Chapter 19
Technological Innovations for Smallholder Farmers in Ghana

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Abstract This chapter explores which community-based technologies have the greatest potential for reducing poverty and vulnerability among many smallholder farmers in Ghana. To this end, the stochastic dominance test was applied to rank outcomes from the different technologies used by the smallholder farmers in the study area. To show the effect of the technology on smallholder farmers' income, propensity score matching was used to test for differences in income of technology adopters and non-adopters. Based on the findings of the study, we conclude that the dominant technologies that have the potential to reduce smallholder farmers' level of poverty and marginality are: inorganic fertilizers for Afigya-Kwabre; zero tillage for Amansie-West; storage facilities for Atebubu-Amantin; marketing facilities for Kintampo South; improved varieties for Gonja East; and pesticides for the Tolon Districts.

Keywords Community-based technology • Innovations • Marginality • Smallholder farmers • Technology adoption

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Introduction

Agricultural technology and innovation are the foundations of rural economic growth and development. For this reason, many governments and aid agencies constantly introduce technological innovations to rural farmers with the view of empowering them. Farmers also innovate and develop indigenous knowledge and technologies to address their specific needs. Yet, many of the interventions introduced to farmers usually assume a top-down approach without assessing the farmers' own capabilities and skills. These wholesale technologies, which also assume that all smallholder farmers are equal in resource endowments or poverty levels, and ignore spatial variations, often lack a cutting edge approach to solving farmers' problems and may worsen farmers' plight.

This study, therefore, employed the *Technology (ex-ante) Assessment and Farm Household Segmentation for Inclusive Poverty Reduction and Sustainable Growth in Agriculture (TIGA)* approach to explore community-based technologies that have the greatest potential for reducing poverty and vulnerability among many smallholder farmers in Ghana. This will form the basis for up-scaling of community specific technologies that yield the desired results. The research also highlights important attributes or indicators which may lead to either more successful or fewer successful outcomes. Optimally, these indicators could also be used to gauge and benchmark the performance of the technologies in any implementation programme.

Poverty and marginality are common in Africa, particularly Sub-Saharan Africa, where more than 40 % of the inhabitants live on less than a dollar a day. Levels of food insecurity also remain stubbornly high, with a third of the population being undernourished (IFAD/WFP/FAO 2011). This is exacerbated by conflict, climate change, poverty-induced migration and natural disasters. Although agriculture is the mainstay of more than two-thirds of Africa's poor, and thus provides the greatest potential for pulling up the millions of people stuck in poverty, agriculture in many countries lacks the much-needed technological innovation and productivity to reduce poverty and vulnerability. While it is true that technologies may abound in many countries, smallholder farmers have not, overall, benefitted from most of these technologies. This may be due to social, cultural, political, natural and economic factors which limit their ability to successfully utilize these technologies.

In Ghana, poverty remains unacceptably high, with 19.2 % trapped in abject poverty (Ackah and Aryeetey 2012). Over 70 % of the poor engage in smallholder agriculture and cultivate less than 2 ha (MoFA 2012; WFP 2009). These farmers who reside mainly in rural areas more often use rudimentary equipment in their farming and most of the technological interventions are beyond their capacity to adopt. Agriculture is also rain-fed and most farmers lack access to financial and other productive resources. This introduces an element of risk into agriculture and exposes smallholder farmers especially to vulnerability, which in turn perpetuates poverty.

Although agricultural research in Ghana has generated a number of technologies aimed at improving the farmer's livelihood and productivity, the impact has been awful or, at best, disappointing (AdeKunle et al. 2012). This emanates from the poor involvement of farmers in research and the 'pouring on farmers' syndrome. To address this challenge of poor outcomes associated with most thwarted technological innovations, it is imperative that research is geared towards unraveling indigenous and community-specific interventions that work best for farmers. This study, therefore, explores local technologies that are best suited to farmers in the three agro-ecological zones of Ghana.

Ghana's population is around 24.6 million (24,658,823) (Ghana Statistical Service 2012a) and agriculture is the backbone of the economy. According to Al-Hassan and Diao (2007), agriculture employs more than 60 % of Ghana's labour force and contributes to about 25.6 % of its Gross Domestic Product (Ghana Statistical Service 2012b). Beyond these, agriculture is also recognized to have a greater impact on poverty reduction than any other sector in developing countries (IFPRI 2004; IFPRI 2009).

Ex-ante technology assessment refers to a forecasted estimation of the performance or outcome of an about-to-be-introduced or potential technology. Braun (1998) echoed ex-ante technology assessment as a systematic analysis aimed at foreseeing the future outcomes of a particular technology in all bases which the technology may touch. Remenyi et al. (2000) also defined ex-ante technology evaluation as predictive evaluations performed to forecast and assess the impact of future technology. Technology assessment should not be muddled with technology evaluation. Yet, technology assessments and discussions at the national and international levels have often been infused with ideological, theoretical and value-based beliefs by people of different technological blocs, techno-optimist, techno-skeptic or non-allied groups. Ruben et al. (1998) add that research on agricultural production technologies takes place from different viewpoints. This partitioning of people into different technological factions eventually leads to social debate and political conflicts between opposing teams (Jamison and Baark 1990).

The first section of this chapter, therefore, provides an explanation of ex-ante methodologies for assessing technology with the overall aim of achieving a unifying front from all fractions of the technological divide. The rest of the paper has been arranged to faciliate readership by technocrats or experts, as well as bureaucrats. Section two deals with methodological issues, while section three deals with outcomes of the research. The last section is dedicated to recommendations from the research.

Overview of Technological Development in Ghana

Efforts to modernize and improve agriculture in Ghana date back to the pre-colonial era. According to Rodney (1984), these emanated from the exploitative colonial system, which was mainly a conveyance system for carrying minerals and other goods from the hinterland to urban areas for onward transport to the west to feed their industries. Long stretches of link roads were constructed which brought many rural farming households into the national focus. This helped in the distribution of farm inputs, as well as the transportation of rural commodities, and thus helped to reduce post-harvest losses. Rural electrification was also pursued to some extent.

The periods after independence also saw governments initiating programmes with the aim of improving agricultural growth and productivity. For instance, the Convention Peoples Party, the then-ruling government, introduced the State Farms System to serve as modules for farmers in Ghana. The Block Farming Systems were another innovative means of enhancing farmers' productivity in such similar modular programmes, particularly for farmers in the transition and savannah zones. Also, fertilizers were introduced into Ghana and were subsidized. Several agricultural colleges were established in Ghana during this period to train extension agents. In addition, there was the establishment of many food crop and agro-processing firms. However, the major agricultural technological breakthrough in post-independent Ghana was the introduction of innovations in the cocoa sector in the 1970s which affected the livelihoods of millions of Ghanaians.

