., 2006).

Onumah et al. (2009) noted that improved production technologies may be available to small-scale farmers but their uptake may be hindered by factors such as weak extension service delivery as pertains in many developing countries including Ghana. The authors therefore called for an improvement of the efficiency of production in the situation where technological innovations are not being used by farmers to initiate productivity growth.

2.5 Efficiency estimation approaches

The estimation of efficiency can be classified into the following three approaches: parametric, non-parametric and semi-parametric estimation. The non-parametric efficiency estimation typically uses data envelopment analysis (DEA) which may or may not account for the stochastic nature of production. The non-parametric approach does not require the specification of a functional form. Here, efficiency is referenced to the best producing farm/farms such that all deviations from the optimum output are attributed to inefficiency. This approach has been considered less appropriate by some authors for analyzing agricultural production in particular due to the inherent stochasticity in production. As noted by Zoltan (2011), the non-parametric (DEA) approach has shortcomings including sensitivity of the efficiency estimates to outliers as well as the potential bias in the estimated efficiency arising from the exclusion of potentially more efficient decision-making units. The approach has however been widely used in the context of agricultural production (Coelli et al., 2002; Hambrusch et al., 2006; Islam, Bäckman and Sumelius, 2011; Watkins et al., 2014; Rahman and Awerije, 2015) and other fields such as engineering, banking, manufacturing among others (Bjurek et al., 1990; Førsund, 1992; Rezitis, 2006; Wanke, 2012; Rezitis and Kalantzi, 2016).

With regard to the parametric efficiency approaches, the stochastic frontier analysis (SFA) is commonly used. The stochastic frontier analysis (SFA) was developed simultaneously but independently by Aigner et al. (1977) and Meeusen and van den Broeck (1977). The stochastic frontier analysis (SFA) takes into cognizance the stochasticity of agricultural production and models efficiency as a function of farm, household and institutional factors that limit the attainment of maximum output. The SFA is based on the assumption that maximum output may be unattainable due to inefficiency. SFA decomposes the error term into pure random effect that takes account of measurement errors and other factors beyond the control of the producer (such as weather) and a non-negative error term that measures inefficiency (or the systematic deviation from the production frontier). The approach has been widely used in the context of agricultural production by authors such

as Rezitis et al. (2003), Bäckman and Lansink (2005), Sumelius and Bäckman (2005), Mayen et al. (2010), and Bäckman et al. (2011).

The determination of the appropriate functional form of the production function is an important procedure in parametric efficiency analysis. Since the production function depicts the technology under consideration, it is required to correctly identify the functional specification of the frontier as well as the distributional assumptions of the composite error term. In terms of the functional form, we can distinguish the Cobb-Douglas and translog functional forms. A third, and less used functional form is the quadratic/extended Cobb-Douglas specification which is less restrictive than the Cobb-Douglas but more restrictive than the translog specification. Usually, a Cobb-Douglas production function with second order terms that are not in logarithmic form is referred to as a quadratic function. However, we have an extended Cobb-Douglas production function when the second order terms are added to the Cobb-Douglas specification. The distributional assumptions of the composite error term leads to a half-normal distribution or a truncated normal distribution. These distributional assumptions are formally tested and the correct specification chosen based on the theory of production.

A third classification of efficiency estimation approaches is the semi-parametric approach which combines some aspects of the parametric and non-parametric approaches. This approach is less common in the analysis of efficiency in agriculture and was therefore not considered in the current study. Sipiläinen et al. (2009) used a semi-parametric two-stage approach involving DEA efficiency scores and truncated regression to assess the performance of Finnish dairy farms.

An important contribution of this study is the case made for an explicit test to determine the production technology type when comparing the efficiency of production. Most researchers make the implicit assumption of a homogeneous production technology when comparing efficiency of production between different production systems. However, as shown by Stigler (1976) and Mayen (2010), failure to test for the technology type may result in misleading results. The results of this study highlight the importance of an explicit test of the homogeneous technology assumption.

2.6 Sample selection bias and propensity score matching

The evaluation of the impact of an intervention or innovation using observational data usually presents the challenge of dealing with sample selection bias. Sample selection bias arises when assignment of respondents to the treated and control groups is not random. For example, participation in microcredit or irrigation may be non-random due to farmers' unwillingness to participate or the existence of some exclusion factors. Farmers with certain innate abilities may also self-select into credit or irrigation. One approach used to reduce the bias in comparisons between the treated and control groups is propensity score matching (PSM). Rosenbaum and Rubin (1983) defined the propensity score as the conditional probability of receiving treatment given pre-treatment characteristics. PSM takes into account the observed differences between the treated and control groups, but does not account for unobserved heterogeneity. The propensity score matching technique reduces selection bias by comparing the outcomes for the treated and control groups that are as similar as possible. The procedure involves the matching of the treated and untreated units to eliminate the effects of confounding factors. Due to the infeasibility of matching respondents based on a multidimensional vector of covariates, the PSM method summarizes these characteristics into the propensity score, $p(X)$, which is a single-index variable (Katchova, 2010).

The outcome of interest in this study is efficiency. The treatment variable, D is binary which may represent participation in credit or irrigation: where $D = 1$ for participants (or the treated), and $D = 0$

for non-participants (the control). The propensity score is expressed as $p(X) = \Pr(D = 1 | X) = E(D | X)$. The propensity score $p(X)$ is then used to match the participants and non-participants according to their observed characteristics X_i .

3. Objectives of the study

The study sought to make a systematic empirical analysis of how the technical efficiency in smallholder rice production in Northern Ghana is associated with the type of production system (irrigated versus rain-fed) and the participation in agricultural microcredit. Specifically, the study sought to achieve the following objectives: (1) to estimate technical efficiency and its determinants in smallholder rice production in Northern Ghana; (2) to evaluate technical efficiency differential between microcredit users and non-users; (3) to assess the relationship between the production system (irrigation versus rain-fed technology) and technical efficiency, and (4) to investigate the scale efficiency of smallholder rice farms in the study area.

Lack of credit for production may set a constraint that limits the productive capacity of farmers. Credit can enable the acquisition and use of improved technology leading to higher efficiency and productivity. The first objective sought to estimate technical efficiency of smallholder farmers as well as the factors associated with inefficiency. This was intended to provide a measure of the level of efficiency. The second objective sought to evaluate the technical efficiency differential between microcredit users and non-users while the third objective assessed the relationship between the system of production (irrigation versus rain-fed production) and technical efficiency. The fourth objective was to investigate scale efficiency and its determining factors among the respondents.

