INTERNATIONAL FOOD
POLICY RESEARCH INSTITUTE
sustainable solutions for ending hunger and poverty

IFPRI®

Supported by the CGIAR

IFPRI Discussion Paper 00785

August 2008

Insecticide Use on Vegetables in Ghana

Would GM Seed Benefit Farmers?

Daniela Horna, International Food Policy Research Institute
Melinda Smale, Oxfam America
Ramatu Al-Hassan, University of Ghana
José Falck-Zepeda, International Food Policy Research Institute
and
Samuel E. Timpo, Biotechnology and Nuclear Agricultural Research Institute, Ghana Atomic Energy Commission

Environment and Production Technology Division

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

The International Food Policy Research Institute (IFPRI) was established in 1975. IFPRI is one of 15 agricultural research centers that receive principal funding from governments, private foundations, and international and regional organizations, most of which are members of the Consultative Group on International Agricultural Research (CGIAR).

FINANCIAL CONTRIBUTORS AND PARTNERS

IFPRI's research, capacity strengthening, and communications work is made possible by its financial contributors and partners. IFPRI gratefully acknowledges generous unrestricted funding from Australia, Canada, China, Denmark, Finland, France, Germany, India, Ireland, Italy, Japan, the Netherlands, Norway, the Philippines, Sweden, Switzerland, the United Kingdom, the United States, and the World Bank.

Published by

INTERNATIONAL FOOD POLICY
RESEARCH INSTITUTE
2033 K Street, NW
Washington, DC 20006-1002 USA
Tel.: +1-202-862-5600
Fax: +1-202-467-4439
Email: ifpri@cgiar.org

www.ifpri.org

Notices

[1] Effective January 2007, the Discussion Paper series within each division and the Director General's Office of IFPRI were merged into one IFPRI–wide Discussion Paper series. The new series begins with number 00689, reflecting the prior publication of 688 discussion papers within the dispersed series. The earlier series are available on IFPRI's website at www.ifpri.org/pubs/otherpubs.htm#dp.

[2] IFPRI Discussion Papers contain preliminary material and research results. They have not been subject to formal external reviews managed by IFPRI's Publications Review Committee but have been reviewed by at least one internal and/or external reviewer. They are circulated in order to stimulate discussion and critical comment.

Contents

List of Tables

List of Figures

ACKNOWLEDGMENTS

This paper is part of study made possible through the support by the USAID-Ghana Mission and the activities of the Program for Biosafety Systems (PBS). PBS is funded by the Office of Administrator, Bureau for Economic Growth, Agriculture and Trade/ Environment and Science Policy, U.S. Agency for International Development, under the terms of Award No. EEM-A-00-03-00001-00. The opinions expressed herein are those of the author(s) and do not necessarily reflect the views of the U.S. Agency for International Development or its Missions worldwide.

The authors would like to thank the anonymous reviewer of this paper who provided helpful comments and suggestions.

ABSTRACT

Tomato, cabbage, and garden egg (African eggplant, or *Solanum aethiopicum*) are important crops for small-scale farmers and migrants in the rural and peri-urban areas of Ghana. Genetic modification has the potential to alleviate poverty through combating yield losses from pests and diseases in these crops, while reducing health risks from application of hazardous chemicals. This *ex ante* study uses farm survey data to gauge the potential for adoption of genetically modified (GM) varieties, estimate the potential impact of adoption on farm profits, and highlight economic differences among the three crops.

Farmers' expenditures on insecticides are below the economic optimum in all three crops, and the estimated function for damage abatement shows that insecticide amounts are significant determinants of cabbage yields only. Nonetheless, yield losses from pests and disease affect insecticide use. A stochastic budget analysis also indicates a higher rate of return to vegetable production with the use of resistant seeds relative to the status quo, even considering the technology transfer fee for GM seed. Non–insecticide users could accrue higher marginal benefits than current insecticide users. Comparing among vegetable crops with distinct economic characteristics provides a wider perspective on the potential impact of GM technology. Until now, GM eggplant is the only vegetable crop that has been analyzed in the peer-reviewed, applied economics literature. This is the first analysis that includes African eggplant.

Keywords: damage abatement, stochastic budget analysis, GM vegetables, Ghana.

ABBREVIATIONS AND ACRONYMS

GM	Full Name
SFB	Shoot and Fruit Borer
TYLCV	Tomato Yellow Leaf curl Virus
DBM	Diamondback Moth
CIMMYT	International Maize and Wheat Improvement Center

1. INTRODUCTION

Ghana's agriculture is characterized by low yields and productivity. Although a number of factors contribute to this low agricultural productivity, constraints on technology availability and use are crucial. The distance between yields that could be achieved from application of recommended practices and actual average yields for most traditional staple crops ranges from 200% to 300% in Ghana (Al-Hassan and Diao 2007). Such yield gap estimates are not available for vegetable crops, but it is not hard to speculate that similar shortfalls in yields exist in those crops. Low yields and productivity are compounded in the long run by production shocks due to environmental stresses such as drought, pests, and diseases. Vegetables tend to be more susceptible to biotic constraints than are other crops.

Not surprisingly, pesticide use has increased over time in Ghana and is particularly elevated in the production of high-value cash crops and vegetables (Gerken et al. 2001). Chemical pesticides are used improperly or in dangerous combinations (Obeng-Ofori et al. 2002). The misuse of chemical pesticides is of so much concern that promotion of safe use of pesticides on vegetables has been placed on the agenda of Ghana's Food and Agriculture Sector Development Policy (Ministry of Food and Agriculture 2002). The use of genetically modified (GM) crops to address pest and disease constraints is therefore an option worth examining. GM vegetables should be evaluated in terms of feasibility, cost-effectiveness, and long-term impact on productivity, yield stability, health, and the environment.

This *ex ante* analysis investigates the potential for adoption of GM vegetables by examining the determinants of insecticide use and estimating the extent to which insecticide use abates damage to the crop. The study also examines the potential impact on growers of adopting GM vegetables through a stochastic simulation of marginal profits. Health and environmental externalities, although important, are not part of this evaluation.

Biotic constraints that cause significant economic damage in Ghana include tomato yellow leaf curl virus (TYLCV), the diamondback moth (DBM) in cabbage, and the shoot and fruit borer (SFB) in garden egg (*Solanum aethiopicum*) (Youdeowei 2002). Tomato is produced primarily by small-scale farmers who are distributed throughout the country and is consumed nearly on a daily basis by Ghanaian households. A broad range of market participants is involved in trading tomato. The country can meet domestic demand only during the rainy season, importing tomato during the remainder of the year from Burkina Faso. In the dry season, the lack of irrigation facilities together with the higher incidence of TYLCV relative to the rainy season drastically reduces total production. For instance, devastating losses to TYLCV disease and a fungal complex in the Upper East Region had major consequences for farmers in 2002 (M. Kyofa-Boahma,[1] personal communication).

Cabbage is a vegetable of expanding commercial importance but of limited production in Ghana, produced by migrants in peri-urban areas for urban consumers. High rates of pesticide application and water consumption in cabbage production incur negative environmental and health externalities. The diamondback moth, or DBM (*Plutella xylostella*), is the most severe biotic constraint in cabbage production. DBM is a readily adaptable pest that has developed resistance to almost every known or approved insecticide in different parts of the world (Obeng-Ofori et al. 2002). According to experts, DBM has already developed resistance to the main insecticides available in Ghana.

Garden egg (*Solanum aethiopicum*) is an indigenous species that is consumed widely in Ghana and is a source of cash for rural households in the southern and central parts of the country. Garden egg is attacked by several local pests and diseases. The most significant biotic constraints for garden egg include SFB, which causes major economic losses (Owusu-Ansah et al. 2001a). Garden egg is produced largely for the local market. Small amounts are currently exported, primarily to niche markets in the United Kingdom mostly for African consumers.

Exploring alternative responses to these productivity constraints is a fundamental means of supporting Ghana's smallholder farmers. One alternative for addressing yield damage from pests and

---

[1] Plant Protection and Regulatory Services Directorate, Ministry of Agriculture, Pokuase-Accra, Ghana.

diseases in vegetable crops is genetic modification. A unique aspect of GM crops is that a desirable trait, such as resistance to a biotic stress, can be transferred to a host cultivar while maintaining other attributes in the cultivar that farmers and consumers value, such as taste. Although no *Bacillus thuringiensis* (Bt) garden egg is currently in the research and development pipeline, genetic modification is feasible given extensive experience with Bt in the other cultivated eggplant species, *Solanum melangena*. The Ghanaian government has given priority to research to develop virus-resistant tomato. Some of the Bt genes have been shown to control damage from DBM. Generally speaking, the Bt transformation is one of the most heavily researched genetic modifications in crops.

Throughout the analysis, we highlight differences among vegetable crops that are related to farmer management practices and the economic characteristics of the crops. We also summarize data concerning farmers' perceptions about insecticides and their practices. Data for the analysis were collected from a self-weighting, random sample of 384 growers, stratified by production zone, from March to May of 2006. Some parameters in the simulation analysis are drawn from published sources.

The study makes several contributions to a growing literature on the adoption and impact of GM crops in developing agricultural economies. First, it is among the few to examine the potential impact of GM vegetables (Krishna and Qaim 2007; Kolady and Lesser 2008a; Kolady and Lesser 2008b). By far the most studied crop and trait combination in the empirically based, peer-reviewed literature on GM crops in non-industrialized countries from 1996 to 2006 is insect-resistant (IR) cotton (Smale et al. 2006). Second, this study is among the few in this literature to address the potential or actual impact of GM crops in sub-Saharan Africa. Aside from numerous publications on IR cotton and IR maize in South Africa and several on the potential for IR maize in East Africa (De Groote et al. 2003), those focusing on West Africa have been based on trade models (Cabanilla et al. 2005; Elbehri and Macdonald 2004; Langyintuo and Lowenberg-Deboer 2006). An *ex ante* study by Edmeades and Smale (2006) addressed the potential impact of GM banana on smallholder farmers in the East African highlands. To our knowledge, this study is probably the first attempt to assess the potential impact of GM crops on farmers in West Africa. Third, relatively few studies have explicitly recognized the year-to-year variability in farm profits by applying stochastic approaches (Hareau et al. 2006; Pemsl et al. 2004). Finally, consistent with the approach recommended in recent econometric studies published on this topic (Qaim and De Janvry 2005; Huang et al. 2002; Shankar and Thirtle 2005), we consider the effects of insecticides on both yield and crop damage and test for the endogeneity of the decision to use insecticides.