Periods of intermittent military rule wiped out some of these programmes, but nonetheless, some agricultural growth and technological interventions were observed. Particularly, during the Acheampong regime, rural electrification, as well as rural communication facilities, mainly post offices, were vigorously pursued which had indirect linkage to agricultural growth and development. Tractors were also introduced in Ghana in large numbers during those military periods. But the dominant programme in the military days that led to food sufficiency in Ghana was the Operation Feed Yourself (OFY) Programme. As the name suggests, this programme encouraged workers in the public sector, particularly in the cities, to cultivate farms on patches of lands around their houses. These periods are also closely linked with the structural adjustment programme (SAP) of 1985.

Periods after the post-structural adjustment have also seen the introduction of many interventions, either by the state, aid agencies or even individuals. For instance, the establishment of the Ministry of Food and Agriculture and other allied agricultural institutions has helped to co-ordinate activities in the agricultural sector. Ghana has also developed an agricultural sector policy document, FASDEP, and an implementation Plan, METASIP. Other programmes, such as the Root and Tuber Improvement Programmes (RTIMP), Millennium Development Authority (MiDA) Programmes, Youth in Agriculture Programmes, Savannah Accelerated Improvement Programmes and District Tractor Services Programmes, have all helped to improve farmers' capacity and enhanced growth in the agricultural sector. But two programmes appear to have had the greatest impact. These were the re-introduction of fertilizer subsidies and the National Cocoa Diseases and Pest Control (CODAPEC) programme, popularly known as "Mass Spraying" to assist all cocoa farmers

From the foregoing, it can be deduced that several technological innovations and agricultural productivity growth programmes have been introduced in Ghana since independence. Whereas some had limited impact, others were of great success. But these successess unequivocally did not affect many rural poor farming households, who lack many resources and the capacity to adopt these technologies. Ex-ante assessment of technology and innovation for poverty and marginality reduction, therefore, provides a more effective tool for exploring interventions that have the potential to reduce farmers' poverty and marginality but also within the farmers' limit of possible adoption.

Assessment of Technological Innovations in Agriculture

Several scholars and researchers have attempted to holistically undertake an assessment (including ex-ante assessment) of technologies introduced into many poor rural farming communities using a variety of different approaches and models (Ruben et al. 1998; Ruben and van Ruijven 2001; van Keulen et al. 1998; Berkhouta et al. 2010; Ruben et al. 2006). These models generally span from normative decision-making and accounting techniques, such as benefit-cost ratios (BCR), internal rate of returns (IRR) and the net present value (NPV), to econometric models, such as multi-market models and supply response models, continuous production functions and efficiency measures, farm household models (FHMs), economic surplus models, general equilibrium models (GCE), policy analysis matrix (PAM) procedures, farming system research (FSR) procedures, and statistical simulation models such as mathematical programming, linear programming or measures of welfare dominance (Veeneklaas et al. 1994; Ruben et al. 1998; Ruben and van Ruijven 2001).

Multi-market models often deal with various agricultural sub-sectors and market distortions, considering interactions in both the product and the factor market, and the impact of price changes on incomes, expenditures and production. These models require a detailed specification of supply and demand elasticities. Farming systems research (FSR) provides a framework for classification of farm households into marginality groups or spots, and a detailed analysis of farm household resource-use decisions. FSR helps to explain the basis of technology choice, and the identification of resource constraints at the farm household level (Steenhuijsen Piters 1995). Mathematical programming procedures are usually applied to analyse optimum allocative choice (Ruben and van Ruijven 2001). They provide insights into the optimal agro-ecological production possibilities for a farm or region and are useful for indicating physical trade-offs between different (long-term) objectives (Ruben et al. 1998). These are based on utility maximization principles and usually use optimization approaches, such as profit maximization or risk minimization, as the objective function.

Multimarket, farming system research and mathematical programming models simulate either a farm household's behavior, such as technological (non) adoption and input choices, or agro-ecological processes separately, and cannot be used directly for ex-ante analysis, because the relationship between technological options and behavioural driving forces is not adequately specified. To address this problem, new research programmes focusing on the integration of economic simulations within biophysical simulation models offer important opportunities for the appraisal of the attractiveness of technological options from the farmers' viewpoint, and the identification of incentives to make their adoption feasible.

The NPV has also been traditionally used to assess the economic benefit of technology implementation in various sectors of the economy. For instance, in assessing vehicle safety technologies in European Union countries in 2006, the European Commission estimated the NPV as the difference between discounted stream of benefits and the required cost:

$$NPV = \sum_{t=0}^{T} NB_t * \frac{1}{(1+r)^t}, \tag{19.1}$$

where NPV is the net present value of the stream of net benefits from year t to T; T is the time horizon of the evaluation; NBt is the net benefits (benefits minus costs) incurred in year t; and r is the rate of discount. Benefit-cost analysis (BCR), through valuation of physical inputs and outputs, can be applied to assess the minimum conditions for technology change or profit. It is expressed as the present value of benefits divided by the present value of costs. BCR has been used to assess technologies in the public sector of many countries. Wulsin and Dougherty (2008), and Garrido et al. (2008) used BCR in assessing health technology in the United States of America and Europe, respectively.

Supply response models (SRM) use (expected) prices as a major explanatory variable for adjustment of agricultural production (Askari and Cummings 1976). Supply response models only consider the production side of the farm household, and linkages between production and consumption decisions, ignoring the characteristics for farm households operating under imperfect markets. But to effectively assess potential impact of technology, economic models (which identify the behavioural reasons for crop or livestock and technology choice) and agro-ecological models (used to select feasible technologies and cropping options for specific agro-ecological conditions and to assess their consequences in terms of sustainability of the resource base) should be combined (Ruben et al. 1998). Combining both approaches into a single analytical framework greatly assists policy-making, enabling the identification of possible trade-offs between economic and environmental objectives, as well as assessment of the impact of government interventions in markets for land, inputs, products, technology and infrastructure on farmers' decisions and the consequences for farm household welfare and sustainability of the resource base. The integration of agro-ecological and socio-economic information, therefore, takes place at the farm household level. Farm household models (FHMs) offer another perspective for the analysis of production and consumption decisions at the farm household level (Singh et al. 1986). Differences in risk behaviour (Roe and Graham-Tomasi 1986), market failures or missing markets (de Janvry et al. 1991), and inter-temporal choice (Deaton 1990; Fafchamps 1993) can also be taken into account. Due to the possibility of analysing both production and consumption decisions, the FHM approach represents a useful starting point for analysis of the effectiveness of potential technologies.

Another new or emerging technology assessment tool of great importance in recent times is that which combines both econometric and biophysical models, generally referred to as bio-economic models. These models incorporate technical input–output coefficients derived from agro-ecological simulation models into econometrically-specified farm household models (FHM) (Ruben and van Ruijvenvan 2001). These models usually involve functional integration of four models, namely biophysical crop growth simulation models, mathematical programming models that reveal the resource allocation implications of alternative crop and technology choices, FHMs that capture farmers' behavioural priorities, and aggregation procedures to address the effectiveness of policy instruments. A common feature of bio-economic models is that they usually originate from two sources – production and consumption models – and can generally be put into three categories. These are: biological process models with an economic analysis component, integrated or meta-bio-economic models (commonly referred to as meta-modelling), and economic optimization models, often used when new and potential technologies have to be included; the process involves the use of mathematical programming approaches with integrated or biological process models. Bio-economic models are used to analyse the impact of different types of economic incentives on farmers' resource allocation decisions, as well as their implications for the natural resource base (Ruben and van Ruijvenvan 2001; Sullivan 2002).