4. Data and methods

4.1 Description of the study area

Ghana is a tropical country with a population of about 25 million people. The country is divided into ten administrative Regions. The study was carried out in Northern Ghana, which comprises three administrative Regions namely the Upper East, Upper West and Northern Regions. Ghana has a total land area of 238,540 km² and a warm humid climate suitable for the cultivation of most tropical crops. The country is made up of six ecological zones, viz. the rain forest, the deciduous forest, the transitional zone, the Guinea Savannah, the Sudan Savannah, and the Coastal savannah. The forest vegetation, transitional zone and coastal savannah experience a bimodal rainfall distribution resulting in two growing seasons – the major and the minor growing seasons. On the other hand, the Guinea and Sudan savannahs which together make up the three Regions of Northern Ghana experience a single rainfall regime resulting in a single cropping season per annum for most crops. The Botanga, Veve and Tono Irrigation Schemes which are among the main irrigation schemes in Ghana are located in northern Ghana and these enable farmers to produce high-value crops such as rice and vegetables particularly during the dry season. Northern Ghana was chosen for the study because of its important contribution to domestic rice production.

4.2 Data collection procedures

The data used in this study was obtained from a farm household survey carried out for the 2013/2014 farming season. Rice-producing households were sampled from the three major irrigation schemes located in Northern Ghana using multistage stratified random sampling. We first identified the major irrigation schemes in Northern Ghana, namely the Botanga Irrigation Scheme in the Northern Region and the Veve and Tono irrigation Schemes in the Upper East Region. Five communities were then

selected at random from each irrigation scheme. Next, there was stratification of the respondents into irrigators and non-irrigators. The sampling was conducted to include equal number of irrigators and non-irrigators. A total of 300 respondents were included in the sample. A face-to-face interview was conducted with each respondent with the aid of a detailed questionnaire which was pre-tested. Most of the farmers did not keep farm records and this meant that the enumerators had to rely on farmers' ability to recall. To enhance the reliability of the data, it was ensured that the data collection took place within a reasonably short time after the harvest.

4.3 Modeling procedures

The thesis consists of four (4) interrelated articles on technical efficiency of rice production in northern Ghana. Both parametric and non-parametric approaches were used in the thesis to estimate the efficiency of production. For the parametric approach the study used stochastic frontier analysis (SFA) while for the non-parametric approach the study used data envelopment analysis (DEA). The SFA employed maximum-likelihood estimation while an input-oriented DEA was used in the non-parametric approach. The inherent stochastic nature of agricultural production and the fact that the data used for the study were obtained by relying on farmers' recall make the stochastic frontier approach more appropriate for the analysis of farm efficiency. Hence, three of the articles (Articles I, II and III) used the SFA to estimate technical efficiency as well as its determinants, while the DEA approach was used in the last article (Article IV) to estimate scale efficiency.

The estimation of the stochastic frontier models in each of the three articles employing the SFA followed the Battese and Coelli (1995) approach where the production function and the inefficiency effects model were estimated simultaneously in a single step. Frontier 4.1 (Coelli, 1996a) was used to analyze technical efficiency in Article I while Stata version 14 was used to analyze technical efficiency in Articles 2 and 3. The computer program DEAP (Coelli, 1996b) was used to analyze scale efficiency in Article IV.

In order to obtain unbiased results of the relationship between microcredit and technical efficiency as well as irrigation and technical efficiency, the study addressed sample selection bias using propensity score matching in Articles II and III. Nearest-neighbor matching technique was used to estimate the propensity score while the common support restriction was imposed to improve the quality of matching (Katchova, 2010). The propensity score analysis was carried out using Stata version 14.

In comparing technical efficiency of the different farm groups (i.e. irrigators versus non-irrigators; credit users versus non-users), the study tested the hypothesis whether the input mix which defines the technology between the farm groups is the same. Assume we want to test whether irrigators and non-irrigators use the same technology. This is done by estimating a joint frontier for both irrigators and non-irrigators and testing for the joint significance of the irrigation dummy and its interaction with the other input variables. A chi-squared test is used to decide whether the two groups employ the same technology in production. Rejection of the null hypothesis (homogeneous technology) implies that the two groups use different technologies in production. Based on the test result, we estimate the production function by including the irrigation dummy as an additional variable as well as its interaction with the other input variables (referred to as the heterogeneous technology) or we estimate the model without the irrigation dummy and its interaction with the other input variables (referred to as the homogeneous technology).

In Article I, the stochastic frontier analysis was used to estimate technical efficiency as well as the determinants of inefficiency. An extended Cobb-Douglas production function was specified based on

a priori test of the appropriate functional specification using the generalized likelihood ratio test. The extended Cobb-Douglas functional form, which is more restrictive than the translog specification but less restrictive than the Cobb-Douglas specification, was preferred above both the translog and Cobb-Douglas specifications. The study assumed a homogenous technology for the farms mainly because the study did not involve a comparison of farm groups. However, the irrigation dummy was included in both the production function and the inefficiency equation because it was considered to have productivity effect (shift in the frontier) as well as influence on efficiency. Battese and Coelli's (1995) single-stage estimation approach was used to obtain estimates of efficiency as well as the determinants of inefficiency. Frontier 4.1 (Coelli, 1996a) was used to obtain estimates of the technical efficiency of production.

In Article II, a stochastic frontier analysis was used to estimate technical efficiency as well as the determinants of inefficiency. Due to the presence of selection bias arising from non-randomness in the participation in credit, propensity score matching was used to match participants to non-participants, thus addressing self-selection (selection bias). The procedure ensured that a comparable group of participants and non-participants were obtained for the efficiency analysis. Based on a formal test of the functional form of the underlying production function, the Cobb-Douglas specification was preferred and used to estimate the technical efficiency for the sub-sample of participants and non-participants. Stata version 14 was used to carry out the propensity score matching and technical efficiency analysis. For this study, the homogeneous technology test was carried out with credit as the variable of interest. The test failed to reject the homogeneous technology assumption implying that users and non-users of credit employed the same technology in production. The study however did not report the homogenous technology in the article.

Article III used a methodology similar to the one in Article II. A stochastic frontier model was estimated to obtain efficiency scores and the determinants of inefficiency. Propensity score matching was used to select comparable groups of irrigators and non-irrigators for the efficiency analysis. The propensity score matching addressed self-selection into irrigation in order to provide unbiased estimates of the impact of irrigation on technical efficiency. A Cobb-Douglas production function was assumed for the study. Stata version 14 was used to carry out the propensity score matching and technical efficiency analysis. The homogeneous technology test was carried out for this study. The test rejected the homogeneous technology assumption implying that irrigators and rain-fed farms employed different technology in production.