2. METHODS

Using data collected from a statistical sample of farmers in Ghana, we evaluate insecticide use as an indicator of the potential adoption of GM varieties. The underlying assumption is that farmers using insecticide would most likely be the first to adopt GM varieties. It is important then to know not only which factors determine insecticide use but also the degree to which insecticide is controlling damage. While the theory suggests that farmers tend to apply higher insecticide doses on vegetables than on other food crops, we hypothesize that such doses are still below the optima and thus do not significantly abate damage. We apply a damage abatement framework to model vegetable production and to determine the effect of insecticide use on yields and yield losses from pests and diseases.

One of the strongest arguments for the use of GM varieties is their potential to reduce the use of pesticides that have negative effects on human health and the environment. If, as suggested above, farmers are using suboptimal doses of insecticide, what would be the benefit of adopting GM varieties? We simulate the effect of GM variety adoption on farm profits, accounting for the risk and uncertainties of production by varying selected parameters in a stochastic analysis. In the simulation analysis, we also consult data drawn from other published studies. Next, we summarize the data design. In the two subsections that follow, we present (1) the econometric model and (2) the stochastic, partial budget analysis.

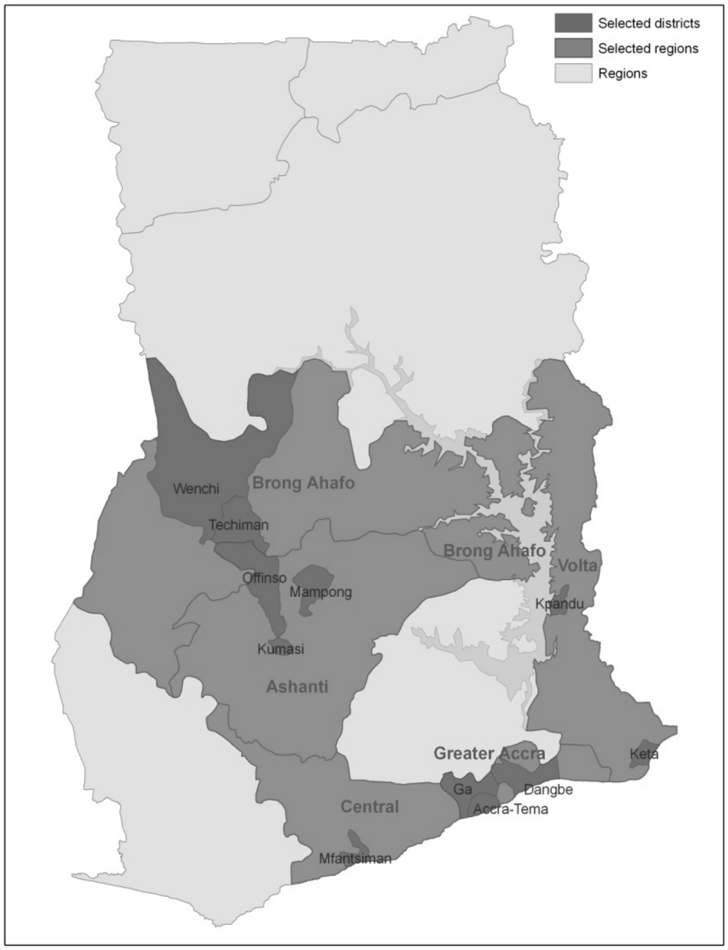
Modeling Production and Insecticide Use

Data

Data on production practices and pest damage were collected through personal interviews with farmers. A random sample of farmers was selected, stratified by production areas located in the southern and central regions of Ghana. Production areas were selected based on prior information, by agro-ecological zone, region, and district. Figure 1 shows the regions and districts selected for study: Greater Accra Region (Accra Metropolitan Area, Dangme East, and Ga West); Central Region (Mfantseman); Ashanti Region (Kumasi Metropolitan Area, Mampong, and Offinso); Brong-Ahafo Region (Techiman and Wenchi); and Volta Region (Keta and Kpandu). With the help of the agricultural extension officers in each district and town, production areas were identified and weighted according to the number of producers per area. Finally, for each crop, a random sample of farmers was drawn after visiting the town and contacting producers. A total of 384 structured questionnaires were administered, consisting of 151 on tomato production, 77 on cabbage production, and 156 on garden egg production.

The following questions are addressed: (1) input use and output; (2) insecticide use, perceptions about pesticides, and pesticide management practices; and (3) general producer characteristics. Pesticides include not only insecticides but also fungicides and other inputs farmers use to control pests. Strictly speaking, in this study we analyze the perceptions on pesticide use but examine the abatement effect of insecticides only. The targeted constraints in cabbage and garden egg are insect pests. Tomato growers in Ghana control the vector of the TYLCV disease, the white fly (Bemisia tabasi), by applying insecticide.

Figure 1. Study sites in Ghana



Source: M. Benza (University of San Diego).

Conceptual Framework

Lichtenberg and Zilberman (1986) were the first to propose the use of the damage abatement framework to estimate a production function. Since then, other authors have modified and extended the model (Babcock et al. 1992; Carrasco-Tauber and Moffitt 1992). Recently, researchers have applied the framework to measure the impact of growing Bt cotton (Huang et al. 2002; Shankar and Thirtle 2005; Qaim and De Janvry 2005).

This framework considers that agricultural inputs such as insecticides are not yield enhancing but abate yield losses. The damage abatement effect is defined as the proportion of the destructive capacity of the damaging agent that is eliminated by applying a certain amount of a control input. Control inputs could be pesticides, labor, cultural practices, a crop variety, or any other input that the farmer uses with the intention of mitigating the impact of pests and diseases.

Guan et al. (2005) proposed a similar framework with a broader characterization of the inputs. The first category of “growth” inputs is directly involved in the biological and agronomic processes of crop growth. The second group, termed “facilitating inputs,” is used to help create favorable growth conditions. Both Lichtenberg and Zilberman (1986) and Guan et al. (2005) recognize the principle that if all inputs intended to control damage are treated as other inputs, then their effects on production will likely be overestimated. The approaches they propose are suitable for estimating the effect of inputs on yield, as well as the interaction effects among inputs.

Lichtenberg and Zilberman (1986) specify a production function in a damage control framework as

$$Y = F\left[\mathbf{Z}, G\left(\mathbf{X}\right)\right], \tag{1}$$

where the vector **Z** represents directly productive inputs and the vector **X** represents the control inputs. The abatement function G(**X**) takes values between [0, 1]. If there is no control of the damage, (G(**X**) = 0) and Q = F [**Z**, 0]; if there is complete control of the damage, (G(**X**) = 1) and Q = F [**Z**, 1].

The most commonly used specification for a production function is the Cobb-Douglass. The main advantage of this specification is that it can be linearly estimated after a simple logarithmic transformation. The Cobb-Douglas function also has important limitations. For example, it implies that inputs are used proportionally, which is not necessarily true. Use of the function also leads to exclusion of observations with zeros because their logarithm is not defined. Quadratic specifications have been applied in order to overcome these limitations (Lansink and Carpentier 2001; Qaim and De Janvry 2005). In the literature, the exponential or logistic distribution has been specified for the abatement function, rendering robust results (Babcock et al. 1992; Pemsl et al. 2005; Qaim and Matuschke 2005). Here, we use a quadratic production function with a logistic abatement function:

$$Y = \left(\alpha + \sum_i \beta_i \mathbf{Z}_i + \sum_i \sum_j \phi_{ij} \mathbf{Z}_i \mathbf{Z}_j + \gamma \mathbf{H} + \varepsilon\right) * \left(\left[1 + \exp\left(\mu - \sigma \mathbf{X}\right)\right]^{-1}\right). \tag{2}$$

Notice that in equation (2), while the function G(**X**) is unobservable, the use of control agents **X** can be directly observed and measured. A main assumption associated with the use of a logistic damage function is that the maximum yield potential is not realized because of a fixed damage effect, μ. Using (2), the value of the marginal product of insecticide can be determined by estimating the value of the change in output due to changes in insecticide use:

$$VMP^{ins} = P^{veg} * \mathrm{F}\left(\mathbf{Z}\right) * \frac{\sigma_i \exp\left(\mu - \sigma \mathbf{X}\right)}{\left[1 + \exp\left(\mu - \sigma \mathbf{X}\right)\right]^2}, \tag{3}$$

where P^{veg} is the market price of the vegetable.

For the estimation of (2) we used the nonlinear least squares procedure in the statistical software STATA. The damage abatement inputs in **X** can be expressed using different units, depending on the type of input. The use of dummy variables is the easiest alternative when quantitative data are not available. In the case of pesticides, researchers have employed either the rate of insecticide applied per hectare or the total amount of insecticide applied (Guan et al. 2005; Shankar and Thirtle 2005).

Endogeneity is often a problem in modeling yield and damage abatement, since the pressures that cause yield damage also lead farmers to decide to apply certain amounts of insecticides. Insecticide use is potentially a dependent variable, but is often specified as an independent variable in the regression model. If insecticide use is actually a choice variable, a regressor is correlated with unobserved variables relegated to the error term, which can bias the estimated regression coefficient. Although many input variables are choice variables, insecticide use is more likely to be endogenous because its use is a response to an observable pest or pathogen. However, the use of insecticides abates damage only if the appropriate doses are applied in a timely manner and in the required amounts. Poor farmers tend to apply insecticides sporadically or preventively as determined by cash constraints more than by pest attacks.