According to Ruben et al. (1998), for an ex-ante assessment of potential or new technologies, modelling and simulation approaches are required. Van Keulen et al. (1998) used a bio-economic model comprising linear programming with constraint optimization and farm household models in their study of sustainable land use and food security in developing countries: DLV's approach to policy support. The possibilities of introduction of more sustainable land use systems and their consequences for socio-economic indicators were analyzed. Indicators included in the sustainability model were use of biocide and soil nutrient loss, with farm income being the optimization constraint. The results showed that more sustainable land use systems can be introduced. Farm households' responses to specific policy instruments were also analyzed with the farm household model (FHM). The model was used to identify those price instruments that affect improvement of the competitiveness of agricultural production in the Atlantic Zone and improved natural resources management, which are two regional development objectives. These objectives were transformed into four clear goal indicators at the farm household level, namely income (utility) and plantain and cassava production were used as indicators for improved competitiveness, while biocide and fertilizer use served as indicators for natural resource management. The model results showed that higher product prices, lower fertilizer prices, and reduced transaction cost favour substitution of actual production activities with alternatives, leading to more sustainable land use. Increased biocide prices, on the contrary, resulted in a decrease in biocide use, mainly as a result of a reduction in cultivated land area.

The authors undertook similar studies in Mali and Costa Rica. An interactive multiple goal linear programming technique was applied to analyze options for rural development. Technical innovations used included more effective integration of arable farming and animal husbandry, based on the use of crop residues and fodder crops to provide high quality forage, the use of animal manure for nutrient cycling in cropping systems, and improved access to animal traction. The authors introduced various constraints reflecting different kinds of market imperfections, such as the possibility of hiring outside labour, availability of chemical fertilizers and price-setting for inputs and outputs. The results indicated that, with full knowledge of alternative (agro-ecologically sustainable) production techniques, the values of sustainability indicators such as soil nutrient, organic matter (O.M) depletion or soil mining can be improved up to 55–80 % by introducing these production techniques without sacrificing required incomes.

The FHM identified microeconomic supply reactions to various policy measures. Production and consumption decisions were jointly analyzed. Four household types were distinguished according to resource endowment and their objective functions to account for straight directions of supply response (SR). Savings and investment were included through the savings and investment model, while different time discount rates accounting for subjective time preferences by type of household food and labour balances were identified for the appraisal of market interactions and exchange among farm types. The agro-ecological sustainability indicators used were the balances of the macro plant nutrients (N, P, K) and soil O. M. content. The results showed that, given a farm household's resources, their goals and aspirations, and their subjective time discount rate, non-sustainable technologies resulting in soil nutrient depletion remain to be practiced. They added that low supply response causing price policies to be largely ineffective is a major constraint for stimulating agricultural intensification. The authors concluded that structural policies such as improving rural infrastructure, credit systems and land policies are required to promote adoption of technological innovation. They stressed that the impact of policy instruments depends on the market, the institutional environment and overall resource availability. They added that, in low income countries like southern Mali, where factor markets for land and capital are not very well developed, instruments of price policy appear to have limited influence on resource allocation, and market and institutional development are the required instruments.

By contrast, in highly commercialized regions, like the Atlantic Zone of Costa Rica, modification of input prices and lower transaction costs appear to be suitable instruments for promoting sustainable land use while maintaining household consumption prospects. The authors recommended a further refinement of the methodology to cope with the absence of the increasingly recognized role of non-agriculture income in farm household decision- making, and the incomplete aggregation of procedures between the farm and regional levels. The authors further recommended a multi-market model which includes migration and agricultural factor use. Roetter et al. (2000), in their synthesis of methodology and case studies, employed simulation models, geographic information systems (GIS) and optimization techniques. Characterization of resources of farmers was done using GIS and a spatial database.

In a case study, a trade-off between cereal production and environmental impact in Haryana, India, primary productivity and milk was estimated using crops and livestock modeling. Multiple goal linear programming was used for optimizing land, water, capital and labour, with objective variables such as food, milk, income, land use, irrigation, N-fertilizer, employment, capital, N loss and biocide index. The preliminary results indicated current availability of water is a major constraint to increasing food production in Haryana. They also developed a technical coefficient generator (TCG) for describing the input–output relations of the various production activities and technologies based on the concept of production ecology. Berkhout et al. (2010), in their study, asked: Does heterogeneity in farmer goals and preferences affect allocative and technical efficiency? A case study in Northern Nigeria fitted a Tobit regression model of the form $E_s = \beta_0 + \sum_{i=1}^{N} \beta_i K_i + \sum_{j=1}^{M} \gamma_j Z_j + \varepsilon_{is}$ first to quantify heterogeneity in farm production attributes among smallholder farmers in a rural African setting; and secondly, to investigate whether heterogeneity in these attitudes and goals indeed results in different production strategies. In the notation, E_s is the score of three efficiency measures – technical efficiency, profit and food allocative efficiency – obtained through data envelopment analysis (DEA); K_i is a vector of household characteristics such as age, level of education and distance to markets; and Z_j is behavioral variables. To arrive at a measure of profit allocative efficiency (E_3), the authors used the linear decomposition proposed by Ray (2004), illustrated as:

$$E_3 = \frac{(\Pi^* - \Pi^A)}{C_A} = \frac{\left(\Pi^* - \Pi^{A''}\right)}{C_A} + \frac{\left(\Pi^{A''} - \Pi^A\right)}{C_A}, \tag{19.2}$$

where Π^* is the profit-efficient production point; C_A is the actual cost level ($C_A = wL^A$); Π^A is the actual level of profit based on the observed level of output and observed use of labor $\left(\Pi^A = pQ^A - wL^A\right)$; and is the level of profit when input-oriented technical inefficiency is eliminated $\left(\Pi^{A''} = pQ^A - wL^{A''}\right)$. The first part of the expression is the allocative efficiency. The latter part of the expression, which is the technical efficiency, equals: $\Pi^{A''} = pQ^A - E^1 wL^A$, with E^I being a measure of input-oriented technical efficiency. Then, the last term in the equation reduces to $(1 - E^I)$. Food efficiency was estimated similar to the more widely used concept of revenue efficiency, albeit using nutritional content of crops instead of output prices.

Three surveys consisting of a survey on general household characteristics, production, farmer goals and preferences were undertaken. The third survey consisted of two parts: a fuzzy pair-wise ranking and a set of Likert scale questions. Data was collected from 155 farmers in seven villages based on differences in market access, population pressure and differences in soils and climate. Farmers indicated their preference for five different goals presented in the fuzzy pair-wise goal ranking, such as getting the highest net benefits from farming; getting the highest subsistence food production; minimizing the risks of farming; safeguarding the soil for future generations; and minimizing labor use in agriculture. Principal component analysis was used to reduce the data from the rankings and the additional questions separately and jointly. Factor analysis was used to reduce the dimensionality of the data, such that z is the minimum set of variables describing most of the variance observed.