In Article IV, a non-parametric efficiency approach was used to estimate the scale efficiency of the farmers. An input-oriented DEA model was estimated under constant returns to scale (CRS) (proposed by Charnes et al., 1978) and variable returns to scale (VRS) (proposed by Banker et al., 1984). The computer program DEAP (Coelli 1996b) was used to estimate the efficiency scores, namely overall technical efficiency, pure technical efficiency and scale efficiency. In the second stage analysis, a truncated regression with bootstrap was used due to the shortcomings of the Tobit model in a two-stage DEA analysis (McDonald, 2009). According to Simar and Wilson (2007), the DEA estimates from the first stage analysis are prone to complex correlations while the procedure does not have a well-defined data generation mechanism. Hence, the Tobit regression is unsuitable for the second stage analysis. A truncated regression with bootstrap following the procedure by Simar and Wilson (2007) was used in the second-stage analysis to assess the relationship between farm size together with other household and farm characteristics, and scale efficiency. The Simar and Wilson approach uses simulation to generate artificial bootstrap samples to construct standard errors and confidence intervals for the second stage analysis.

4.4 Choice of variables for the study

The study relied on household survey data. The choice of variables for the efficiency analysis was based on economic theory as well as the current literature. The variables included conventional factors of production namely land, labor, seed, fertilizer, expenditure on other variable inputs and capital. The land variable comprised the area of land (farm size) in hectares used to cultivate rice. The labor variable comprised both family and hired labor. Fertilizer was measured as the quantity of chemical fertilizer used in production. The capital variable was defined to include the value of small farm equipment such as spraying machines, bullock plows and carts, cutlasses, and hoes. Farm-level data included farm size, degree of specialization in rice production, input and output levels and their respective prices, among others. The study also included the following characteristics of the household head: age, gender and educational level (or status). These variables were used because the farm household is a decision-making unit and the household head is assumed to be the most important person in decision-making that relate to farm production. Even though the characteristics of other household members may play a role in the household's production, the study did not account for those factors. The approach used in this study is in line with other studies (e.g. Coelli et al., 2002; Bäckman et al. 2011) that focused on the headship of the household. Other household characteristics included household size, the number of adult working members, and the dependency ratio. Institutional factors included participation in microcredit, irrigation and fertilizer input subsidy. For the credit dummy variable, a farmer who used credit for farming was designated as "credit user" and vice versa. Farmers obtained credit from formal and informal lenders. The study, however, did not distinguish between formal and informal credit sources although it is possible that the different sources of credit may differ in their influence on efficiency. The credit variable therefore represents the use of borrowed funds to carry out production during the farming season.

For the analysis of the factors determining inefficiency in rice production, the model included farm, household, institutional and geographical factors. This was in line with economic theory and current literature. Notable among the variables used in the study are the age, gender, educational level/status and years of farming experience of the household head, use of microcredit, extension contact, participation in off-farm work, use of irrigation, herd size/herd ownership, association membership, among others (see Coelli et al., 2002; Bäckman et al. 2011; Islam, Bäckman and Sumelius, 2011; Islam, Sipiläinen and Sumelius, 2011; Al-hassan 2012).

Most of the variables in the inefficiency model are expected to have a positive association with efficiency but age and participation in off-farm work are expected to have either positive or negative association with efficiency. For example, education and extension visits are expected to enhance human capital and the ability to take advantage of opportunities to advance production. Similarly, farming experience is expected to enhance the knowledge and skills of the producers while membership in farmer-based organizations is expected to enhance acquisition of production inputs and access to services. Thus, farming experience and membership in farmer-based organizations are expected to be positively associated with efficiency. The use of irrigation and credit are anticipated to be positively associated with efficiency of production because credit allows farmers to acquire the needed production inputs on time and in the optimal quantities while irrigation enables producers to overcome water shortage. Participation in off-farm work can have either positive or negative association with technical efficiency of farming because it can lead to allocation of labor away from farming (which can reduce labor availability for production) or have a liquidity-relaxing effect on production which can ensure the acquisition of farm inputs. Age is anticipated to have an indeterminate association with technical efficiency because younger farmers may be more

adventurous and enthusiastic about new farming methods while older farmers may be more conservative but may have more family labor to deplore in farming.

5. Results and discussion

The objective of the study was to empirically investigate the role of agricultural microcredit and the production system (irrigated versus rain-fed rice production) in farm performance and technical efficiency of production of small-scale agrarian households in northern Ghana. The study focused on smallholder rice producers because smallholders constitute about 90 percent of all farmers in Ghana. The four articles that comprise this thesis focused on the same topic, technical efficiency, using different estimation approaches (SFA in articles I, II and III, and DEA in article IV). The discussions in each article are interrelated because the study used the same data set to answer all the research questions which are covered in each of the articles. This section provides a summary of the results as contained in each article and a discussion of the main findings, the main contributions of the study to the existing literature on efficiency and productivity, and the general conclusions based on the study.

5.1 Technical efficiency and its determinants in smallholder rice production in Northern Ghana (Article I)

The existence of substantial technical inefficiency in production and low levels of productivity have been reported in smallholder agriculture in most developing countries including Ghana. The important role of agriculture in the socio-economic development of most developing countries calls for measures to address the gaps in efficiency and productivity of smallholder farmers. Improving the efficiency of resource use at the current level of technology has been identified as a key strategy to improve agricultural productivity in smallholder agriculture in order to achieve the goals of food security and increasing household income. Consequently, much of the research attention in the agricultural sectors of developing countries has been focused on measures to enhance the efficient use of available resources and the existing technology.

The Food and Agriculture Organization (FAO, 2015, p.2) observed that in Ghana “agriculture remains largely rain-fed and subsistence-based, with rudimentary technology used to produce 80 percent of total output.” It further added that food production by smallholders “is still characterized by low productivity” (FAO, 2015, p.2). It was in this light that the current study was proposed to assess the technical efficiency of Ghanaian smallholder rice farmers and the determinants of inefficiency in order to understand the current state of farm performance and measures to improve upon the efficiency level. It was the anticipation of the authors that the results would go a long way to improve the productivity of smallholder farmers in Ghana. The estimation of farm-level technical efficiency may provide an understanding of how farmers use existing technologies and the potential that may exist for improving productivity through an improvement in farmers’ efficiency. Furthermore, the result may prove useful to policymakers in addressing certain aspects of farm household characteristics that influence productivity and efficiency.