An instrumental variables estimation is recommended (Qaim and De Janvry 2005; Shankar and Thirtle 2005) if a Hausman test provides evidence of endogeneity. The Hausman test consists of estimating an insecticide use equation, adding the regression residuals to the production function as an additional regressor, and testing for the significance of the coefficient. If the estimated coefficient on the residuals is not statistically significant, the data provide no support for the hypothesis that insecticide use is endogenously determined. In that case, observed insecticide use in a single-equation estimate will provide better statistical results. In each crop model, we tested for endogeneity with a quadratic production function.

In our study, variables for household characteristics (age, gender, education, experience with the crop, training in the use of insecticides, and district and regional dummies) and production variables (use of other chemical and damage control inputs like biopesticides and fungicides) were used as regressors in the insecticide function. Although distance to markets and/or main roads could be important variables for vegetable crops, valid data were not available to test this hypothesis. Distance would be relevant only for garden egg and tomato production, as cabbage is almost entirely produced in urban and peri-urban areas, with easy access to both markets and roads.

We performed a Hausman test for endogeneity on the data. Failure to reject the hypothesis of exogeneity indicates the instrumental variables regression would not improve the estimation. To explore whether the severity of targeted constraints affects farmer demand for insecticides while controlling for other factors, we estimated a probit regression. This regression was estimated only for the cases of tomato and garden egg, since almost all cabbage producers make use of insecticides.

Stochastic Budget Analysis

Data

To develop partial budgets and simulate potential adoption scenarios for a set of GM crops in Ghana we use the data collected from conventional vegetable producers. GM vegetables have not yet been introduced in any African country. In fact, only a few GM vegetables have been introduced worldwide, although several are undergoing biosafety regulatory review.

In our survey, we elicited subjective yield distributions from growers in order to gauge which growers recognize the pest or disease and the perceived extent of yield losses on the farm. Photos were used to improve recognition of the pest or disease. The triangular distribution (minimum, maximum, mode) is the simplest distribution to elicit from farmers, approximates the normal distribution, and is especially useful in cases where no sample data are available (Hardaker et al. 2004).

Best-fit distributions were also used for variables that were easy to obtain from farmers: (1) output price, (2) insecticide cost, and (3) spraying cost. Triangular distributions, on the other hand, were used to model variables that measure (1) technology efficiency (trait expression), (2) the technology fee, (3) reduction rates in insecticide use, and (4) reduction rates in spraying cost. Explanations of the minimum, mode, and maximum values adopted for all these variables are found in Table 1. We chose these levels based on conversations with biophysical scientists.

The technology fee was expressed as a percentage increase in seed price. While all cabbage producers use formal seed, only some tomato producers do. There is no formal seed of garden egg, but for our purposes we assumed that the price of garden egg seed was equivalent to that of tomato seed. The technology fee is a sensitive issue because the price of GM seed will affect adoption. Other estimates in the literature on biotech crops have reflected the temporary monopoly conferred in this capital-intensive innovation through intellectual property instruments (Falck-Zepeda et al. 2000; Moschini and Lapan 1997). We speculate that the public sector would tend to charge lower technology fees than the private sector.

Table 1. Assumptions and distribution used in tomato, cabbage, and garden egg partial budget simulations

Partial Budget Components	Virus-Resistant Tomato	Bt Cabbage	Bt Garden Egg
Yield	The yield values were estimated: Best-fit distribution adjusted to minimum, mode, and maximum yield elicited from each farmer. Average of minimum, mode, and maximum values.		
Yield losses	Best-fit distribution based on values elicited from farmers.		
Technology efficiency	Triangular distribution (low = 60, mean = 80, and high = 100) based on literature (Traxler and Godoy-Avila 2004; Pray et al. 2002; Qaim and Zilberman 2003).		
Produce price	Best-fit distribution based on information collected from farmers.		
Seed cost	For the conventional seed scenario, we used the average cost across observations. For the GM scenario, we used an average cost of $55/hectare.	Average cost across observations.	For the conventional seed scenario, we used the average cost across observations. For the GM scenario, we used the average cost of the formal seed of tomato ($55/ha).
Technology fee	Triangular distribution of percentage over price of formal seed (low = 25%, mode = 50%, and high = 75%).	Assumed 50% increase over formal seed (low = 25%, mode = 50%, and high = 75%).	We assumed increase seed cost of 50% on average (using the same triangular distribution values as in tomato and cabbage).
Insecticide cost	Best-fit distribution based on information collected from farmers.		
Insecticide cost reduction	Triangular distribution (low = 0%, mode = 25%, and high = 35%). This value could be higher depending on the level of yield losses caused by other pests.		
Spraying cost	Best-fit distribution based on information collected from farmers.		
Spraying cost reduction	Triangular distribution (low = 0%, mode = 25%, and high = 35%). The reduction in labor is related to the reduction in total pesticide applied.		

Source: Author's results

Conceptual Framework

The comprehensive guide produced by CIMMYT (1988) was used as the basis for calculating partial budgets and simulating the profitability of traditional and GM seed. Expected total income, total costs, expected net income, and net return on investment were calculated per hectare. We used market prices to estimate the costs of seed, insecticide, and fertilizer. Average land rent prices were used to calculate the land cost. Water costs were estimated using information about time spent and/or costs incurred in carrying water from a river or main source to the plot. Labor costs were listed separately because of their magnitude and importance. Average wages paid to hired labor were used to estimate the total family labor costs. That assumption seems reasonable in the production areas studied, where labor markets are active and farmers produce the crops commercially. Male and female labor days were valued equally, as there was no evidence available to justify valuing them differently.

There are two salient, well-known disadvantages of the partial budget approach used to estimate the marginal economic returns from adopting a genetically engineered variety on farms. First, a budget for a single farm activity ignores other farm and nonfarm activities, treating prices as exogenous. That assumption is not tenable for semi-subsistence growers of food crops. Second, budget calculations do not take institutional constraints on farmer decision making into account. In this instance, the use of this approach is justifiable because (1) growers most likely to use improved varieties of vegetables are commercially oriented, although they may have nonfarm sources of income; and (2) variety change is likely to affect only the production of the target crop, unless there are substantial changes in the demand for labor for other farm or nonfarm activity.

We use survey data combined with data from published sources to predict the marginal returns to vegetable production, for insecticide users and non–insecticide users, in two scenarios: (1) the status quo, and (2) use of GM seed. The scenarios were simulated only for insecticide users in cabbage production because almost all growers use insecticide. For garden egg, we did not have a representative number of non–insecticide users and thus we include all growers in the simulation. Only those costs that vary with the introduction of the new technology are included in the partial budget simulation. A seed price difference is expected for GM seed, but the absolute value of this price difference varies widely according to the technology provider and its market power. Cost savings associated with the use of GM seed are represented by the reduction in insecticide applications and/or labor costs, if any.

Assumptions used in partial budget scenarios are summarized in Table 1. To account for the risk and uncertainty of agricultural production, some of the parameters were replaced by distributions. The distributions used in our study were based either on literature review (e.g., technology fee, abatement effect, insecticide and spraying costs reduction) or on the primary data collected from farmers (e.g., yield variability within and across farmers, yield loss due to constraint, price fluctuations, costs of seed, insecticide, and spraying).

We used @Risk software (an add-in to Excel) to estimate candidate distributions and select the ones that best fit the information collected in the survey. We selected distributions that best fit the triangular distributions elicited from farmers under three scenarios: (1) without the constraint, (2) with the constraint but without using insecticide, and (3) with the constraint and chemical control of the pest. In @Risk, we drew from the sample distributions of each yield parameter (minimum, maximum, mode) to generate yield variability both within and across observations.

Yield losses due to targeted constraints were derived from the elicited yields:

$$\mathrm{E}(\mathrm{Y}_{loss}) = \frac{\left[\mathrm{E}(\mathrm{Y}_{c=0}) - \mathrm{E}(\mathrm{Y}_{i,c=1})\right]}{\mathrm{E}(\mathrm{Y}_{c=0})}, \tag{4}$$

where $\mathrm{E}\left(\mathrm{Y}_{loss}\right)$ is the expected yield loss ratio, $\mathrm{E}\left(\mathrm{Y}_{c=0}\right)$ is the expected yield without the constraint, $\mathrm{E}\left(\mathrm{Y}_{c=1}\right)$ is the expected yield with the constraint, and *i* indicates use of insecticide (1 if farmers use insecticide or 0 otherwise). Based on expected yield losses, expected damage abatement with insecticide can also be estimated as

$$\mathrm{E}\left(\mathrm{Y}_{abat}\right) = 1 - \mathrm{E}\left(\mathrm{Y}_{loss}\right). \tag{5}$$

While actual damage and damage abatement are variables that are difficult to estimate, this represents a fair approximation of damage abatement. Yield losses reported by farmers tend to be upward biased because it is difficult for farmers to single out the effect of any individual pest. With respect to estimating abatement of yield losses, farmers often relate stronger pesticide effects with higher doses of pesticides.

3. RESULTS

Practices and Knowledge

Farmers in the study areas had some difficulties distinguishing among types of chemical inputs. Sampled farmers often classified foliar fertilizers, insecticides, and fungicides as pesticides. Foliar fertilizer was applied by one-quarter of the tomato growers and one-fifth of the garden egg growers surveyed. Less than 10% of cabbage growers used foliar fertilizer. Overall, 86% of vegetable growers surveyed used insecticides. In the Central Region, the rate of insecticide use was much lower than in the other regions (45% of tomato growers and 58% of garden egg growers). Slightly more than half the farmers surveyed used fungicides. Rates of application appeared to be higher in the Brong-Ahafo and Ashanti regions, relative to the Greater Accra, Central, and Volta regions. Use of organic practices was noted, but appears to be rare. Use of biopesticides is negligible except for cabbage, where the levels of pesticides applied overall were extremely high and some tolerance of other pesticides has been reported. Spraying of neem (*Azadirachta indica*) extracts is a biological alternative to chemical control. Neem is an African tree whose seeds and leaves can be used to produce a natural and effective insect repellent. However, few farmers relied solely on neem to control tomato pests. On the contrary, among the farmers interviewed, neem was used only in the Brong-Ahafo Region (about 5%) as a complement to chemical control by farmers who were already using high levels of pesticides.