In order to increase the efficiency of the DEA approach, the authors aggregated outputs of the 22 crops into three main groups: cereals, legumes and high-value crops (roots, tubers and vegetables), adding rice and sugarcane as separate crops, and using eight different kinds of inputs. The results of the fuzzy ranking suggested that staple food production and sustainability are the most important attributes to farmers in the area of study, followed by risk aversion, while gross margins and labor use minimization are relatively unimportant. The researchers also found that, on average, farmers are relatively food efficient but far from profit efficient. They further added that this not only results from household characteristics directly, but also from personal goals and preferences. They concluded that both socio-economic characteristics and goals and preferences have direct effects on efficiency levels, in addition to some indirect effects of household characteristics through changes in goals and preferences. They stressed that, since village dummies qualify as potential instruments for behavioral factors, it suggests local conditions are strongly related to expressed attitudes and preferences. Hence, they recommended that further studies should be undertaken to identify the causal relationships between the different behavioral factors and socio-economic characteristics and focus on how rural agricultural policies should account for this effectively.

Ruben and van Ruijven (2001) analyzed technical coefficients for bio-economic farm household models: a meta-modelling approach with applications for Southern Mali fitted with a bio-economic model of two components – production and consumption. The authors applied a meta-modelling approach for the production side of a bio-economic farm household simulation model in order to generate continuous production functions on the basis of discrete production data that can be derived from agro-ecological simulation results. In the study, a typical farm household in the 'Koutiala' region of Southern Mali was used, composed of 25 people, with 12 active people that supply 1800 labour days, and have at their disposal 18 ha of land with defined soil quality characteristics, three pairs of oxen and four ploughs. The production side of the model included a set of 1443 technical coefficients for cropping activities (maize, cotton, millet, sorghum, cowpea and groundnuts) and 96 technical coefficients for livestock activities (milk and meat production).

A range of input–output coefficients for potential production (technological) activities that guarantee higher levels of input efficiency, such as control of crop losses, making use of improved input applications, crop residue management strategies, better timing of operations (soil preparation, weeding, grazing) and the implementation of soil erosion control measures, and lower levels of soil nutrient depletion were estimated from agro-ecological simulation models. The consumption side of the model was based on a cross-section budget survey regarding expenditures for cereals, meat, milk, vegetables and non-agricultural commodities.

This survey data was used to estimate marginal utility of consumption for different expenditure categories, making use of a continuous farm household utility function. Expected prices for produced commodities and inputs (labour, traction, implements, fertilisers and manure) were derived from local surveys. Expected utility of consumption (corrected for nutrient losses) under given market conditions and defined resource constraints was optimized.

The meta-modelling approach was applied to the series of several hundreds of data points for all crop and livestock activities to derive continuous production functions for each activity, making use of the Battese (1996) procedure to account for zero input use. For arable cropping, the authors estimated the following Cobb–Douglas production function:

$$lnY = \beta_0 + \beta_1 \ln(L) + \beta_2 \ln(T) + \beta_3 \ln(N) + \beta_4 \ln(P) + \beta_5 \ln(M), \tag{19.3}$$

where Y represents the quantity of the different harvested crops (in monetary units); L and T are the total amounts of labour and traction (in working days); N and P are the amounts of active ingredients of nitrogen and phosphorous fertilisers applied to the crop (in kg/ha); and M is the amount of manure applied (in kg/ha). Livestock activities were defined for meat and milk production under different regimes of animal feeding. For livestock, a linear specification of the production function was estimated as:

$$lnY = \beta_0 + \beta_1(q1) + \beta_2(q2) + \beta_3(q3) + \beta_4(q4) \ldots + \beta_{10}(q10), \tag{19.4}$$

where q(1)...q(10) represent feed sources available during the wet and dry seasons that correspond to different levels of energy intake and digestible organic matter. The estimated functions for crop and animal production were incorporated into a non-linear bio-economic farm household model, which was optimized for the objective of expected utility of consumption, given the availability of resources (land, labour, traction):

$$\begin{aligned} Max\ \ EU &= \sum \left(u \cdot C \middle| \left(Y^* - p_e \cdot E\right)\right., \\ \text{s.t}\ Y^* &= p_i \cdot I + p_c \cdot C + p_l \cdot L, \end{aligned} \tag{19.5}$$

where C represents a vector of consumption goods; Y^* represents income derived from production; I represents the different inputs; L is labour force; and p are their respective prices. The vector E includes environmental externalities (e.g., nutrient losses) valued against their replacement costs.

The household model was first optimised under the assumption of perfect markets, allowing for separability, and thus, sequential optimization. This base run of the model was used as a reference point. Subsequently, the authors imposed constraints on the labour, capital and animal traction market by limiting the use of these inputs to the quantities owned by households. The model specifications with different market imperfections were optimised in a non-separable way, which meant that the production and consumption parts were estimated simultaneously.

The standard Gams software was used for the optimisation. The results showed that the coefficients for labour were positive and significant, and especially in cotton and cowpea production, the elasticity of labour was high. The traction elasticities for cereals and cotton were estimated between 0.06 and 0.20, while for cowpea and groundnut, these were estimated to be about 0.7. The (valid) coefficients for different types of fertiliser were lower than 0.3; for sorghum, cowpea and groundnut, the fertiliser coefficients were not significant. The authors, however, were unable to explain the negative coefficients for manure in millet and cowpea production. The study also found that all functions for crop production have increasing returns to scale.

The livestock results showed a negative constant, implying that cattle needs feed for maintenance, which does not contribute directly to production, and only above a certain level of food intake do cattle start producing milk and meat. The results of the optimization also indicated that, with market imperfections, utility decreases compared to the situation with perfect markets. The results for the consumption side of the model suggested consumption of all categories of goods is lower when market constraints are taken into consideration, while also indicating a shift from meat consumption towards cereals if per capita income falls, which is consistent with consumer demand theory where meat is normally considered to be a luxury good. Consequently, a decrease in income will cause a more than proportional fall in meat consumption. Cereals are considered to be basic requirements for food security, and therefore, cereal consumption does not decrease as much as meat consumption. The researchers concluded that decision-support systems for policy-makers should be able to address issues related to the implications of technological change for farmers' welfare and sustainable resource management, and could be helpful in identifying feasible policy instruments to induce farmers towards the adoption of these technologies. They added that behavioural aspects of farmers' choice and available options for technological change must be combined within a single and consistent modeling framework. They further stressed that the meta-modelling approach provides a useful tool for exploring the characteristics of the discrete technical input–output coefficients that are subsequently incorporated into the framework of a dynamic and continuous bio-economic farm household model. They stressed that these procedures enable improvement of the specification and the robustness of meta-models based on data sets derived from different disciplines, and, therefore, policy simulations based on such integrated models could provide consistent estimates of response elasticities based on income, substitution and scale effects (Foster et al (1984); Frimpong and Asuming-Brempong (2013).