The first article in the dissertation focused on estimating technical efficiency and its determinants among farm households in the study area. A stochastic frontier production function was used to measure the efficiency of production. The model incorporated an inefficiency effects model to measure the determinants of inefficiency. Factors such as irrigation, cropping intensity and geographical location (regional dummy) were included in the production function as intercept shifters to account for productivity differences.

The choice of the functional form for the production function was based on the generalized likelihood ratio test. The extended Cobb-Douglas functional form (quadratic specification) was preferred to the translog and Cobb-Douglas specifications. The inefficiency effects model also contained variables such as use of microcredit, degree of specialization in rice production, membership in a farmers' organization, participation in extension services, and participation in off-farm work which are important determinants of inefficiency in the productive efficiency literature. The gender and age of the household head and the rice variety planted were also included in the inefficiency model. The selection of variables was based on production economic theory as well as the current literature on efficiency analysis. As in other studies, the household head was considered to be the most important decision-maker in the household.

The results from the analysis indicated a mean technical efficiency score of 63.8 percent, with the scores ranging between 3 and 93 percent. Hence, producers in the study area could potentially increase their technical efficiency by 36.2 percentage points at the current level of input use and existing technology. The result is quite similar to the technical efficiency scores obtained in Articles II, III and IV. The result is at variance with Schultz's (1964) hypothesis that small-scale farmers in traditional agricultural production are "poor-but-efficient. As shown by this study, there are significant efficiency gains to be derived if farmers use resources more efficiently in production at the current level of technology.

Expenditure on other variable inputs had the highest output elasticity, followed by land and labor. Capital had the least output elasticity. The output elasticities of labor, other costs, and capital increased at an increasing rate suggesting that producers may be constrained in their use of these production inputs. The output elasticity of seed however increased at a decreasing rate according to *a priori* expectation of the authors since over-seeding is likely to reduce output and productivity levels. The return to scale was measured at 0.94 indicating diminishing returns to scale in rice production in the study area. The result is consistent with the results in Articles II and III but at variance with the result in Article IV which indicated that majority of the farms operated at increasing return to scale. Increasing returns to scale in production has been reported by authors such as Ajibefun and Abdulkadri (2004), Singbo and Lansink (2010), Bhatt and Bhat (2014) and Wondemu (2016). On the other hand, authors such as Bielik and Rajcaniova (2004), Nyagaka et al. (2010) and Rosli et al. (2013) have reported decreasing returns to scale in their studies. The difference in the returns to scale measures is attributed to the different models used in this study. In the first three articles, a stochastic frontier analysis (SFA) was used to estimate the production function which incorporated dummy variables to account for productivity differences (e.g. between irrigators and non-irrigators). On the other hand, the data envelopment analysis (DEA) model used to estimate the production function in article IV did not take into account those productivity differences.

About 95 percent of the inefficiency of production was explained by the inefficiency effects model. The intercept dummy variables included in the production function to measure productivity shifts showed that farmers in the Northern Region together with producers who double-cropped their land and users of irrigation were located on a higher production frontier indicative of higher productivity. The findings are consistent with results in Articles II and III. The result shows that irrigation enhances rice production in the study area. Increasing smallholder farmers' access to irrigation is therefore an important policy measure.

The study also measured the determinants of efficiency (or by implication, inefficiency). The technical efficiency of production was higher for male farmers, producers who are more specialized in rice production, and members of farmers' associations, but lower for household heads with more

years of formal education. These variables therefore play important roles in rice production efficiency in the study area. The results are largely consistent with the findings of the other articles in the dissertation.

5.2 Agricultural microcredit and technical efficiency: The case of smallholder rice farmers in Northern Ghana (Article II)³

The important role of microcredit in enhancing the technical efficiency of smallholder farm households is well acknowledged in the economic literature. Microcredit has also received wide recognition and considerable research attention in recent times due to its critical role in raising the productivity and efficiency of farm households. Smallholders' low use of microcredit has also been highlighted in the economic literature despite the important role of credit in smallholder production.

Ghana's agricultural policy focuses on the improvement of productivity at the farm level. The use of microcredit by smallholders who produce about 80 percent of the nation's crops has been recognized as one of the critical factors to promote agricultural productivity at the farm level. Credit enables farmers to adopt improved technologies and make better use of existing technologies through the acquisition of productivity-enhancing factors of production. Microcredit also influences the risk-taking behavior of farmers.

Farmers in northern Ghana obtain credit from diverse sources, both formal and informal. The formal credit sources include commercial and rural banks. Informal credit sources are however more important to smallholder farm households due to the relaxation of collateral requirements, less bureaucratic procedures, quick access to funds, and existence of some form of formal or informal relationship between lenders and borrowers in the informal financial service sector. Many smallholders also borrow from friends, relatives and moneylenders, while non-governmental organizations and some government social-protection programs also extend microcredit to smallholder farmers. For the current study, the sources of the credit included both formal and informal sources such as rural banks, government-subsidized credit programs, non-governmental organizations, farmers' cooperatives, relatives and moneylenders. The study did not differentiate between formal and informal credit sources, even though the different sources could potentially differ in their degree of association with technical efficiency. For the credit dummy variable, a farmer who used credit for farming was designated as "credit user" and vice versa.

The study contributes to the production efficiency literature by shedding more light on the role of microcredit in smallholder production systems. Many previous studies simply included the credit variable as an additional explanatory variable in the inefficiency effects model to capture the relationship between credit and technical efficiency while others compared the differences in efficiency between credit users and non-users without accounting for the problem of selection bias. The efficiency estimates from such studies are prone to biases from the presence of sample selection. This study therefore took this limitation into account by employing a matching technique referred to as the propensity score matching (PSM) to identify comparable farms for the estimation of technical efficiency based on pre-treatment characteristics of the respondents. This procedure eliminates or significantly reduces selection bias arising from the non-randomness in assignment of farms into the treated group (participants in microcredit). The PSM approach has been widely applied in agriculture to account for selection bias and to estimate the impact of an intervention or innovation by controlling

³ The study considered household use of microcredit and not simply access to microcredit. The term "access to microcredit" as used in the article should appropriately read "use of microcredit" or "participation in microcredit".

for exogenous factors that influence assignment to the treatment condition (Mayen et al., 2010; Katchova, 2010). The propensity score is the conditional probability of receiving treatment (participating in credit) given pre-treatment characteristics.

The study used the PSM method to select comparable farms for the estimation of technical efficiency. A stochastic frontier production function was used to estimate the efficiency of the PSM subsample from which efficiency estimates for microcredit users and non-users were obtained. The tests of hypotheses concerning the appropriate functional form and the inefficiency effects model indicated a Cobb-Douglas production function as the appropriate functional form and the presence of inefficiency effects in the specified frontier model. The traditional average response model is therefore not suitable for this estimation.

