Insecticide Use on Vegetables in Ghana: Would GM Seed Benefit Farmers?

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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 (GM) 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-engineered varieties, estimate the potential impact of adoption on farm profits, and highlight economic differences among the three crops. Farmer's 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 the pests and diseases affect insecticide use. Stochastic budget analysis also indicates a higher rate of return to vegetable production with the use of resistant seeds relative to status quo, even considering the technology transfer fee for GM seeds. 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.

1. Introduction

Ghana's agriculture is characterized by low yields and productivity. Although a number of factors contribute to low agricultural productivity, constraints on technology availability and use are crucial. The estimated yield gap for most traditional staple crops in Ghana ranges from 200% to 300% (Al-Hassan and Diao 2006). Although estimates of the yield gap in vegetable crops are not available, it is not hard to speculate that these are at least as large in magnitude. Low crop yields are compounded in the long-run by production shocks caused by environmental stresses such as drought, pests and diseases. Vegetables are very susceptible to both biotic and abiotic constraints. Farmer responses to these constraints are proportionate to the problem.

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). Biotic constraints that cause significant economic damage in Ghana include yellow-leaf-curl-virus (TYLCV) in tomato, diamondback moth (DBM) in cabbage, and shoot and fruit borers (SFB) in garden egg (*Solanum aethiopicum*) (Youdeowei 2002). These three crops (tomato, cabbage, and garden egg) have distinctive economic characteristics.

Tomato is produced primarily by small-scale farmers who are distributed throughout the country and consumed nearly on a daily basis by Ghanaian households. A broad range of market participants is involved in trading tomato. The country is able to meet domestic demand only during the rainy season, importing tomato during the remainder of the year from Burkina Faso. In the dry seasons, the lack of irrigation facilities during the dry season, together with the higher incidence of TYLCV relative to the rainy seasons, drastically reduce 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 (Kyofa-Boahma, M.[6] personal communication).

Cabbage is a vegetable of growing 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 Diamond Back 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 regions on the country. A plant that is native to Ghana, garden egg is attacked by several local pests and diseases. The most significant biotic constraints for garden egg include the fruit and stem borers, which cause 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 UK 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 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 are valued by farmers and consumers, such

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as taste. Although no 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 melangina*. The Ghanaian government has placed priority on research to develop virus-resistant tomato (VR tomato). Some of the Bt genes have been shown to control damage from the DBM. Generally speaking, the Bt transformation is one of the most heavily researched genetic modification in crops.

This ex-ante analysis has two major purposes, addressed in two steps. First, we investigate 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. In the second step, we examine the potential impact of adopting GM vegetables on growers through a stochastic simulation of marginal profits. 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 was 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 2008; Kolady and Lesser 2007). 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 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 Eastern Africa (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 bananas 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 recognized 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 econometrics studies published on this topic (Qaim and Janvry 2005; Bhavani and Thirtle 2005; Huang et al. 2002), we consider the effects of insecticides on both yield and on 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. A damage abatement model provides the framework to model vegetable production and to determine the effect of insecticide use on yields and yield losses from pests and diseases. We then simulate the effect of GM technology adoption on farm profits, accounting for the risk and uncertainties of production by varying elected parameters in a stochastic analysis. In the simulation analysis, we also consult on 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.

Data

Farm level information on production practices and pest damage was 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); Volta Region (Keta and Kpandu). With the help of the Agricultural Extension officers in each district, specific town and 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, 151 on tomato production, 77 on cabbage production and 156 on garden egg production.

Questions addressed: 1) input use and output; 2) insecticide use, perceptions about insecticides, and insecticide management practices; and 3) general producer characteristics. Strictly speaking, we examine the use of insecticides in this study. Pesticides include not only to insecticides, but also fungicides and other inputs farmers use to control pests. Tomato growers in Ghana control the vector of the TCLV disease, the white fly (*Bemisia tabasi*), by applying insecticide.

Modeling production and pesticide use

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). Recent, researchers have applied the framework to measure the impact of growing Bt cotton (Bhavani and Thirtle 2005; Huang et al. 2002; Qaim and Janvry 2005).

This framework considers that agricultural inputs such as pesticides have both a direct effect on yield and an effect through abating damage. 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 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 :

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

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) then 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. This function also has important limitations, among them: 1) the inputs are not necessarily use in a proportional way as the Cobb-Douglas implies; and 2) Cobb-Douglas leads to exclusion zero input observations because their logarithm is not defined. Quadratic specifications have been used to overcome these limitations (Oude Lansink and Carpentier 2001; Qaim and de Janvry 2005). In the literature, the exponential or logistic distribution have 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** is 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.