A significant percentage of farmers in our survey reported that they had experienced more than one acute physical effect on their health after applying pesticides. The average number of different health effects per farmer, considering all crops, was 2.87. More than two-thirds (69%) had felt a burning sensation on the skin. Almost half stated that they had experienced headaches after applications (47%). More than one-third of farmers reported itchy or watery eyes (38.7%), coughing or breathing difficulties (35.4%), or dizziness (33.4). Sensations of coldness (23.8%) and nausea and vomiting (13.6%) were also cited. Only three respondents reported no effects at all. Some differences appear to be discernible by crop, which is probably related to the combinations and amounts of chemicals applied. In addition to these effects, farmers mentioned other symptoms, including back pain from the sprayer knapsack, stomach trouble and loss of appetite, weakness and joint pains, itching and skin rashes, and fainting. Twenty-eight percent of farmers stated that at least once, they had sought medical attention (conventional or traditional) or opted for self-medication depending on the severity of the symptoms.

The extent to which growers protect themselves from the hazards of chemical use is an indicator of their knowledge about chemicals (Table 2). While only 6% used empty containers for other uses, in the case of each of the target crops, about one-fifth transferred the pesticide to another container before application. More than two-thirds wore long sleeves, trousers, or overalls (68.25%), and nearly half wore boots (46.5%). One-quarter used gloves, while wearing goggles was rarer (11.8%). Few ate, drank, or smoked when applying chemicals. There were no meaningful differences in use of safety practices among crops.

Table 2. Farmer use of safety practices for chemical application, by target crop (%)

Practice	Tomato	Cabbage	Garden Egg	All Target Crops
Uses pesticide in other than original container	23.3	23.0	19.9	21.8
Uses empty pesticide containers for other uses	6.8	6.8	4.8	6.0
Covers nose and mouth	30.7	45.3	44.3	39.5
Uses gloves	18.9	33.3	26.8	25.3
Wears long sleeves, trousers, or overalls	65.6	65.3	72.0	68.2
Wears boots	34.4	58.1	51.4	46.5
Wears goggles	10.9	8.0	14.7	11.8
Eats while applying	5.5	9.5	4.2	5.8
Drinks while applying	3.9	10.7	8.4	7.2
Smokes while applying	2.3	4.0	3.5	3.2
Valid *n*'s	127–129	72–74	144–146	346–349

Source: Authors' results

Less than half the farmers surveyed had received training regarding the safe use of chemicals. Although more than half of the growers of each crop reported that they understood the symbols and instructions on the label, when enumerators provided an example for farmers to interpret, a far smaller percentage could correctly follow instructions. Only about half of farmers surveyed (56.3%) stated that they use recommended levels. Nearly a third stated that they use more than the recommended levels, with only 10.9% reporting that they use less.

According to Owusu-Ansah et al. (2001b), vegetable farmers in Ghana use a weekly calendar to spray the crop with "cocktails" of synthetic insecticides with active ingredients such as cyhalothrin, pirimiphos, and dimethoate. The insecticide most frequently applied by the farmers interviewed was cyhalothrin (40% of total). Cyhalothrin is a pyrethroid insecticide active against a wide range of foliar insects and mites at low concentrations (Obeng-Ofori and Ankrah 2002). Cyhalothrin can be found on the market in two formulations: Karate 2.5 EC (contains 25 grams of active ingredient per liter) and Karate 5 EC (contains 50 grams of active ingredient per liter). On vegetables such as cabbage, tomato, and garden egg, the current recommendation in Ghana is to apply a rate of 200 to 800 milliliters of insecticide per hectare. Weekly applications are recommended to combat DBM. These amounts add up to a total of 12 to 16 applications for a crop that lasts 90 to 100 days in the field. The pre-heading stage is the critical period of DBM attacks.

Approximately 90% of farmers applied doses above the recommended rates in single applications but considerably lower doses than recommended in terms of total amounts. On average, tomato farmers who used cyhalothrin applied approximately 2.4 liters of insecticide per hectare in total (equivalent to US$21). Similar volumes of cyhalothrin were applied by garden egg producers, who used around 2.9 liters per hectare of this insecticide, adding US$26. Cabbage producers applied by far the highest rates, on average 6.3 liters per hectare (equivalent to US$56). Nevertheless expenses on synthetic insecticides were relatively low when compared with total production costs, ranging from 2% in tomato and garden egg to 17% in cabbage production.

These data confirm that few tomato, cabbage, and garden egg growers were familiar with the appropriate use of pesticides. In general, pesticide applications tend to be higher on legumes, fruit, vegetables, coffee, and industrial crops than on other food or subsistence crops like root, tubers, and cereals (Gerken et al. 2001). Doses that are persistently higher than recommended can contribute to the development of the insect's resistance to insecticides, as appears to be the case with DBM.

Determinants of Insecticide Use

Descriptive statistics of the main explanatory variables used are presented by crop in Table 3. Table 4 shows the results of the probit regression on factors affecting the probability that growers use insecticides. Perceived yield losses due to TYLCV and SFB significantly increase the probability that farmers apply insecticides in production of tomato and garden egg. Human capital variables, including years in school, experience growing the crop, and training in the use of insecticide, positively affect the likelihood that farmers apply insecticides to tomato. In the insecticide use function for garden egg the only other significant variables are related to district fixed effects. This variable expresses, among other characteristics, district differences in distance to market, production practices, and relative economic or social importance of the crop within the district. Since most of the cabbage producers are insecticide users, no probit regression was estimated for insecticide application on cabbage.

Results from Hausman tests for endogeneity of insecticide use are presented in Table 5. Different specifications were tested including variables accounting for training in pesticide use or use of other types of pesticides, but the residual term remains statistically insignificant. Endogeneity of insecticide use was not severe enough to bias the estimation of the production function. Shankar and Thirtle (2005) report similar findings for pesticide use on cotton in South Africa, where cash-constrained farmers also apply suboptimal doses. Farmers prefer to use preventive control measures rather than curative applications on tomato and cabbage because they are more susceptible to pest attacks. Garden egg, because it is a native crop, has greater adaptability to local conditions including a number of pests in comparison with tomato, cabbage, and other introduced vegetables. In addition, farmers may set a higher economic threshold for this crop given that quality standards are low. In other words, the level of economic losses that triggers the decision to control pests is much higher in production of garden egg than in production of other vegetables that have higher quality standards, higher market prices, or higher production costs. Despite these differences among crops, in each crop the results of the Hausman test favor the hypothesis that insecticide use is exogenously determined. Thus, a variable recording observed use of insecticides was used as a regressor instead of the predicted values from the insecticide use function. Employing an F-test on the coefficients of zero-one variables for regions, we also failed to reject the null hypothesis that region has no effect on use (F value with 2 and 339 degrees of freedom = 0.71).

Table 3. Summary statistics of explanatory variables

Variable	Unit	Tomato		Cabbage		Garden Egg	
		Mean	SD	Mean	SD	Mean	SD
Age	years	40.9	10.8	38.5	10.3	38.1	10.1
Gender	dummy, female = 1	0.3	0.4	0.1	0.2	0.07	0.26
Education	years	8.4	4.1	8.8	4.2	8.8	4.3
Experience with crop	years	12.8	8.6	9.1	6.5	9.1	6.7
Credit	$	71.8	179.8	128.6	418.9	44.2	145.0
Training in pesticide use	dummy, yes = 1	0.3	0.5	0.5	0.5	0.4	0.5
Area with target crop	hectare (ha)	1.2	1.4	0.3	0.4	0.7	0.5
Total area	ha	2.4	2.3	0.6	0.5	2.8	6.7
Total income	$	2,299.4	2,203.4	5,795.7	7,339.0	2,255.8	2,353.5

Table 3. Continued

Variable	Unit	Tomato		Cabbage		Garden Egg	
		Mean	SD	Mean	SD	Mean	SD
Output price	$/kilogram	0.3	0.1	0.3	0.2	0.3	0.2
Labor cost	$/ha	464.4	400.7	960.3	663.0	641.1	578.4
Land cost	$/ha	53.1	47.5	43.7	40.0	42.0	19.2
Seed cost	$/ha	28.1	26.2	91.6	63.0	25.7	31.1
Fertilizer cost	$/ha	150.0	166.1	198.4	249.4	132.0	95.6
Insecticide cost	$/ha	19.2	21.2	201.9	254.2	30.3	27.6
Water cost	$/ha	11.8	36.3	52.4	180.6	10.2	45.0

Source: Authors' results

The estimated production functions, including the quadratic specification and the damage abatement specification, are presented in Table 6. Findings illustrate strong differences among vegetable crops. In tomato production, labor, fertilizer, and experience with the crop are main factors affecting productivity in both specifications. Seed and the interaction effect between labor and insecticide are the main determinants of cabbage production with the quadratic framework. Labor and insecticide use become significant in cabbage production using the damage abatement specification. Land use was not included in the cabbage production function because it was highly correlated with location variables. In the Greater Accra Region, cabbage producers use marginal lands in urban and peri-urban areas; they neither own the land nor pay a rent for it. In the Ashanti Region, variation in prices paid for land was not large.

Table 4. Probit results reporting marginal effects for insecticide use

	Tomato (n = 151)		Garden Egg (n = 156)	
Variable	Coef.	p-value	Coef.	p-value
Age (years)	-0.0019	0.31	0.0020	0.24
Education (years)	0.0091	0.06	-0.0075	0.16
Gender (female = 1)	-0.0536	0.22	0.0051	0.90
Crop experience (years)	0.0083	0.01	0.0025	0.44
Yield loss (%)	0.1251	0.06	0.1230	0.02
Farm gate price ($/kg)	-0.1690	0.26	-0.1408	0.13
Fungicide use ($/ha)	-0.0002	0.87	-0.0001	0.85
Fertilizer cost ($/ha)	0.0001	0.64	0.0001	0.69
Pesticide use training (dum)	0.0659	0.08	-0.0415	0.29
Credit ($/ha)	0.0003	0.17	0.0001	0.64
Pseudo R2		0.45		0.33
Log likelihood		-37.28		-35.22

Source: Authors' results
Note: Fixed effects of district and region were measured by the use of dummy variables that are not presented in this table.