The results indicated a mean efficiency of 63 percent for microcredit users and 61.7 percent for non-users. Even though the average efficiency of microcredit users was marginally higher than non-users, the difference in mean efficiency between the two groups was not statistically significant. In contrast, the study found a statistically significant relationship between credit and overall technical efficiency at the 10% level in article IV. However, the relationship between credit and pure technical efficiency in article IV was not significant. The variation in the results could be attributed to the different methodologies used in the study. It is however important to note that the provision of microcredit alone does not guarantee efficiency of production. For example, microcredit users may misallocate credit in the absence of technical guidance from extension agents on proper farm management practices. Misallocation of credit can also occur when there is lack of supervision on the appropriate use of the credit. The size of loans offered to the respondents was also found to be very small and this could limit the effective utilization of the loan to enhance productivity and efficiency.

Land had the highest output elasticity followed by seed and labor. Capital had the least output elasticity among the inputs used in production. Rice production in the study area was characterized by diminishing returns to scale, measured at 0.79. Similar results were obtained in Articles I and III. Furthermore, the inefficiency effects model explained about 72 percent of the inefficiency in rice production in the study area. Thus, about 28 percent of inefficiency in rice production was due to factors beyond the control of the producers.

The study also revealed that irrigators alongside farmers in the Northern Region and households who double-cropped their land were located on a higher production frontier which indicates higher productivity. The result is similar to what was obtained in Articles I and III. The result is plausible since irrigation enables farmers to intensify input use.

Participation in microcredit was related to the gender of the household head, household income, participation in irrigation, total household assets, improved variety adoption, distance to the nearest market, contact with extension agents, location of the farm, and awareness of microfinance institutions operating in the area. Participation in microcredit was higher for households with higher income and total assets as well as for farmers who had contact with extension agents. Similarly, participation in microcredit was higher for farmers who were aware of the presence of microfinance institutions in the area and households located in the Northern Region. However, lower participation in microcredit was reported for male household heads, users of irrigation, households who lived far from a local market, and adopters of improved varieties.

The determinants of technical efficiency included the gender, age and years of formal education of the household head, degree of specialization in rice production (measured as the share of land under rice

cultivation), distance to the nearest market, herd ownership, and use of irrigation. Technical efficiency was higher for male household heads, older (experienced) farmers, farmers who allocate more land to rice production, farmers living farther away from a local market, owners of cattle and users of irrigation. The converse was true for household heads with more years of formal education. The quadratic of the age variable however had a positive and significant relationship with technical inefficiency. The results are largely consistent with the findings of the other articles in the dissertation.

The study also estimated the average treatment effect of the treated (ATT) using propensity score matching. In this analysis, the treatment variable was use of microcredit while the outcome of interest was technical efficiency. The result of the average treatment effect of the treated indicated that participants in microcredit were 1.3 percentage points more technically efficient than non-participants. The result supported the value obtained using the propensity score subsample to estimate the technical efficiency thus indicating the robustness of the technical efficiency estimate.

5.3 Production technology and farm efficiency: Irrigated and rain-fed farms in Northern Ghana (Article III)

The role that irrigation technology plays in the efficiency and productivity of smallholder farmers is one of the most discussed topics in the productive efficiency literature with regards to smallholder agriculture. Irrigation infrastructure is not well developed in most developing countries including Ghana thus restricting smallholders' use of irrigation technology for crop production. Only 3 percent of Ghana's crop land is under irrigation while the potential for irrigation remains largely untapped. Irrigation enables intensification of input use and can therefore contribute to the attainment of higher productivity and efficiency.

Since agriculture in Ghana is mainly rain-fed and subsistence-based, the need for irrigation cannot be over-emphasized. The modernization of agriculture to ensure food security, employment creation and poverty alleviation are enshrined in the vision of Ghana's Ministry of Food and Agriculture, and one of the strategies to achieve this goal is the promotion of irrigation to smallholder farmers across the country. Efforts to make irrigation technology available to farmers include the construction of irrigation schemes across the country to facilitate production activities throughout the year. The existing irrigation infrastructure is however inadequate to meet the needs of the large number of smallholders who produce about 80 percent of the country's food.

Previous studies that examined irrigation technology and efficiency of smallholder farmers include Makombe et al. (2007), Al-hassan (2008), Tilahun et al. (2011), Al-hassan (2012), among others. These studies highlight the important role of irrigation in farm efficiency among smallholder farmers. As shown by Gebregziabher (2012), irrigation shifts the production frontier upwards, which is indicative of higher productivity with irrigation technology.

Article 3 contributes to the literature on production efficiency by shedding more light on the role of irrigation in smallholder production systems. The study is innovative in the sense that a formal test of the homogeneous production technology assumption was carried out which is missing in most of the previous studies. Most of the previous studies made an implicit assumption of a homogenous technology but failed to formally test the hypothesis. As shown by Stigler (1979) and Mayen et al. (2010), the failure to test for the technology type is likely to lead to misleading efficiency estimates, hence the need to carry out a formal test of the production technology type.

The study also addressed self-selection into irrigation using propensity score matching (PSM). The PSM approach accounted for sample selection bias which was missing in many of the previous studies. Selection bias arises when there is non-random assignment of the respondents into irrigation (the treatment condition). This means that certain factors may influence whether or not a farmer is a participant in irrigation. PSM technique ensures that the participants in irrigation are matched to the non-participants with the same propensity score. This matching procedure eliminates or significantly reduces selection bias and allows the comparison of efficiency between the two groups.

The study rejected the homogenous technology assumption implying that irrigators and rain-fed farmers employed different (heterogeneous) technologies in production. The production function was therefore modeled following the heterogeneous technology assumption by including the irrigation dummy variable and its interaction with all the input variables as additional variables. The irrigation dummy variable was included in both the production function and the inefficiency model because it is considered to have productivity effects (shift in the frontier) as well as influence on technical efficiency. The results of the study indicated that irrigation had a positively significant relationship with productivity and efficiency of rice production in the study area. Irrigators were 9.2 percentage points more efficient than non-irrigators. Irrigators had a mean efficiency of 63.4 percent while rain-fed farms had an efficiency of 54.2 percent.

The study also revealed that the location of the farm is related to the productivity of smallholder rice producers in the study area. Producers in the Northern Region were more productive compared to their counterparts in the Upper East Region. The result agrees with the findings in articles I and II.

The factors influencing the participation of smallholder farm households in irrigation included the number of contacts with extension agents, membership in a farmers' association, value of livestock (proxy for wealth status), farm capital endowment and the degree of specialization in rice production.