The estimation of (2) requires the use of non-linear least squares (NLSQ). 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 is not available. In the case of pesticides, researchers have employed either the rate of pesticide applied per hectare or the total amount of pesticide applied have been employed (Bhavani and Thirtle 2005; Guan et al. 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 pesticides. Pesticide use is potentially a dependent variable, but is specified as an independent variable in the regression model. If pesticide use is a choice variable, a regressor is correlated with un-observables relegated to the error term, which generates bias in the regression coefficient. Although many input variables are choice variables, pesticide use is the most likely to be endogenous because the use of abatement inputs is a response to an observable pest or pathogen. If a Hausman test provides evidence of endogeneity, an instrumental variables (IV) estimation is recommended (Bhavani and Thirtle 2005; Qaim and Janvry 2005). The Hausman test consists of estimating a pesticide use equation, adding the regression residuals to the production function as an additional regressor, and testing for the significance of the coefficient. The specification of the production equation for Hausman test:

$$Y = F\left(\mathbf{Z}\right) * \left(\left[1 + \exp\left(\mu - \sigma \mathbf{X}^{pred}\right)\right]^{-1}\right) \tag{4}$$

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, the use of observed insecticide use in a single-equation estimate will provide better statistical results.

In our study, variables for household characteristics (age, gender, education, and experience with the crop, training in the use of insecticides, district and regional dummies) and production variables (use of other chemical and damage control inputs like bio-pesticides and fungicides) were used as regressors in the insecticide function. We use the standard Cobb-Douglas production function to test for endogeneity in each crop model (tomato, garden egg, cabbage). We also estimated a model that pools the three crops.

The Hausman test led to failure to rejection the hypothesis of exogeneity of insecticide use in this empirical context, so that no instrumental regression for insecticide use was needed. 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

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 to investment were calculated per hectare. We used market prices to estimate the costs of seed, insecticides and fertilizers. Average land rent prices were used to calculate land cost. Water costs were estimated using information about time and/or costs incurred in carrying the water from the 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. This 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. There was no evidence available to justify valuing them differently.

There are two salient, well-known disadvantages of using partial budgets to estimate marginal economic returns. First, a budget for one activity on a representative farm clearly ignores other farm and non-farm activities. Prices are treated as exogenously determined by market supply and demand. These assumptions are not valid for semi-subsistence growers of food crops because there are significant interrelations among resources allocated to various production activities. Furthermore, semi-substance farms have a dual role as consumers and producers of outputs from their activities.

In this instance, the use of partial budgets is justifiable because 1) growers who are most likely to improved varieties of vegetables are commercially-oriented producers, although they may have non-farm sources of income; 2) variety change is likely to affect only the production of the target crop, unless there are substantial changes in the demand for labor that competes with another farm or non-farm activity.

We use survey data combined with data from published sources to predict the marginal returns to vegetable production, for insecticide 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 included 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 use 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. In order 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).

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 farm. Photos were used to improve recognition of the pest or disease. The triangular distribution (minimum, maximum, mode) is the simplest distributions to elicit from farmers, approximates the normal distribution, and is especially useful in cases where no sample data are available (Hardaker et al. 1997).

We used @Risk software (an add-in to excel) to estimate candidate distributions and select the one that best fit the information collected in the survey. We selected distributions that best fit the triangular distributions elicited from farmers under 3 scenarios: 1) without the constraint, 2) with the constraint but without using insecticides, and 3) with the constraint and chemical control of the pest. In @Risk, we drew from the sample distributions of the 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:

$$\mathrm{E}(\mathrm{Y}_{loss}) = \frac{\left[\mathrm{E}(\mathrm{Y}_{c=0}) - \mathrm{E}(\mathrm{Y}_{i,c=1})\right]}{\mathrm{E}(\mathrm{Y}_{c=0})} \tag{5}$$

$\mathrm{E}\left(\mathrm{Y}_{loss}\right)$ 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:

$$\mathrm{E}\left(\mathrm{Y}_{abat}\right) = 1 - \mathrm{E}\left(\mathrm{Y}_{loss}\right) \tag{6}$$

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

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 3) reduction rates in spraying costs. Explanation on minimum, mode, and maximum values adopted for all these variables are reported 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 were these were equivalent to tomato costs. The technology fee is a sensitive issue as the prices of GM seed will affect adoption. Other estimates in the literature about 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 probably tend to charge lower technology fees than the private sector.

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 is applied by one quarter of the tomato growers and one fifth of the garden egg growers surveyed. Less than 10 percent of cabbage growers use foliar fertilizer. Overall, 86 percent of vegetable growers surveyed use insecticides. In the Central Region, the use rate of insecticide is much lower than in the other regions (45% of tomato growers and 58% of garden egg growers). Slightly more than half the farmers surveyed use fungicides. Rates of application appear 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 bio-pesticides is negligible except for cabbage, where the levels of pesticides applied overall are 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 rely solely on neem to control tomato pests. On the contrary, among the farmers interviewed, neem is used only in the Brong-Ahafo Region (about 5 %) as a complement to chemical control by farmers who are already using high levels of pesticides.