Access to credit, seed, and fertilizer are significant factors affecting garden egg production using the quadratic specification. Land close to irrigation areas has a higher value and tends to be of better quality. Some garden egg production areas, like the Volta Region, have this advantage. The water variable was not significant for any of the production functions. This variable reflects greater access of the farmer to water but also higher labor costs involved in carrying the water from the source to the plot. Hence, the estimated relationship is negative across crops.

As expected, insecticide use is a significant factor in cabbage production. In tomato and garden egg production, insecticide use does not have a significant effect. In cabbage, although statistically significant, the value marginal product of insecticides (US$39.58) is above the average price of the most common wide-spectrum insecticide (US$9), meaning pesticide use is still below the economic optimum.

Table 5. Testing for endogeneity

	Tomato				Cabbage				Garden Egg			
	Quadratic		Hausman		Quadratic		Hausman		Quadratic		Hausman	
Variables	**Coef.**	***p*-value**	**Coef.**	***p*-value**	**Coef.**	***p*-value**	**Coef.**	***p*-value**	**Coef.**	***p*-value**	**Coef.**	***p*-value**
Constant	5,984	0.06	4,358	0.25	14,967	0.04	38,801	0.02	7,121	0.04	871	0.82
	3,189		3,752		6,976		15,785		3,410		3,778	
Credit	0.92	0.77	1.36	0.65	2.49	0.50	2.81	0.47	7.27	0.07	7.38	0.07
	3.09		2.98		3.70		3.82		4.00		4.04	
Experience	108.43	0.09	116.82	0.06	-235.85	0.34	-265.29	0.32	-53.61	0.54	-53.87	0.55
	63.43		61.86		243.93		263.81		86.19		88.79	
Insecticide	51.42	0.47	66.78	0.49	18.32	0.42	-30.18	0.42	-18.60	0.76	28.12	0.70
	70.39		95.80		22.40		37.47		61.32		73.60	
Insecticide sq.	0.18	0.82	0.21	0.78	0.00	0.96	0.01	0.60	0.11	0.85	0.14	0.82
	0.77		0.75		0.02		0.02		0.57		0.59	
Labor	11.25	0.01	10.15	0.01	2.33	0.44	-0.08	0.98	5.73	0.04	5.48	0.07
	3.98		3.91		2.96		3.52		2.82		3.02	
Labor sq.	-0.004	0.04	-0.004	0.06	0.000	0.88	0.000	0.25	-0.001	0.13	-0.001	0.17
	0.002		0.002		0.000		0.000		0.001		0.001	
Land	4.04	0.91	18.63	0.59	-182.53	0.43	-288.05	0.30	129.01	0.13	145.04	0.10
	35.74		34.74		230.93		272.40		85.34		86.62	
Land sq.	0.04	0.57	0.01	0.87	0.93	0.46	1.58	0.28	-0.70	0.35	-0.78	0.31
	0.07		0.07		1.24		1.44		0.75		0.76	
Seed	-147.78	0.03	-117.23	0.09	110.47	0.12	61.74	0.42	119.08	0.02	106.66	0.05
	68.89		67.50		70.86		76.53		49.86		53.36	
Seed sq.	1.16	0.03	0.96	0.07	-0.37	0.14	-0.20	0.46	-0.66	0.02	-0.59	0.05
	0.51		0.52		0.25		0.27		0.28		0.30	
Residual			-24.79	0.75			43.17	0.17			-64.31	0.27
			76.38				30.90				58.25	
Valid obs.		151		141		76		68		156		143
R-sq		0.30		0.32		0.52		0.55		0.39		0.41
Adj R-sq		0.22		0.23		0.43		0.44		0.33		0.34

Source: Authors' results; Note: Fixed effects of district and region were measured by the use of dummy variables that are not presented in this table.

Table 6. Estimated damage abatement functions

Yield	**Tomato**				**Cabbage**				**Garden Egg**			
	Quadratic		**Damage Framework**		**Quadratic**		**Damage Framework**		**Quadratic**		**Damage Framework**	
	Coef.	***p*-value**	**Coef.**	***p*-value**	**Coef.**	***p*-value**	**Coef.**	***p*-value**	**Coef.**	***p*-value**	**Coef.**	***p*-value**
Constant	4792.19	0.15	6,772.44	0.13	9,285.10	0.33	25572.69	0.12	-9,363.54	0.06	-14,302.40	0.09
<u>Location</u>												
District	-640.14	0.27	-896.57	0.19					779.60	0.03	1,455.27	0.02
Region	1365.93	0.27	1,771.18	0.24					961.56	0.07	1,618.19	0.06
<u>Household characteristics</u>												
Age	-23.19	0.68	-27.8	0.71	-126.81	0.43	23.44	0.94	-63.57	0.31	-139.54	0.17
Gender (fem = 1)	108.87	0.94	69.73	0.97	-95.38	0.99	-3748.52	0.75	518.42	0.75	11.64	1.00
Education	-141.63	0.33	-217.71	0.26	127.15	0.75	439.50	0.52	147.83	0.42	343.58	0.30
Crop exp.	184.65	0.01	229.23	0.04	52.39	0.84	-373.39	0.46	18.81	0.84	25.78	0.88
<u>Growth inputs</u>												
Credit									31.30	0.00	-15.15	0.41
Sq. credit									-0.03	0.01	0.00	0.89
Labor	7.91	0.05	11.00	0.04	-2.85	0.70	-69.68	0.02	4.93	0.10	6.50	0.19
Sq. labor	0.00	0.10	0.00	0.09	0.00	0.54	0.05	0.00	0.00	0.23	0.00	0.43
Land	-16.65	0.62	1.39	0.98					125.45	0.15	312.37	0.03
Sq. land	0.07	0.28	0.04	0.63					-0.68	0.38	-1.95	0.07
Seed	-110.14	0.12	-151.13	0.11	132.26	0.08	439.13	0.00	101.21	0.05	142.53	0.11
Sq. seed	0.83	0.12	1.15	0.10	-0.41	0.12	-1.37	0.01	-0.61	0.04	-0.89	0.08
Fertilizer	19.76	0.06	27.1	0.05	5.11	0.88	-45.02	0.41	45.73	0.03	63.04	0.09
Sq. fertilizer	-0.01	0.33	-0.01	0.25	-0.04	0.44	0.02	0.82	-0.09	0.07	-0.13	0.16
Water	-48.18	0.19	-74.55	0.13	-31.54	0.15	-43.42	0.27	-15.62	0.69	-27.15	0.71
Sq. water	0.14	0.45	0.26	0.35	0.02	0.30	0.03	0.44	0.04	0.71	0.08	0.69
Insecticide	34.27	0.61			8.35	0.75			2.11	0.97		
Sq. insecticide	0.28	0.71			-0.03	0.14			-0.10	0.87		
Interaction insecticide*labor					0.03	0.03						

Table 6. Continued

Yield	Tomato				Cabbage				Garden Egg			
	Quadratic		Damage Framework		Quadratic		Damage Framework		Quadratic		Damage Framework	
	Coef.	***p*-value**	**Coef.**	***p*-value**	**Coef.**	***p*-value**	**Coef.**	***p*-value**	**Coef.**	***p*-value**	**Coef.**	***p*-value**
<u>Damage abatement</u>												
μ			-0.37	0.480			0.88	0.04			0.06	0.89
σ_1 (insecticide)			0.06	0.264			0.02	0.00			0.0014	0.75
σ_2 (interaction labor/insecticide)							-0.00001	0.00				
σ_3 (credit)											0.06	0.39
R2		0.28	0.84		0.51		0.84		0.41		0.77	
Adjusted R2		0.18	0.79		0.38		0.79		0.31		0.74	
VMP Insecticide		11.70	24.57		7.56		39.58		-0.96		0.48	

Source: Authors' results
Note: Fixed effects of district and region were measured but are not presented in this table.

In the case of cabbage, the labor-insecticide interaction was also included in the abatement component of the production function. Cabbage production is relatively labor intensive given the short period of cultivation (90 days or less), the limited use of technological equipment and machinery, and the small size of plots (less than 0.3 hectare on average). Most of this labor is used for chemical applications. According to the Guan et al. (2005) classification, labor is significant both as a growth-enhancing input and as a facilitating input. Similarly, credit was included in the abatement function of garden egg as a control input. Often farmers ask for credit in order to buy the most expensive production inputs, namely pesticides.

It is possible to estimate the magnitude of the damage abatement and relate it to insecticide use. We call this value the estimated abatement effect. The estimated abatement gives us indirect information about the yield that could be attained if insect pests were not present. By comparison, the expected abatement effect of insecticide is calculated from the yield that producers (insecticide users and nonusers) expect to obtain in the presence and absence of the constraint. Expected abatement gives us information about the perception of the farmer concerning the effectiveness of insecticides in controlling the targeted constraint.

The Kolmogorov-Smirnov test[2] reveals that the distribution of expected abatement is significantly different than the estimated abatement for all the crops. The maximum differences between the cumulative distributions, *D*, are 0.63 for tomato, 0.61 for cabbage, and 0.52 for garden egg, with a corresponding *P* of 0.000. While in tomato and garden egg production, insecticides are not abating damage significantly, farmers' expectations about the insecticide control effect are lower than the estimated abatement effect. In cabbage production, on the other hand, insecticide use significantly abates damage (probably of insects or pests other than DBM), but farmers expect a still higher control effect leading most likely to future higher application doses. This will likely lead to a higher number of pesticide applications.