Considering the agricultural systems and agro-ecological conditions in Ghana, and based on the foregoing discussions, the meta-modelling approach involving econometric analysis of ex-ante technologies and FHM for estimating potential adoption rate of the various technologies were used. The FHM provided causality analysis in order to assess socio-economic factors influencing technology use. The aggregation procedures, the fourth component of the bio-economic approach, with which the effectiveness of policy intervention at the regional level has to be addressed, was taken into account within the common technology assessment framework design (TIGA).

Methodology

Ex-ante Assessment of Suitable Technological Innovation

Following Scaillet and Topaloglou (2010) and Davidson and Duclos (2000), in identifying which commonly practiced technology gives superior welfare outcome, the stochastic dominance test was applied to rank outcomes from the different technologies used by the smallholder farmers in the study area. Consider the distribution of independent samples of welfare measures such as per capita expenditure, Y of smallholder farmers using any two technologies, A and B with cumulative density functions F_A and F_B with the lower bound of the common support fixed at zero and the upper bound fixed to any acceptable poverty line, that is, (0, Z). Then,

$$F_A(x) = \frac{1}{N}\sum_{i=1}^{N} 1\left(X_i^A \leq Z\right), \tag{19.6}$$

$$F_B(x) = \frac{1}{M}\sum_{i=1}^{M} 1\left(X_i^B \leq Z\right), \tag{19.7}$$

where X_i^A and X_i^B represent distribution of per capita expenditures of smallholder farmers who use technology A and B respectively, N and M represent sample sizes of the two technologies, and $1(\cdot)$ takes a value of 1 when the farmer is equal to or above the poverty line and zero otherwise. The stochastic dominance for A can be expressed as:

$$D_A^1(x) = F_A(x) = \int_0^x dF_A(Y). \tag{19.8}$$

For any integer, $S \geq 2$,here S is the order of the stochastic dominance, $D_A^s(x)$ takes the form:

$$D_A^s(x) = \int_0^x D_A^{s-1}(Y)dy. \tag{19.9}$$

Technology A is said to be dominant over B at order S if $D_A^s(x) \leq D_B^s(x)$, for all $X \in [0, Z_{\max}]$. Following Davidson and Duclos (2000), the general form is specified as:

$$D^{s}_{(x)} = \frac{1}{(S-1)!}\int_{0}^{x} (Z - Y_i)^{S-1} dF(Y). \tag{19.10}$$

For a random sample of N independent observations, the natural estimator of $D^{s}_{(x)}$ is specified as:

$$\hat{D}^{S}_{(x)} = \frac{1}{(S-1)!}\int_{0}^{x} (Z - Y_i)^{S-1} dF(Y) = \frac{1}{N(S-1)!}\sum\nolimits_{i=1}^{N} (Z - Y_i)^{S-1}\left(X_i^A \le Z\right). \tag{19.11}$$

The main hypothesis for testing dominance at order $S = 1, 2, 3$ (first, second and third order dominance) is stated as:

$$H_0 : D^{s}_{A}(x) - D^{s}_{B}(x) = 0 \ for \ \ all \ \ Z \in [0, Z], \tag{19.12}$$

$$H_1 : D^{s}_{A}(x) < D^{s}_{B}(x) = 0 \ for \ \ all \ \ Z \in [0, Z]. \tag{19.13}$$

This was done using a t-test. The variance for the test was specified as:

$$\left[\hat{D}^{S}_{A}(x) - \hat{D}^{S}_{A}(x)\right] = Var\left(\hat{D}^{S}_{A}(x)\right) + Var\left(\hat{D}^{S}_{A}(x)\right). \tag{19.14}$$

The t-statistic on the basis for which H_0 is tested is stated as:

$$\frac{D^{s}_{A}(x) - D^{s}_{B}(x)}{\sqrt{Var\left(\hat{D}^{S}_{A}(x)\right) + Var\left(\hat{D}^{S}_{A}(x)\right)}}. \tag{19.15}$$

Four outcomes are possible: A dominates B; B dominates A; no dominance because $A = B$; or no dominance because A crosses B. When A crosses B, the second and third order dominance are used to test for differences. For A to be said to be dominant over B, the null hypothesis must be rejected.

Potential Adoption Rate

The Farming Systems Research approaches were used to predict the maximum adoption rate of the recommended technologies in the zones. According to Hildebrand and Russell (1996), the likelihood that a farmer will adopt a technology depends on farmer categories, production goals and the environment. This is mathematically expressed as:

$$PAR = \left(\frac{F^*G^*E}{10000}\right). \tag{19.16}$$

In the notation, F = Frequency of farmer categories (%), G = Frequency of production goals (%) and E = frequency of production environments (%).

From the study, four farmer categories, very poor, poor, rich and very rich, were identified. Factors that influence these farmers' production goals are access to production resources and institutions (credit, FBOs, extensions), age, and gender. An indicator used for the production environment is whether households are settlers or natives. A composite indicator for farmers' goals (G) and environment (E) was estimated using weighting values. Males were given a weight of 1 and females 0.5, while respondents 50 years or younger were given a weight of 1 and those older than 50 were given a weight of 0.5. The rest of the indicators were given a weight of 1. The composite indicator was estimated as:

$$C_i = \frac{\sum_{i=1}^{n} w_i X_i}{\sum_{i}^{n} w_i}. \tag{19.17}$$

In the notation, C_i is the composite indicator value for G or E and w_i is the weight of indicator X_i.

Income Effect of Technological Innovations

To show the effect of the technology on smallholder farmers' incomes, propensity score matching was used to test for differences in income of the treated (adopters of the technology) and the untreated (non-adopters of the technology). The income differential was then expressed as a percentage change of the income of adopters had they not adopted the technology (counterfactual).

Data Collection

Characteristics of the Study Area

Ghana is located between latitudes 4.5°N and 11.5°N and longitudes 3.5°W and 1.3°E (Antwi-Agyei et al. 2012), and can be distinguished into five main agro-ecological zones of fairly homogeneous climate, landform, soil, vegetation and land use systems (MoFA 2012) typical of West Africa. Ghana's population is around 24.6 million (24,658,823) (Ghana Statistical Service 2012a) and agriculture is the backbone of the economy. Generally, annual average temperatures range from 26.1 °C in places near the coast to 28.9 °C in the extreme north, with the highest