Land had the highest output elasticity followed by labor while capital had the lowest output elasticity among the production inputs. A 1% increase in land area will lead to 0.45% increase in rice output while a 1% increase in labor is associated with a 0.3% increase in output. Additionally, a 1% increase in capital will result in 0.04% increase in rice output. The study also showed that irrigators had higher output elasticity of seed and fertilizer compared to non-irrigators. The use of these inputs in production is therefore higher under irrigation technology relative to rain-fed production. Irrigators however had lower output elasticity of land, labor and capital. Furthermore, the return to scale for irrigators was 0.7 compared to 0.9 for rain-fed farms. This means that increasing all inputs by 1% will lead to 0.7% increase in output on irrigated farms and 0.9% increase on rain-fed farms. These findings are consistent with the results obtained in articles I and II.

With regards to the determinants of technical efficiency, the study identified the gender and educational status of the household head, association membership, herd ownership, and the use of irrigation technology as the important factors. Being a female farmer was associated with lower technical efficiency while irrigation technology, ownership of cattle, and membership in a farmers' group had positive and significant effect on technical efficiency of the producers. Contrary to *a priori* expectations, years of formal education was negatively related to technical efficiency. A likely explanation for this result is that educated farmers may be part-time farmers or likely to allocate labor away from the farm due to engagement in off-farm work.

A major contribution made by the study was that assuming a wrong technology type in comparative efficiency analysis is likely to produce misleading results. When selection bias was controlled and the

appropriate technology was assumed (i.e. different technology), the study found the mean efficiency difference between irrigators and non-irrigators to be 9.15 percentage points. However, when selection bias was controlled and the wrong technology was assumed (i.e. same technology), the study found the mean efficiency difference between irrigators and non-irrigators to be 25.6 percentage points. Furthermore, with selection bias and assuming the same production technology, the mean efficiency difference between irrigators and rain-fed farms was 28.3 percentage points (compared to 10.5 percentage points for the different technology assumption). The wrong production technology assumption therefore overstates the efficiency difference between the two farm groups. In sum, both technology type and selection bias were demonstrated to influence the efficiency measures in the current study justifying the need to account for both selection bias and production technology type in comparative efficiency analysis.

5.4 Does farm size matter? Investigating scale efficiency of peasant rice farmers in northern Ghana (Article IV)

In article IV, the study involved the estimation of technical and scale efficiency of farm households in northern Ghana using a non-parametric efficiency estimation approach (data envelopment analysis, DEA). The study sought to empirically investigate whether smallholders are scale efficient in production at the current level of land allocation to rice cultivation. The results are meant to provide insights into whether smallholders need to adjust their farm sizes in order to be more efficient. The results of the study will be insightful in the light of on-going debate surrounding the productivity and efficiency of small-scale versus large-scale farms in developing countries (see for example, Collier and Dercon, 2013; Larson et al., 2012).

A farm is considered to be scale efficient when its size of operation is optimal such that any adjustment to its size renders it less efficient. A farm can capitalize on the advantages of the scale of operation to improve its efficiency. From a technical point of view, a technically efficient farm could be scale inefficient.⁴ It is therefore possible for a farm to employ the best practice in production but fail to operate at the optimal scale. Given that smallholders typically operate relatively small farms, it is important to investigate whether increasing the scale of operation can improve the efficiency of production.

The DEA approach is a relative efficiency measurement procedure whereby relatively inefficient farms are compared to the efficient farms in the sample. An efficient production frontier is formed by linking all the efficient farms in the sample by a continuous locus. The inefficient farms are then compared to this efficient frontier and all deviations from the efficient frontier are considered as inefficiency. The basic DEA models include the Charnes, Cooper and Rhodes (CCR) model and the Banker, Charnes and Cooper (BCC) model. The CCR model (Charnes et al., 1978) is based on the assumption of constant returns to scale while the BCC model (Banker et al., 1984) assumes variable returns to scale. Depending on whether a constant or variable returns to scale is assumed, the technical efficiency measure may be either overall technical efficiency or pure technical efficiency. The ratio of overall technical efficiency to pure technical efficiency gives a measure of the scale efficiency.

⁴ According to Coelli et al. (2005), the variable returns to scale DEA model (pure technical efficiency) provides efficiency scores that are greater than or equal to the scores obtained from the constant returns to scale DEA model (overall technical efficiency). Hence in principle, pure technical efficiency can be equal to unity (indicating technical efficiency) while scale efficiency is less than unity since $SE = TE-CRS / TE-VRS$. However, this may not necessarily reflect differences in managerial ability as indicated in the article. Similarly, the reverse is true: a farmer may be scale efficient but not technically efficient: for example, when the two efficiency measures are equal but less than unity.

In article IV, the study analyzed efficiency in terms of three measures namely overall technical efficiency (OTE), pure technical efficiency (PTE) and scale efficiency (SE). The approach enabled identification of the likely sources of inefficiency. Overall technical efficiency measures efficiency under constant returns to scale assumption using the CCR model while pure technical efficiency measures efficiency under variable returns to scale assumption using the BCC model.⁵ An important aspect of the pure technical efficiency measure is that it reflects the effect of managerial ability on efficiency.

The DEA formulation used a constrained minimization objective function (as opposed to a constrained maximization function) due its mathematical tractability (Coelli et al., 2005). The estimation used linear programming and was carried out using the computer program DEAP version 2.0 which provides estimates of the overall and pure technical efficiencies as well as the scale efficiency.

The determinants of scale and technical efficiency were estimated by regressing the efficiency estimates on farm and farmer characteristics that have influence on efficiency. Due to limitations with the standard Tobit model in a two-stage DEA approach (Simar and Wilson, 2007; MacDonald, 2009), the study used a truncated regression with bootstrap in the second stage analysis to estimate the determinants of efficiency. The procedure, known as the Simar and Wilson (2007) approach uses simulation to create artificial bootstrap samples from which corrected standard errors and confidence intervals are generated.

The results of the study revealed that smallholder rice producers in northern Ghana had overall technical efficiency of 46.6 percent and pure technical efficiency of 65.1 percent. It is interesting to note that pure technical efficiency which accounts for farmers' managerial ability, had an efficiency estimate that is quite similar to the efficiency estimates obtained in articles I, II and III. Scale efficiency was estimated at 69.5 percent. The results indicate high inefficiencies in production which are either technical or scale in nature.