Partial Budgets

Tomato, cabbage, and garden egg production are profitable activities in spite of the numerous constraints farmers face along the production and marketing chain. Tomato and cabbage show the highest rates of return on investment. Differences across regions affect the profitability of the crop. Thus, tomato shows a higher rate of return in the Brong-Ahafo, Ashanti, and Volta regions (see Figure 1). Garden egg is very profitable in the Volta Region, while in the other study areas it is more of a subsistence crop that may be sold but does not receive special attention as a commercial crop. Cabbage is more profitable in the Greater Accra Region than in the Ashanti Region, mainly because of the extent of DBM damage in the Ashanti Region.

Results from the partial budget simulations are summarized in Table 7 by crop. In the case of tomato, results are also disaggregated according to whether the producer uses insecticides or not. Farmers who use insecticide report higher total incomes due to higher yields and lower expected crop losses. Yields included in the total incomes reported by farmers are those they harvested in the 2005 season, while expected yield losses are estimated from elicited, triangular distributions that represent a longer time period. Expected yield losses can be as high as 64% when farmers do not use insecticide. Insecticides reduce yield losses by as much as 42%. On average, insecticide users and non–insecticide users receive similar prices for their produce. The great variability of tomato prices during the year is incorporated into the distribution used in the simulation. Higher incomes due to GM seed adoption are expected with or without the use of insecticides.

---

[2] The Kolmogorov-Smirnov test has the advantage of making no assumption about the distribution of the data.

Table 7. Partial budget scenarios

Variable	**Tomato/TYLCV**				**Cabbage/DBM Insecticide Users (*n* = 71)**		**Garden Egg/SFB (*n* = 156)**	
	Insecticide Users (*n* = 122)		**Non–Insecticide Users (*n* = 29)**					
	Non GM	**GM**	**Non GM**	**GM**	**Non GM**	**GM**	**Non GM**	**GM**
Total income ($/ha)	**2,725.6**	**3,645.7**	**1,546.5**	**2,337.5**	**6,034.1**	**7,575.6**	**2,961.2**	**3,745.7**
- Yield (kg/ha)	10,122	13,539	5,848	8,839	21,570	27,081	10,466	13,239.2
min. (kg/ha)	7,069		4,371		17,348		8,148	
mode (kg/ha)	9,942		5,671		21,163		10,568	
max. (kg/ha)	13,356		7,502		26,202		12,682	
Yield loss (%)		0.42		0.64		0.32		0.33
Tech. efficiency (%)		0.80		0.80		0.80		0.80
- Price ($/kg)	0.27	0.27	0.26	0.26	0.28	0.28	0.28	0.28
Total costs ($/ha)	**787.8**	**826.0**	**800.3**	**862.3**	**2,075.3**	**2,033.2**	**985.5**	**1,021.5**
Costs that vary ($/ha)	**101.7**	**139.9**	**33.1**	**95.1**	**541.7**	**499.6**	**129.7**	**165.8**
- Seed cost ($/ha)	29.9	82.5	20.5	82.5	93.6	140.4	25.7	82.5
Technology fee (%)		0.50		0.50		0.50		0.50
- Insecticide cost ($/ha)	33.7	27.0	0.0	0.0	255.1	204.1	31.1	24.9
Insect. cost reduct. (%)		0.20		0.00		0.20		0.20
- Spraying cost ($/ha)	38.0	30.4	12.6	12.6	193.0	154.4	73.0	58.4
Spray. cost reduct. (%)		0.20		0.00		0.20		0.20
Income change ($/ha)		**920.1**		**791.0**		**1,541.5**		**784.50**
Costs change ($/ha)		**38.2**		**62.0**		**-42.15**		**36.02**
Marginal rate of return (RoR)		**23.07**		**11.76**		**35.73**		**20.78**
RoR	**2.46**	**3.41**	**0.93**	**1.71**	**1.91**	**2.73**	**2.00**	**2.67**
RoR change		**0.95**		**0.78**		**0.82**		**0.66**

Source: Author's results

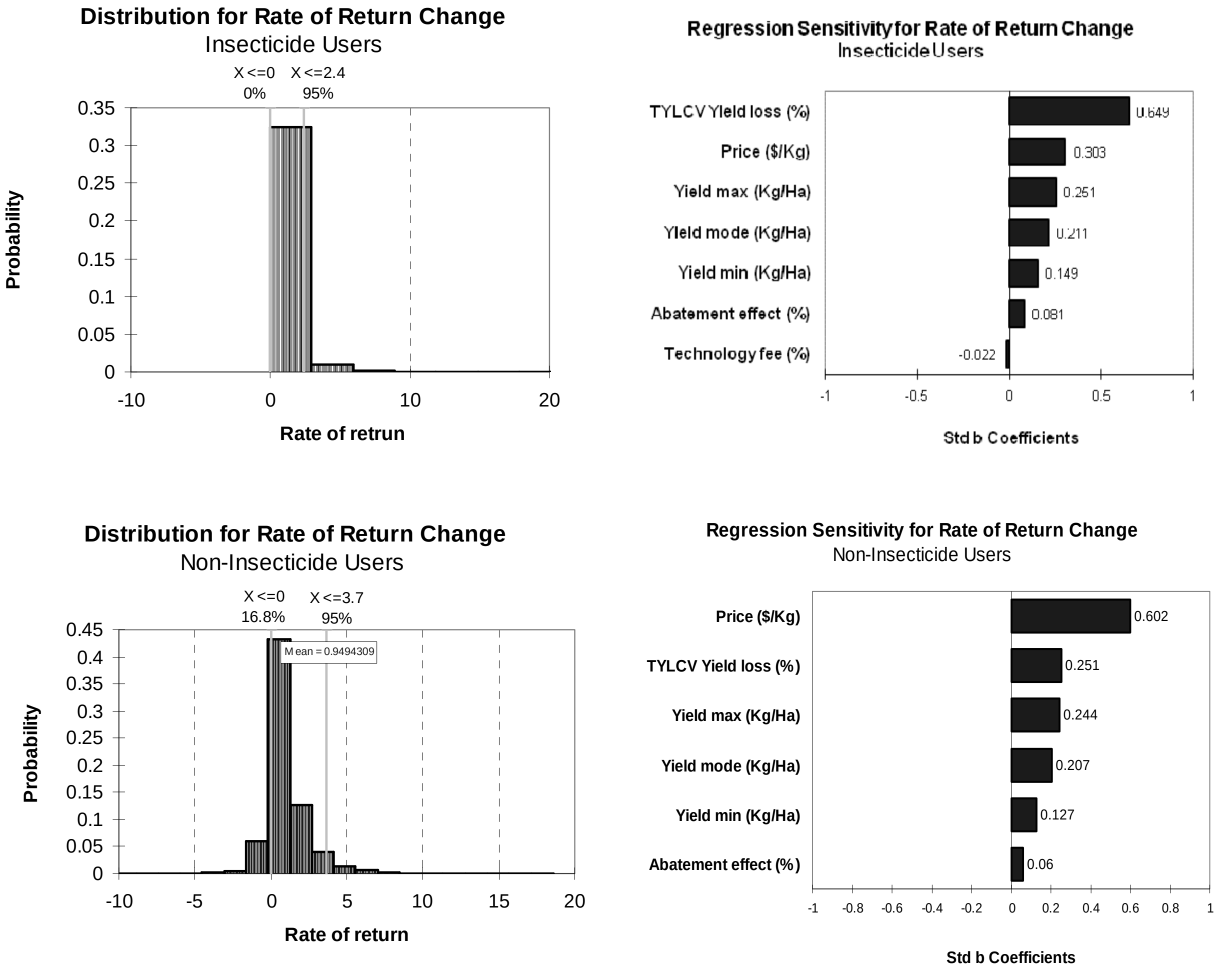
With respect to costs, total costs are greater for non–insecticide users than for farmers who make use of insecticide. Quite often, family labor is used to replace the use of an expensive input. Labor is by far the largest cost component in vegetable production in Ghana, but unless labor is hired, farmers do not regard it as a cost. As noted above, these budgets treat the value of family labor and hired labor equally. However, total costs that vary (seed, insecticide use, and costs of insecticide application) are lower when farmers do not use insecticide.

Given our assumptions regarding the effectiveness of GM seed in controlling TYLCV and the low costs involved, estimated marginal returns for virus-resistant tomato seed adoption are high. Adoption of virus-resistant tomato increases the profitability of the crop for both insecticide users and non–insecticide users. The technology fee associated with GM seed is the only factor that reduces the profitability of tomato production, and its effect is significant only for producers who are currently using insecticides. The risk that farmers face is another issue, however. The probability of a lower rate of return is 17% for farmers who do not apply insecticides to control white fly (vector of TYLCV). According to our simulations, there are almost no chances of lower profitability for farmers who are already using insecticides and have decided to adopt virus-resistant tomato seed (Figure 2). Regression-sensitivity analysis in @Risk demonstrates that expected yield loss, price, and the variability of yields account for most of the increment in rate of return to tomato production.

Results for cabbage are comparable to those of tomato producers. In cabbage, expected yield losses average 32% but vary greatly across producers. Higher total incomes with the use of Bt cabbage are due to the control of such losses. Total costs that vary are slightly lower for the GM scenario than with the use of conventional seed. Seed costs, insecticide costs, and spraying costs are higher than for the other vegetables and represent a relatively large percentage of the total costs. Given the large net income change and the small change in costs, marginal returns to the use of Bt seed are very high. The rate of return to cabbage production increases from 1.71 to 2.73, so that cabbage producers are much better off. However, the distribution of returns indicates that growers have an 11% probability of lower rates of return to cabbage production if they adopt Bt cabbage (Figure 3). The regression-sensitivity analysis shows that yield loss, price, insecticide costs, and variability of income account for most of the changes in rates of return.