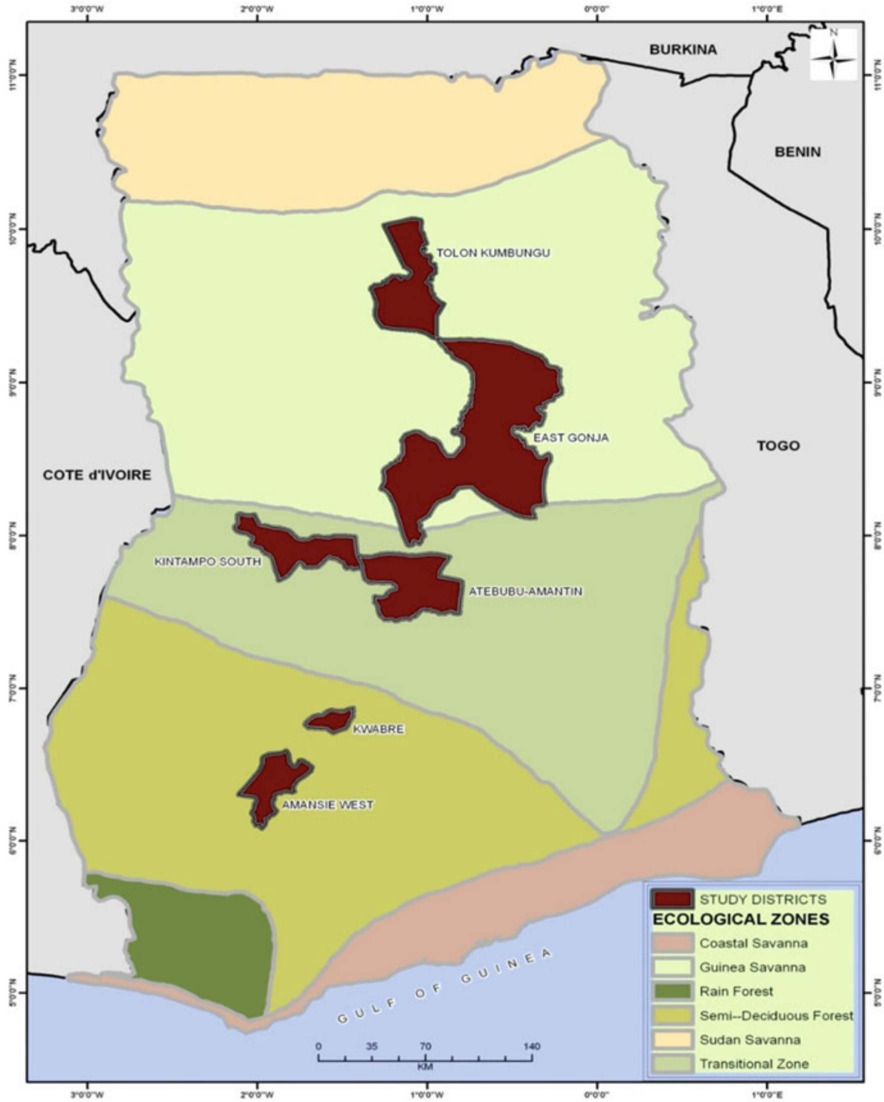

Fig. 19.1 Map of Ghana showing study locations

temperatures recorded in the Upper East Region (MoFA 2012). The topography of Ghana is predominantly undulating, with slopes less than 1 %. Average annual rainfall is about 11,796 mm, according to the Ghana Meteorological Service (2010), as cited in MoFA (2012), and less than 0.5 % of agriculture is under irrigation (World Bank 2010). Figure 19.1 shows a Map of Ghana with the study locations.

Selection of Study Area

An ex-ante assessment of the potential benefits of new technologies in communities and households provides the most reliable means of gauging a household's acceptance of the new technology (Wood 2003). It is, therefore, appropriate to select communities with populations for whom the technology is intended. Even then, it is unlikely that such studies can be carried out in all the potential communities where the new technology might provide significant impact. Therefore, the overall focus of sampling is to reach all strata of the people living in potential communities, particularly poor and small-scale farmers living in marginal or less-favoured areas (LFA's). Following Wood (2003), Stoorvogel et al. (2004), and Smale et al. (2003), the study adopted a multistage sampling procedure in selecting respondents. This involved zoning or stratification of Ghana into three parts, namely savanna, transition and forest zones, on the basis of differences in vegetation, income and livelihood activities. Two districts were selected purposively from each strata or zone using the crop type produced. Three communities within each district were randomly selected using the lottery approach. A simple random sampling technique was employed to select farmers within the communities. Following Yamane (1967), the sample size for each community was estimated as:

$$n = \frac{N}{1 + N(e^2)}, \tag{19.18}$$

where n = the sample size, N = population, and e = significance level.

The sampling frame for each community was established with village elders, District Assemblies and the Ministry of Food and Agriculture District directorates. The survey included poverty or marginality hotspot mapping using a Global Positioning System (GPS), a collection of primary data on household and farm level factors, and agro-ecological variables using structured questionnaires (Simelton 2012). Key informant and expert interviews were also conducted. In all, 402 smallholder farmers were interviewed for the study. This comprised 139 respondents from the forest zone, 156 from the transition zone, and 107 from the savannah zone. The proportion of the respondents from the various zones in the total sample is shown in Fig. 19.2.

Results and Discussions

Trend Analysis of Technological Interventions

The trend analysis of technological innovations provides project implementers with the historical overview of major technological interventions in the intended project sites and the purpose or reason for introducing the interventions. This section,

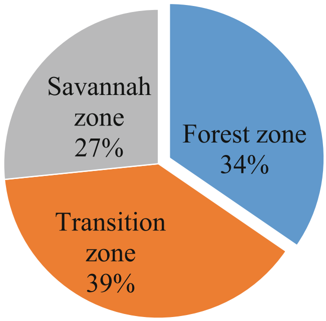

Fig. 19.2 Distribution of smallholder farmers in the study area

therefore, presents a brief temporal overview of interventions in the study zones, based on expert opinions, key informants and focus group discussions.

Since Ghana's independence in 1957, the then-ruling government, the Convention Peoples Party (CPP), made a steady effort to modernize agriculture in Ghana. According to the key informants, the CPP government introduced an early maturing rice variety, the 'Red rice', into the savannah zone. Also, during the same period, cowpeas, improved maize varieties and special yam seeds were introduced into the zone. The period under CPP also saw the establishment of state farms and block farms in the forest and transition zones, respectively. These farms served as models to train farmers.

The CPP government was closely followed by periods of rule by military regimes, which adversely affected progress. However, the Acheampong regime stands out in terms of agricultural development and technological advancement. For the first time, under the Acheampong-led National Redemption Council (NRC) government, Massey-Ferguson tractors were introduced into Ghana in 1974. Marketing Standards Boards were also established to ensure and maintain standardization in selected crops. The government also introduced local breeds of banana into the savannah zone in 1973. To improve food security, the Acheampong government introduced cassava into the savannah zone for the first time, cassava having hitherto been grown mainly in the forest zone. In the south, particularly among public workers, the Operation Feed Yourself (OFYS) Programme was also introduced. This programme made Ghana self-sufficient in the production of several crops. Silos were constructed across the country to reduce post-harvest losses. However, this period was also followed by other military regimes which virtually wiped out the successes achieved during the period.

After Ghana returned to civilian rule in 1979, under the leadership of Dr. Hilla Liman, attempts were made once again to boost agricultural production. The government introduced fertilizers into the country and also subsidized them as a means of improving crop yields. These fertilizer subsidies and other agro-input subsidies were wiped out during the Structural Adjustment Programmes (SAP). Periods after the Peoples National Party (PNP) and the Liman-led government saw more military rule. In 1992, when Ghana turned into a democratic state, the

National Democratic Congress (NDC) government introduced an improved maize variety, Dobidi, through MoFA, in conjunction with IFAD.