It was observed that majority of the farms were characterized by increasing returns to scale, which is at variance with the results obtained in articles I, II and III. The result is however consistent with the findings of Ajibefun and Abdulkadri (2004), Singbo and Lansink (2010), Bhatt and Bhat (2014) and Wondemu (2016). As mentioned earlier, the inconsistency in the returns to scale measure may be partly due to the different methodologies employed in the analysis as well as the incorporation of dummy variables as intercept shifters in the stochastic frontier model to characterize technology choice (Mayen et al., 2010) but not in the DEA model. The study also revealed a positive association between farm size and scale efficiency. Scale efficiency increased with farm size while the quadratic term of the farm size variable was negative and significant. Hence scale efficiency increased at a decreasing rate with farm size. On the other hand, pure technical efficiency decreased with farm size while the quadratic term of the farm size variable was positive and significant. The result implies that smallholders become comparatively less pure technically efficient with an increase in farm size. However, the overall technical efficiency measure had no significant relationship farm size. The significant relationship between farm size and pure technical efficiency may highlight the importance of farmers' managerial abilities to technical efficiency. This is because the pure technical efficiency measure accounts for farmers' managerial ability and the decrease in efficiency as farms become larger could be related to farmers' managerial ability. According to Ross et al. (2009), larger farms

⁵ According to Coelli et al. (2005), the variable returns to scale DEA approach forms a convex hull of intersecting planes that is able to envelope the data points more tightly compared to the conical hull of the constant returns to scale DEA model.

misallocate resources which make them less technically efficient. On the other hand, scale efficiency increases when farm size increases. The results thus provide some justification for smaller farms in the area to increase their scale of operation to take advantage of unexplored economies of scale. However, such a decision must consider the managerial ability of the producers.

The study also revealed that participation in irrigation, the degree of specialization in rice production, and the location of the farm were significantly related to the three efficiency measures. The positive association between irrigation and productivity is well documented in the literature. Economic theory also supports the notion that efficiency increases with the degree of specialization. Geographical location also had a significant relationship with farmers' level of efficiency with the efficiency of producers in the Northern Region being higher than for those in the Upper East Region. It may be argued that the Upper East Region being furthest from the national capital may encounter relatively higher prices and cost of production. The Region is also more prone to dry spells during the farming season which may account for the lower farm performance. The results are largely consistent with the results in articles I, II, and III.

The results also indicated that participation in microcredit and agricultural extension services had positively significant association with scale and overall technical efficiencies. Both variables however had no effect on pure technical efficiency. The result is at variance with the finding in article II where credit had a non-significant relationship with technical efficiency. The inconsistency is hard to explain. However, it must be noted that credit had a statistically significant relationship with overall technical efficiency but not with pure technical efficiency. Overall technical efficiency is measured under constant returns to scale assumption while pure technical efficiency is measured under the assumption of variable returns to scale. Pure technical efficiency which takes into account farmers' managerial ability on their efficiency had a non-significant association with microcredit which agrees with article II. Since scale efficiency is a ratio of overall technical efficiency to pure technical efficiency, the significant effect of credit on scale efficiency could derive from the overall efficiency measure. Furthermore, the study accounted for selection bias in article II but not in article IV – instead there was bootstrapping of the DEA scores to provide appropriate standard errors as suggested by Simar and Wilson (2007). The different methodologies used in the analysis may therefore partly explain the differences in the results.

Furthermore, the gender of the household head had no effect on pure and overall technical efficiency. However, being a male household head had a positive and significant effect on scale efficiency.

6. Conclusions and suggestions for further research

6.1 Conclusions

The objectives of the study were to provide empirical evidence of (1) technical efficiency and its determinants in smallholder rice production in northern Ghana; (2) technical efficiency differential between microcredit users and non-users; (3) the relationship between the production system (irrigated versus rain-fed production) and technical efficiency; and (4) scale efficiency and its relationship with farm size in smallholder rice production. The study focused on smallholder agriculture which has received considerable attention in recent research due to its important role in socio-economic development of rural communities in many developing countries. The main conclusions of the study are summarized below.

The results of the study indicate significant technical inefficiency in production which contrasts the view held by Schultz (1964) that small-scale farmers are “poor-but-efficient”. An important lesson to

be drawn from this study is that productivity growth in smallholder agriculture can be achieved by ensuring a more efficient use of the available resources and current technology (without the introduction of new technologies). This point is justified by the following reasons. First, smallholder production systems develop over time as farmers experiment on their own. It may be argued that with time, farmers could learn to make better use of existing technologies or adopt new ones developed by research stations. However, since the introduction of a new technology does not guarantee its acceptability and adaptability to the new environment, especially in the short-run, improving the current level of resource-use efficiency with the existing technology seems a reasonable policy option to promote productivity growth in smallholder production systems.

Second, the objectives of resource-poor farm households may differ from conventional thinking, such that decision-making in the process of production may be influenced by factors other than profit-maximization. For example, resource allocation by many poor households may be done to achieve livelihood security (including food security) rather than profit maximization due to risk aversion and other factors. Under such conditions, suboptimal utilization of resources may occur. The results of the study pointed to the suboptimal utilization of some inputs particularly land, fertilizer and capital.

Third, improving managerial abilities of smallholder producers could lead to technical efficiency gains at the current level of technology. Since most of the inefficiencies in production were technical in nature, improving the managerial ability of the producers could enhance the efficiency of smallholders without the introduction of new technologies. The weak association between extension services and technical efficiency is, therefore, a matter of concern because most smallholders do not usually have formal education and training. The provision of extension services is therefore important as a major avenue for these farmers to receive technical advice on production.

Smallholders in the study were found to operate at suboptimal scale. The estimated scale efficiency among the respondents was 70%, with larger farms being closer to their most productive scale. The study also showed that farm size had a contrasting relationship with scale and pure technical efficiency; hence being scale efficient does not necessarily imply the attainment of technical efficiency. Scale efficiency increased with farm size but at a decreasing rate. On the other hand, pure technical efficiency of the producers was found to be negatively associated with farm size, indicating that smallholder farmers become less pure technically efficient when their farm size increases. Since pure technical efficiency accounts for the influence of managerial ability on production, the conclusion is that the respondents lack the required managerial ability to manage larger farms, hence the inverse relationship between farm size and pure technical efficiency.

The study also highlighted the importance of irrigation to technical efficiency and productivity growth in smallholder agriculture. Irrigation is important to agricultural productivity and efficiency because it allows the intensification of input use. Increasing irrigation supply is therefore important to agricultural growth in Ghana, particularly rice production which has been targeted by the Government of Ghana as a means of achieving national food self-sufficiency, employment creation and income generation.