The simulations for garden egg were conducted with the whole sample, including insecticide users and non–insecticide users. In this crop, insecticide applications are related more to regional differences and crop profitability. Relative proximity to markets or availability of water to grow the crop during the dry season probably leads to higher profits in garden egg. The variability of insecticide use among regions can be taken into account by adjusting the distribution that best fits the survey observations. Similar to cabbage and tomato, total income from garden egg is expected to be higher with GM seed adoption due to the abatement effect of the technology. Total costs that vary are significantly higher for the Bt scenario because seed price would increase dramatically with certified seed and a formal market channel for this crop. Currently, farmers recycle seed from previous cropping seasons or buy it from specialized farmers. The additional income generated by the use of GM seed is several times higher than the increase in additional costs. These results may justify the adoption of the technology, but there is still a 15% probability of earning less in garden egg production with Bt seed (Figure 4). The main factors determining a higher rate of return relative to the status quo are the extent of yield loss, product price, and yield variability. With respect to garden egg, the technology fee decreases the profitability of the GM seed but the effect is small.

Figure 2. Regression sensitivity and distribution of rate of return change for tomato



Source: Authors' results

Figure 3. Regression sensitivity and distribution of rate of return change for cabbage

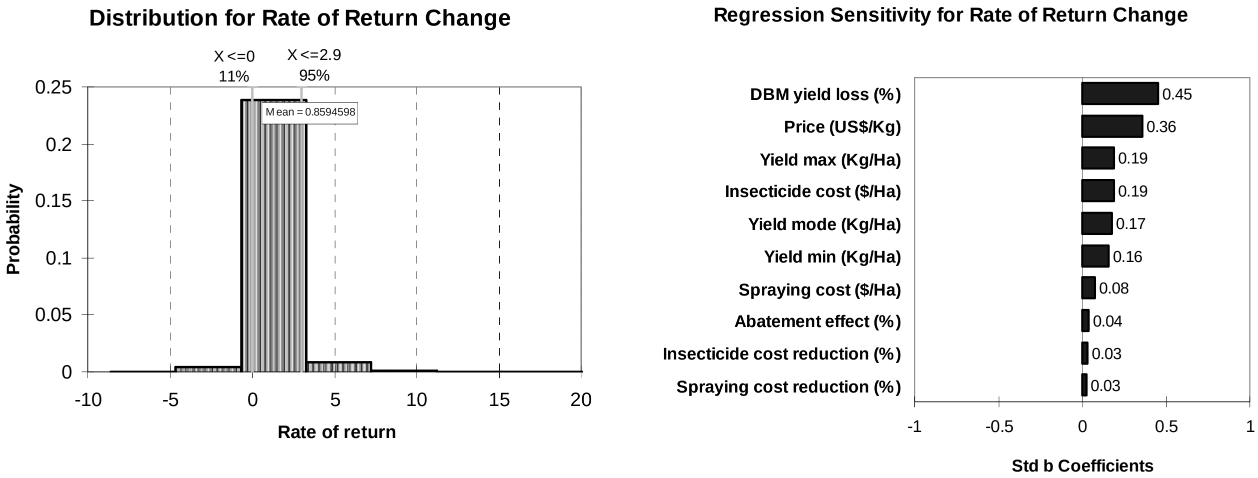
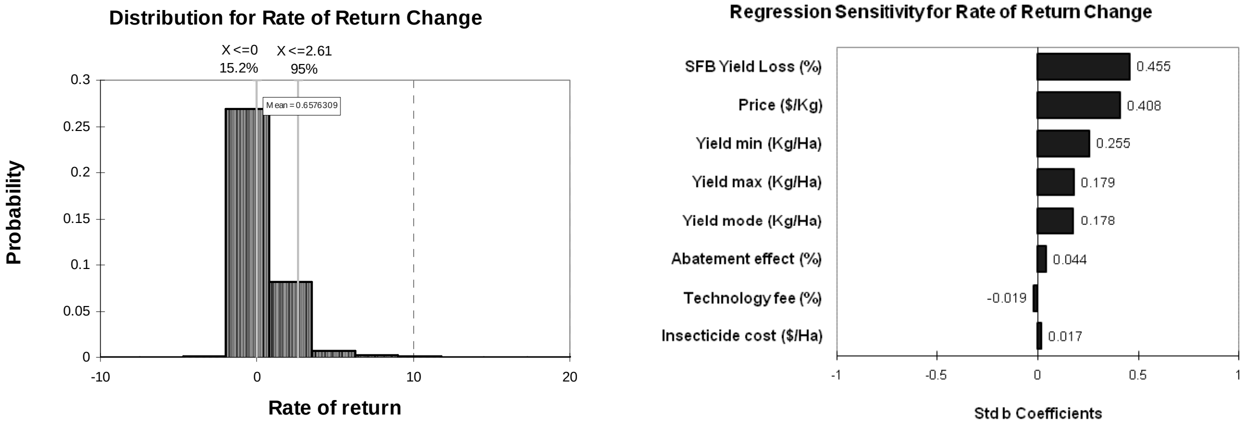


Figure 4. Regression sensitivity and distribution of rate of return change for garden egg



Source: Authors' results

4. CONCLUSION

In Ghana, the use of GM seed is expected to reduce the use of insecticides and labor in spraying to control biotic constraints such as DBM in cabbage, TYLCV in tomato, or SFB in garden egg. Ideally, GM seed could increase net returns to farmers by combating yield losses while reducing costs. In this study, we evaluate insecticide use in vegetable production in Ghana as an indicator of the potential adoption and impact of GM varieties. We use data collected through personal interviews with farmers selected in a random sample, stratified by production area. With econometric analysis, we explore the determinants of insecticide use and estimate damage abatement functions for each of the three vegetable crops. Applying a stochastic analysis in @Risk, we simulate the effect of GM technology adoption on profits and account for the risk and uncertainties of production by varying selected parameters.

To what extent are insecticides overused in vegetable production in Ghana? Our findings indicate that while farmers invest little in insecticides, inappropriate management of pesticides is cause for concern. Overall, insecticides seem to be underused in vegetable production in Ghana because of high costs. The econometric analysis shows that at the rates currently applied by farmers, insecticides significantly abate damage only in the case of cabbage. Thus, among the three crops examined, the prospect of reducing the costs of insecticide use through growing GM crops is only likely to affect adoption in cabbage. In addition, the introduction of GM seeds for all three crops studied may not necessarily reduce the total amounts of insecticide used. Most likely, farmers would continue to use wide-spectrum insecticides to control secondary pests.

Would GM vegetable seed adoption benefit farmers in Ghana? The simulations show that there are high probabilities of higher profits in all three crops if farmers decide to adopt GM seed, despite the technology fee. Variability in price and yield as well as expected yield losses are the factors that cause the largest changes in rates of return in our estimations. Despite the variability, these factors tend to increase the profitability of the crops. The technology fee is the only factor that decreases the profitability of the GM alternative, but that cost is offset by the expected abatement effect of the GM seed.

Any agricultural technology that reduces yield variability or yield losses from damage will contribute to long-term poverty reduction among vulnerable groups, other factors held constant. This *ex ante* study provides some idea of the scope of the potential impact among vegetable growers in Ghana. In addition to insect resistance, other attributes have been suggested to improve tomato, cabbage, and garden egg production in Ghana. Heat tolerance, easier transportability, and better postharvest quality are some attributes demanded in tomato and garden egg. Those attributes may be introduced via biotechnology or using conventional germ plasm selection and enhancement. In the long term, vegetable varieties that possess such attributes may represent an attractive economic alternative to farmers. The introduction of several traits tailored to meet the needs of farmers in Ghana is indeed possible with current biotechnology techniques. Moreover, garden egg, as a crop of African origin, shows a high level of diversity in Ghana. The development or introduction of a GM garden egg variety should be done in a way that local genetic diversity of the crop is not adversely affected.

REFERENCES

Al-Hassan, R., and X. Diao. 2007. Reducing regional disparities in growth and poverty reduction in Ghana: Policy options and public investment implications. In *Poverty reduction strategy in the new millennium: Emerging issues, experiences, and lessons,* edited by L. Zhang and S. Fan, 221–249. China Financial Economic Press (in both English and Chinese).

Babcock, B. A., E. Lichtenberg, and D. Zilberman. 1992. Impact of damage control and quality of output: Estimating pest control effectiveness. *American Journal of Agricultural Economics* 74 (1): 163–172.

Cabanilla, L. S., T. Abdoulaye, and J. H. Sanders. 2005. Economic cost of non-adoption of Bt-cotton in West Africa: With special reference to Mali. *International Journal of Biotechnology* 7 (1/2/3): 46–61.

Carrasco-Tauber, C., and L. J. Moffitt. 1992. Damage control econometrics: Functional specification and pesticide productivity. *American Journal of Agricultural Economics* 74 (1): 158–162.

CIMMYT (International Maize and Wheat Improvement Center). 1988. *From agronomic data to farmer recommendations: An economics training manual.* Completely rev. ed. Mexico City, Mexico: CIMMYT.

De Groote, H., B. Overholt, L. J. O. Ouma, and S. Mugo. 2003. Assessing the potential impact of Bt maize in Kenya using a GIS based model. Paper presented at the 25th International Conference of the International Association of Agricultural Economists, August 16–22, Durban, South Africa. Available from: http://www.syngentafoundation.com/projects_programs_insect_resistant_maize_reports.htm.

Edmeades, S., and M. Smale. 2006. A trait-based model of the potential demand for a genetically engineered food crop in a developing economy. *Agricultural Economics* 35 (3): 351–361.

Elbehri, A., and S. Macdonald. 2004. Estimating the impact of transgenic Bt cotton on West and Central Africa: A general equilibrium approach. *World Development* (Oxford) 32 (12): 2049–2064.

Falck-Zepeda, J., G. Traxler, and R. G. Nelson. 2000. Surplus distribution from the introduction of a biotechnology innovation. *American Journal of Agricultural Economics* 82: 360–369.

Gerken, A., J.-V. Suglo, and M. Braun. 2001. *Crop protection policy in Ghana.* Pokuase-Accra, Ghana: Integrated Crop Protection Project, PPRSD/GTZ.