Under the New Patriotic Party (NPP), which won power from the NDC government in 2000, fertilizer subsidies were re-introduced. The Cocoa Mass Spraying Programme was also introduced, which boosted yields of cocoa farmers, along with the cocoa certification programme. New cassava varieties with high starch content, improved oil palm seedlings, and improved soybean varieties were introduced under the NPP-Kuffuor government. Through the Millennium Development Authority, yam minisetts technology, as well as improved maize seeds, were also introduced into selected districts across the nation.

The NDC government, after their re-installation in 2008, re-introduced the Block Farm Programme and the District Tractor Services Concept. In 2009, the Village Mango Project was introduced into the transition zone, offering farmers, on the average, five improved mango seedlings to maintain and nurture. This was followed by the Root and Tuber Improvement and Marketing Programme (RTIMP), introduced across the country with the overall aim of providing improved planting materials such as yam minisetts and cassava cuttings.

The foregoing discussions show that there have been a number of intermediations in technological programmes introduced into Ghana by various governments. However, most of these programmes failed to identify the specific local challenges of the farmers. Monitoring and supervision were poor and the required resources were either not available or were not provided at the time that they were required. Corruption and bureaucracy also crippled most of these interventions and prevented the targeted farmers from benefitting from the available resources. For instance, some politicians and bureaucrats hauled fertilizer or bought the subsidized fertilizer and re-sold to farmers at higher prices. Also, in some cases, only farmers known to be allied with the government in power benefitted from the interventions.

Technologies That Will Work for Poor Smallholder Farmers

Agricultural technologies are often locational, since they are affected by environmental changes. Technologies work best when they are adapted to the specific conditions of the intended beneficiaries and have optimum adoption rates. Therefore, technologies that give the greatest potential welfare benefit to the intended user group and increase the beneficiary's utility are to be chosen IFPRI (2009). Also, cultural/economic support systems and political or administrative conditions surrounding the target area may influence the scaling up of a technology. The stochastic dominance test provides a measure of the welfare benefits of a technology for smallholder farmers. From the results of the test, six main technologies are suggested for up-scaling in each district of the study zones. This is of particular importance, as farmers in the study zones and districts were involved in production of different crops and, hence, faced different technological challenges.

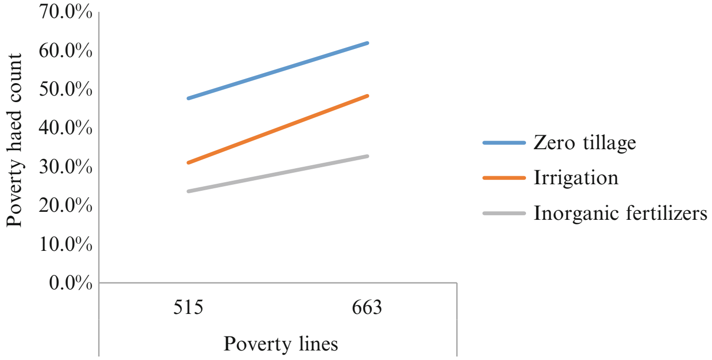

Fig. 19.3 Stochastic dominance test results for Afigya-Kwabre District

Smallholder farmers in the Afigya-Kwabre District of the forest zone were mainly involved in vegetable production, such as okro, tomatoes and garden eggs. Farmers in this district were mainly constrained by fertilizer and irrigation facilities for dry season farming and erratic rainfall conditions which affected their production. From the first order stochastic dominance test (see Fig. 19.3), the inorganic fertilizers provided the greatest welfare benefits to households. Fertilizer technology has the greatest dominance, as fewer of the smallholders who applied the technology have their income below the poverty line. However, application of fertilizer without adequate soil moisture will not lead to the intended benefit. Therefore, the technology best fitted for such communities will be one which combines irrigation facilities and fertilizer application.

Smallholder farmers in the Amansie West District have cocoa as their main crop, but also engage in food crops such as maize and cassava on a subsistence basis. As such, during the cocoa off-seasons, households are faced with food insecurity, which pushes many of them into illegal mining and other coping mechanisms. Since most of the farmers grow cocoa, they do not use weedicides to control weeds, as they claim the practice has implications for some useful flora and fauna. However, farmers who engaged in off-season farming using zero tillage were better off, as shown in the results in Fig. 19.4. Therefore, it would be useful to provide farmers in this district with resources such as weedicides and fertilizers to enter into off-season farming.

In the transition zone, although the technologies intersect, the best results after testing for first, second and third order dominance are marketing and irrigation in the Kintampo South District (see Fig. 19.5), and storage facilities and the use of inorganic fertilizers for smallholder farmers in the Atebubu-Amantin District (Fig. 19.6).

This observed difference in the zones emanates from differences in crop types produced by smallholder farmers, even within the same zone. Whiles ginger is the major crop produced by farmers in the Kintampo South District, maize is the major crop produced by smallholder farmers in the Atebubu-Amantin District. Also, in the

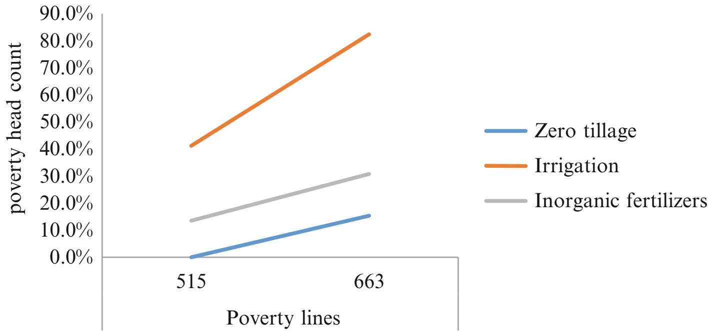

Fig. 19.4 Stochastic dominance test results for Amansie-West District

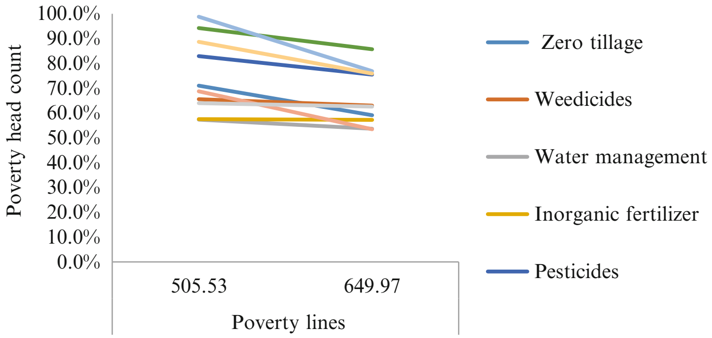

Fig. 19.5 Stochastic dominance test results for Kintampo South District

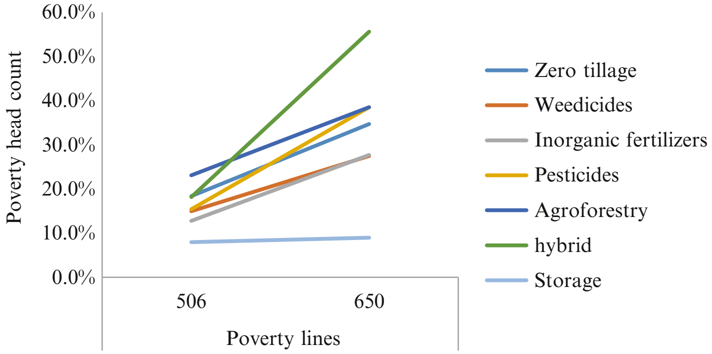

Fig. 19.6 Stochastic dominance test results for Atebubu-Amantin District

Tolon District of the savanna zone, pesticides and improved seeds were identified as the dominant technologies for reducing poverty among smallholder farmers in the district (Fig. 19.7). Similarly, in the Gonja-East District, improved seeds and agro-forestry were identified as the two dominant technologies (Fig. 19.8).