The results further suggest that the financial sector did not meet the demands of the producers in terms of their credit needs as majority of the farmers were credit-constrained (i.e. unable to borrow, or the amount of credit demanded fell short of the amount received). The average loan size of GH¢246 (approximately US\$ 63) is very small for investment purposes. The study recognizes that credit per se does not guarantee higher technical efficiency and productivity, hence the importance of other

institutional factors such as the provision of extension services and irrigation technology, farm mechanization, and support to farmer-based organizations.

6.2 Main contribution of the research to the applied economic literature

The research contributes to the applied economics literature by providing an empirical evidence of smallholders' technical efficiency and how this is related to the production system (irrigated versus rain-fed production) and the use of agricultural microcredit. Technical efficiency estimates in the study are quite similar despite the different methodological approaches used in the estimation. The research provides further evidence that smallholder agricultural production is characterized by considerable inefficiencies at the current level of technology and input use.

Most of the previous studies on smallholder farming have ignored selection bias when assessing technical efficiency between users and non-users of microcredit and irrigation. The current study therefore employed propensity score matching to reduce the effect of selection bias in the sample to provide more reliable outcomes of the association between the variables of interest (microcredit and the production system) and technical efficiency.

The research also makes a significant contribution to the applied economics literature by incorporating the test of production technology type in the analysis which is absent in most of the previous studies. As shown by this study and supported by other authors (for example Stigler, 1976; Mayen et al. 2010), an explicit test of the production technology is important in (comparative) efficiency analysis in order to obtain unbiased estimates. In the context of Ghanaian agriculture, this is the first analysis that explicitly incorporates the test of technology in the estimation of technical efficiency.

The study also included the extended Cobb-Douglas functional form in the test of functional forms in the efficiency analysis. The result highlights the importance of such comprehensive test of the functional form rather than limiting the test to only the translog and Cobb-Douglas specifications as done by most researchers.

In addition, very few studies have examined the relationship between the degree of specialization in production and technical efficiency of smallholders who typically produce many crops at the same time. The degree of specialization in rice production was found to have a strong statistical association with technical efficiency of the smallholders in articles I, II and IV which is an important contribution to the literature.

Finally, the study contributes to the literature on intensification of input use by smallholders. Smallholders typically rely on natural rainfall to produce crops which limits the cropping intensity. However with irrigation, double cropping is possible within the year. As shown in this study, the intensification of input use is positively related to productivity. This provides further insight into smallholder production systems.

6.3 Policy implications

The results of the study lead to some important policy recommendations that could potentially increase the technical efficiency of smallholder rice farmers in Ghana. To begin with, the study revealed considerable inefficiencies in production and a high scope for improving the level of technical efficiency of smallholder rice farmers in northern Ghana. Hence, improving efficiency of smallholders may require taking into account the factors associated with inefficiency.

Microcredit users and non-users did not differ in their level of technical efficiency of production according to this study. The result is contrary to our expectation and could suggest imperfections in the rural credit market or inappropriate use of credit. From a policy perspective, the study recommends targeting of credit to farmers who demonstrate the need for it. Such a screening mechanism will ensure that credit goes to only producers who need it to improve their production activities.

Irrigation had a statistically significant association with the productivity and technical efficiency of smallholder farm households in the current study. The irrigation variable had a positive and significant relationship with all types of efficiency measures analyzed in this study. The modernization of agriculture is a key agricultural policy of the Government of Ghana and this policy stresses the provision of irrigation to smallholders. Provision of irrigation technology to smallholders is therefore likely to enhance their productivity and efficiency of production, all things being equal.

Producers in the Upper East Region were consistently less technically efficient than those in the Northern Region which raises questions regarding the factors inducing the efficiency differentials. Even though the two Regions share fairly similar climatic conditions, the Upper East Region is farther from the national capital which may influence input prices and hence the cost of production. However how this influences efficiency is unclear. From a policy perspective, the study finds the need for a critical examination of the specific institutional and farmer characteristics influencing farmers' activities in the Upper East Region.

The study also identified the determinants of technical efficiency in smallholder rice production in northern Ghana to include membership in farmer-based organizations. Farmer organizations have been shown to serve as important conduits for the transfer of technology and innovation, provision of extension, credit and other key services to smallholders. The promotion of the activities of these organizations in rural areas is therefore an important policy instrument that is likely to improve smallholder production systems and farm performance.

Farm size was positively associated with the scale efficiency of rice farmers in the study. The study therefore justifies the expansion of smallholders' landholding to take advantage of economies of scale. Farm size however exhibited a negative association with pure technical efficiency with the quadratic term of the farm size variable having a positive and statistically significant association with efficiency. Pure technical efficiency provides a measure of managerial ability of farmers. Hence, the result suggests that farmers become less technically efficient when their farm sizes increase. The implication of the results is that the ability of smallholders to take advantage of economies of scale in production is dependent on their managerial abilities. Hence, efforts are required to enhance farmers' managerial ability through extension education and training in modern methods of production.

The study also showed that scale efficiency of smallholder rice farmers in northern Ghana had a statistically positive association with the use of irrigation and credit, as well as the number of extension contacts. Hence, institutional factors such as public investments in irrigation and extension services and the provision of microcredit are likely to have positive influence on the efficiency of smallholder rice farmers in the study area.

6.4 Suggestions for further research

The study did not find any significant difference between the mean efficiencies of credit users and non-users contrary to our expectation. The use of propensity score matching to account for self-selection into irrigation and microcredit is an innovative approach but the procedure did not account

for selection arising from unobservable factors. A further research that accounts for both observable and unobservable confounding factors is therefore suggested.

The efficiency of farmers in the Upper East Region was lower than that of their counterparts in the Northern Region and this warrants further investigation into the factors associated with inefficiency among producers in that region. Geographical factors therefore seem to have an important relationship with the technical efficiency of the producers in the study area.

The current study investigated scale efficiency focusing mainly on smallholder farmers. However a study which compares scale efficiency between small-scale farmers and medium and/or large-scale farmers may provide further useful insights into the effects of scale of production on technical efficiency.

It is often argued that smallholder farmers do not usually aim at profit maximization but have the goal of livelihood security and therefore may not be profit maximizers. The current study did not investigate the profit-maximizing behavior of smallholder producers and a further study to investigate this behavior may be useful in understanding the factors influencing the efficiency of smallholder agriculture.

Finally, participation in farmer-based organizations had a positive and significant relationship with smallholder farms' efficiency in the current study. Given the important roles that these groups play in the production activities of rural dwellers the study suggests a further investigation into their roles especially in relation to technical efficiency, acquisition of inputs, access to services and as channels for the transfer of innovations.

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