Guan, Z., A. O. Lansink, A. Wossink, and R. Huirne. 2005. Damage control inputs: A comparison of conventional and organic farming systems. *European Review of Agricultural Economics* 32 (2): 167–189.

Hardaker, J. B., R. B. M. Huirne, J. R. Anderson, and G. Lien. 2004. *Coping with risk in agriculture.* Wallingford: CABI Publishing.

Hareau, G. G., B. F. Mills, and G. W. Norton. 2006. The potential benefits of herbicide-resistant transgenic rice in Uruguay: Lessons for small developing countries. *Food Policy* 31 (2): 162–179.

Huang, J., R. Hu, C. Fan, C. Pray, and S. Rozelle. 2002. Bt cotton benefits, costs, and impacts in China. *AgBioForum* 5 (4): 153–166.

Kolady, D. E., and W. Lesser. 2008a. Is genetically engineered technology a good alternative to pesticide use? The case of GE eggplant in India. *International Journal of Biotechnology:* 10 (2/3): 132–147.

———. 2008b. Can owners afford humanitarian donations in agbiotech? The case of genetically engineered eggplant in India. *Electronic Journal of Biotechnology* [online] 11 (2). Available from: http://www.ejbiotechnology.info/content/vol11/issue2/abstract/5/index.html#. ISSN: 0717-3458.

Krishna, V. V., and M. Qaim. 2007. Estimating the adoption of Bt eggplant in India: Who benefits from public-private partnership? *Food Policy* 32: 523–543.

Langyintuo, A. S., and J. Lowenberg-Deboer. 2006. Potential regional trade implications of adopting Bt cowpea in West and Central Africa. *AgBioForum* 9 (2): 111–120.

Lansink, A. O., and A. Carpentier. 2001. Damage control productivity: An input damage abatement approach. *Journal of Agricultural Economics* 52 (3): 11–22.

Lichtenberg, E., and D. Zilberman. 1986. The econometrics of damage control: Why specification matters. *American Journal of Agricultural Economics* 68 (2): 261–273.

Ministry of Food and Agriculture. 2002. *Food and agriculture sector development policy*. Accra: Government of Ghana.

Moschini, G., and H. Lapan. 1997. Intellectual property rights and the welfare effects of agricultural R&D. *American Journal of Agricultural Economics* 79 (4): 1229–1242.

Obeng-Ofori, D., and D. A. Ankrah. 2002. Effectiveness of aqueous neem extracts for the control of insect pest cabbage (*Brassica oleracea* var *capitata* L.) in the Accra plains of Ghana. *Agricultural and Food Sciences Journal of Ghana* 1 (July): 83–94.

Obeng-Ofori, D., E. O. Owousu, and E. T. Kaiwa. 2002. Variation in the level of carboxylesterase activity as an indicator of insecticide resistance in populations of the diamondback moth *Plutella xylostella* (L.) attacking cabbage in Ghana. *Journal of the Ghana Science Association* 4 (2): 52–62.

Owusu-Ansah, F., K. Afreh-Nuamah, D. Obeng-Ofori, and K. G. Ofosu-Budu. 2001a. Growth promoting properties and yield effects of aqueous neem seed extract, Biobit, and Karate on local garden eggs (*Solanum integrifolium* L.) in the field. *Journal of the Ghana Science Association* 3 (3): 136–144.

———. 2001b. Managing infestation levels of major insect pests of garden eggs (*Solanum integrifolium* L.) with aqueous neem seed extracts. *Journal of the Ghana Science Association* 3 (3): 70–84.

Pemsl, D., H. Waibel, and A. P. Gutierrez. 2005. Why do some Bt-cotton farmers in China continue to use high levels of pesticides? *International Journal of Agricultural Sustainability* 3 (1): 44–56.

Pemsl, D., H. Waibel, and J. Orphal. 2004. A methodology to assess the profitability of Bt-cotton: Case study results from the state of Karnataka, India. *Crop Protection* 23 (12): 1249–1257.

Pray, C., J. Huang, R. Hu, and S. Rozelle. 2002. Five years of Bt cotton in China—the benefits continue. *Plant Journal* 31 (4): 423–430.

Qaim, M., and A. de Janvry. 2005. Bt cotton and pesticide use in Argentina: Economic and environmental effects. *Environment and Development Economics* 10: 179–200.

Qaim, M., and I. Matuschke. 2005. Impacts of genetically modified crops in developing countries: A survey. *Quarterly Journal of International Agriculture* 44 (3): 207–227.

Qaim, M., and D. Zilberman. 2003. Yield effects of genetically modified crops in developing countries. *Science* 299: 900–902.

Shankar, B., and C. Thirtle. 2005. Pesticide productivity and transgenic cotton technology: The South African smallholder case. *Journal of Agricultural Economics* 56 (1): 97–116.

Smale, M., P. Zambrano, J. Falck-Zepeda, and G. Gruère. 2006. Parables: Applied economics literature about the impact of genetically engineered crop varieties in developing economies. EPTD Discussion Paper 158, International Food Policy Research Institute, Washington, D.C.

Traxler, G., and S. Godoy-Avila. 2004. Transgenic cotton in Mexico. *AgBioForum* 7 (1&2): 57–62.

Youdeowei, A. 2002. *Integrated pest management practices for the production of vegetables.* Integrated Pest Management Extension Guides, no. 4. Accra, Ghana: Ministry of Food and Agriculture Plant Protection and Regulatory Services Directorate with the German Development Cooperation (Deutsche Gesellschaft fur Technische Zusammenarbeit).

RECENT IFPRI DISCUSSION PAPERS

For earlier discussion papers, please go to www.ifpri.org/pubs/pubs.htm#dp.
All discussion papers can be downloaded free of charge.

784. *Agriculture for development in Ghana: New opportunities and challenges*. Clemens Breisinger, Xinshen Diao, James Thurlow, and Ramatu M. Al-Hassan, 2008.

783. *Understanding the investment and abandonment behavior of poor households: An empirical investigation*. Ruth Vargas Hill, 2008.

782. *Access to irrigation and the escape from poverty: Evidence from Northern Mali*. Andrew Dillon, 2008.

781. *Structural changes in the Philippine pig industry and their environmental implications*. Maria Angeles O. Catelo, Clare A. Narrod, and Marites M. Tiongco, 2008.

780. *Evaluating alternative policy responses to higher world food prices: The case of increasing rice prices in Madagascar*. David Coady, Paul Dorosh, and Bart Minten,, 2008.

779. *Contract farming of swine in Southeast Asia as a response to changing market demand for quality and safety in pork.* Marites Tiongco, Maria Angeles Catelo, and Ma. Lucila Lapar, 2008.

778. *On-site and off-site long-term economic impacts of soil fertility management practices: The case of maize-based cropping systems in Kenya.* Ephraim Nkonya, Patrick Gicheru, Johannes Woelcke, Barrack Okoba, Daniel Kilambya, and Louis N. Gachimbi, 2008

777. *Development under conditions of inequality and distrust: Social cohesion in Latin America*. Marco Ferroni, Mercedes Mateo, Mark Payne, 2008.

776. *Exploring strategic priorities for regional agricultural R&D investments in East and Central Africa.* Liangzhi You and Michael Johnson, 2008.

775. *Reforming the agricultural extension system in India: What Do We know about what works where and why?* Katharina Raabe, 2008.

774. *An experimental inquiry into the effect of yardstick competition on corruption*. Angelino Viceisza, 2008.

773. *Alianzas para la innovación agroalimentaria en Bolivia: Lecciones para la formulación de políticas.* Frank Hartwich, Luis Ampuero, Tito Arispe, Vicente EguezJaime Mendoza, y Nancy Alexaki, 2008.

772. *Tracing power and influence in networks: Net-Map as a tool for research and strategic network planning*. Eva Schiffer and Douglas Waale, 2008.

771. *Estimating household income to monitor and evaluate public investment programs in Sub-Saharan Africa.* Samuel Benin and Josee Randriamamonjy, 2008.

770. *Does Africa trade less than it should, and if so, why? The role of market access and domestic factors*. Antoine Bouet, Santosh Mishra, and Devesh Roy, 2008.

769. *Impacts of the Hutan Kamasyarakatan social forestry program in the Sumberjaya Watershed, West Lampung District of Sumatra, Indonesia.* John Pender, Suyanto, John Kerr, and Edward Kato, 2008.

768. *Finance and cluster-based industrial development in China*. Jianqing Ruan and Xiaobo Zhang, 2008.

767. *Introducing a genetically modified banana in Uganda: Social benefits, costs, and consumer perceptions*. José Falck-Zepeda, Enoch Kikulwe, and Justus Wesseler, 2008.

766. *Global macroeconomic developments and poverty*. Eugenio Diaz-Bonilla, 2008.

765. *Economic partnership agreements between the European union and African, Caribbean, and Pacific countries: What is at stake for Senegal.* Valdete Berisha-Krasniqi, Antoine Bouet and Simon Mevel, 2008.

764. M*arriage behavior response to prime-age adult mortality: Evidence from Malawi*. Mika Ueyama and Futoshi Yamauchi, 2008.

763. I*mpacts of inventory credit, input supply shops, and fertilizer microdosing in the drylands of Niger*. John Pender, Tahirou Abdoulaye, Jupiter Ndjeunga, Bruno Gerard, and Edward Kato, 2008.

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

www.ifpri.org

IFPRI HEADQUARTERS
2033 K Street, NW
Washington, DC 20006-1002 USA
Tel.: +1-202-862-5600
Fax: +1-202-467-4439
Email: ifpri@cgiar.org

IFPRI ADDIS ABABA
P. O. Box 5689
Addis Ababa, Ethiopia
Tel.: +251 11 6463215
Fax: +251 11 6462927
Email: ifpri-addisababa@cgiar.org

IFPRI NEW DELHI
CG Block, NASC Complex, PUSA
New Delhi 110-012 India
Tel.: 91 11 2584-6565
Fax: 91 11 2584-8008 / 2584-6572
Email: ifpri-newdelhi@cgiar.org