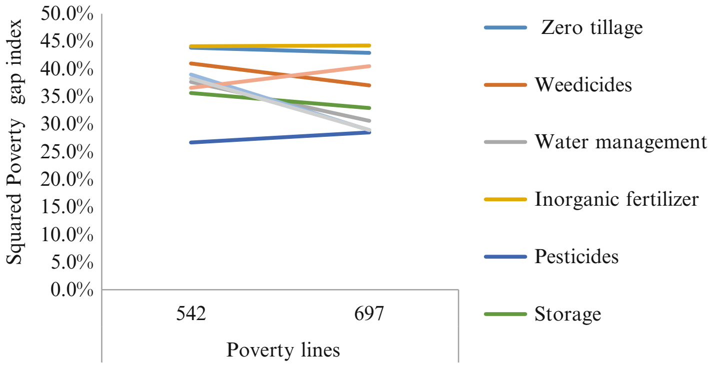

Fig. 19.7 Stochastic dominance test results for Tolon District

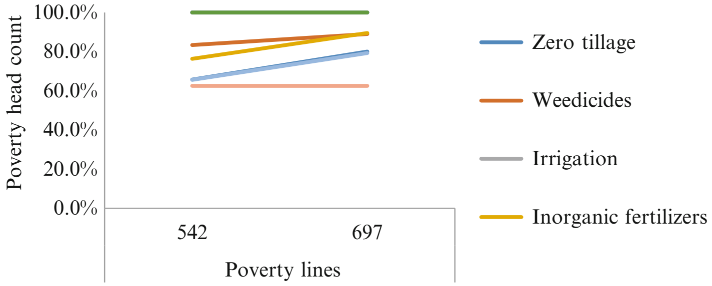

Fig. 19.8 Stochastic dominance test results for East-Gonja District

Potential Adoption Rate

The results of the potential adoption rate (PAR) of the technologies are shown in Table 19.1. The table presents the four farmer categories, very poor, poor, rich and very rich, aggregate value of the production goals index (G), and the production environment (E) for each of the farmer categories. From the results, the PAR for the forest zone is 23.3 %. This means that, other things remaining constant, the rate at which the technologies in the forest zone will be adopted or diffused is 23.3 %. This is, however, different from maximum adoption, which is the percentage of farmers who will adopt the technology. Predicted adoption rate for the transition and savannah zones are 22.5 % and 18.0 %, respectively.

Income Effect of Technologies

Table 19.2 shows the income effect of the recommended crop technologies for the study locations. The results of the *t*-test showed significant differences in income

Table 19.1 Potential adoption rates in the zones

	Forest Zone				Transition zone				Savannah zone		
Farmer categories	Very poor	Poor	Rich	Very rich	Very poor	Poor	Rich	Very rich	Very poor	Poor	Rich
Farmer categories (%)	14.4	46	38.1	1.4	9.6	65.4	22.4	2.6	31.8	42.1	26.2
Production goals (%)	50.6	55.1	53.9	68.8	48.3	53.4	49.5	51.6	43.9	48.3	44.2
Production environment (%)	35.0	45.8	42.1	50.0	48.9	43.5	41.9	33.3	39.2	39.3	39.3
PAR (Zone)	23.3				22.5				18.0		

Table 19.2 Income effect of crop technologies in study locations

District	Technology		N	Per capita expenditure	Mean difference	df	t	Sig. (2-tailed)	Income effect (%)
Afigya Kwabre	Inorganic fertilizers	Adopters	55	1171.12	914.18	66	3.420	.001	355.8
		Non-adopters	13	256.95					
Amansie-West	Zero tillage	Adopters	13	2313.32	1046.13	69	2.169	.034	82.6
		Non-adopters	58	1267.19					
Atebubu-Amantin	Storage	Adopters	47	7390.29	6258.03	65	1.917	.060	552.7
		Non-adopters	20	1132.26					
Kintampo South	Marketing	Adopters	2	891.65	70.85	87	.154	.878	8.6
		Non-adopters	87	820.80					
Gonja East	Improved seeds	Adopters	8	1018.67	660.85	55	3.388	.001	184.7
		Non-adopters	49	357.82					
Tolon	Pesticides	Adopters	17	513.42	173.64	48	1.701	.095	51.1
		Non-adopters	33	339.78					

between adopters and non-adopters of the technologies, except for the Kintampo South District. This insignificant difference may be due to the small sample size of adopters. The results further indicate income change from 8.6 % to 552.7 % for adopters of the various technologies.

Conclusions

Based on the findings of the research, the following conclusions are drawn:

- Dominant technologies that have the potential to reduce smallholder farmers' level of poverty and marginality are: inorganic fertilizers for Afigya-Kwabre; zero tillage for Amansie-West; storage facilities for Atebubu-Amantin; marketing facilities for Kintampo South; improved varieties for Gonja East; and pesticides for the Tolon Districts.
- Potential adoption rate varied among the various poverty segments.
- The technologies have significant effects on the incomes of adopters.

Policy Recommendations

The following recommendations are made from the study:

- Government should strengthen, resource, and build the capacity of institutions to train and offer support to smallholder farmers. These institutions should have a separate wing to see to the needs of smallholder farmers in helping them adopt innovations.
- The Ministry of Food and Agriculture (MoFA) and other partner organisations and ministries should also provide routine workshops and training for smallholder farmers.
- Government, through its Extension Services Directorate, should help disseminate, diffuse or up-scale technologies that have greater potential of reducing poverty and marginality.
  - For the Afigya-Kwabre District, technologies that enhance soil fertility, such as use of inorganic fertilizers, has a greater likelihood of reducing poverty in the district.
  - In the Amansie-West District, activities that will provide income to smallholder farmers during the off-cocoa season, such as use of zero tillage for short duration cropping, specifically vegetables, will help.
  - In the Atebubu-Amantin District, storage facilities for maize and a warehouse credit facility that will provide some income for farmers as they look for a good market price is the dominant strategy.

– In the Kintampo South District, marketing farmer-based organisations gives the farmers higher income.
– Improved yam minisetts is recommended for the Gonja East District
– Pesticides for controlling yam borers is the best technology for smallholder farmers in the Tolon District.

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