A significant percent 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. Over 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%), nausea and vomiting (13.6%) were also cited. Only 3 respondents reported no effects at all. Some differences appear to be discernible by crop, which is probably related to the combinations and levels 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. While only 6 percent use 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 wear long sleeves, trousers or overalls (68.25%), and nearly half wear boots (46.5%). One-quarter use gloves, while wearing goggles is rarer (11.8%). Few eat, drink or smoke when applying chemicals. There are no meaningful differences in use of safety practices among target crops.

Less than half the farmers surveyed had received any training regarding the safe use of chemicals. Although over 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%) state that they use recommended levels. Nearly a third state that they use more than the recommended levels, with only 10.9% reporting that they use less.

Vegetable farmers use a weekly calendar to spray the crop with ‘cocktails’ of synthetic insecticides, such as, Karate, Actellic and Dimethoate (Owusu-Ansah et al. 2001b). The insecticide most frequently used by the farmers interviewed was Karate (40% of total). Karate is a pyrethroid insecticide active against a wide range of foliar insects and mites at low concentrations (Obeng-Ofori and Ankrah 2002). Karate can be found on the market under 2 formulations: Karate 2.5 EC (contains 25 g of active ingredient / 1L of Karate) and Karate 5 EC (contains 50 g of active ingredient / 1L of Karate). On vegetables such as cabbage, tomato and garden egg, the current recommendation in Ghana is to apply Karate 2.5 EC at the rate of 200 – 800 ml / ha. Weekly applications are recommended to combat DBM. These amounts add to a total of 12 to 16 for a crop that last 90 to 100 days in the field. The pre-heading stage is the critical period of DBM attacks.

Approximately 90% of farmers apply dosages of Karate above the recommended rates in single applications but considerably lower doses that recommended in the aggregate level. On average, tomato farmers who use Karate apply approximately 2.4 L /ha of Karate equivalent to US$ 21 in total. Similar volumes of Karate are applied by garden egg producers, who use around 2.9 L / ha of this insecticide, adding a total of US$ 26. Cabbage producers apply by far the highest volumes of Karate / ha, on average 6.3 L /ha totaling US$ 56. Expenses on synthetic pesticides are relatively low, varying from 2% of total production costs in tomato and garden egg to 17% in cabbage production.

These data confirm that few tomato, cabbage, and garden egg growers are familiar with the appropriate use of pesticides. In general, pesticide applications tend to be higher on legumes, fruit, vegetables, coffee and industrial crops than in 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 main explanatory variables used are presented by crop in Table 2. Table 3 shows the results of the probit regression on factors affecting the probability that growers use insecticides. Perceived yield losses due to the TLYV 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 the 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 4. 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 to 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 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 support 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.

Two additional diagnostic tests were performed before estimating the damage abatement functions. The chi-squared statistic for the Chow test indicates that separate regression models for each crop perform better than a pooled model for all three vegetables. 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).

The estimated production functions, including the quadratic specification and the damage abatement specification, are presented in Table 5. Findings illustrate strong differences among vegetables 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 wad 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 do not own the land neither pay a rent for them. In the Ashanti region, there was not a large variation in prices paid for land.

Access to credit, seed and fertilizer are significant factors affecting garden egg production using in quadratic specification. Land close to irrigation areas has a higher value and tend 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 function. 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.

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 limit use of technological equipment and machinery, and the small size of plots (less than 0.3 Ha 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 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 non-users) 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[7] reveals that the distribution of expected abatement is significantly different than the estimated abatement for all the crops. The maximum difference between the cumulative distributions, *D*, is: 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 significantly abating damage, farmers' expectations on insecticide control effect are lower than the estimated abatement effect. In cabbage production, on the other hand, insecticides are significantly abating damage (probably of other insect pest different from DBM) but farmers expect still higher control effect leading most likely to future higher application doses.

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 rate of returns to investments. Differences across regions affect the profitability of the crop. Thus, tomato shows a higher rate of return in Brong-Ahafo, Ashanti and Volta Regions. Garden egg is very profitable in 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 Greater Accra region than in the Ashanti region, mainly because of the extent of DBM damage in the Ashanti region.

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[7] The KS-test has the advantage of making no assumption about the distribution of the data.

Results from the partial budget simulations are summarized in Table 6 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 lower yields and higher expected crop losses. Yields included in the total incomes reported by farmers are those they harvested in 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 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.

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 VR tomato seed adoption are high. Adoption of VR tomato increases the profitability of the crop for both insecticide 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 VR 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 these 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 the 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 and non-insecticide users. In this crop, insecticide applications are related more with 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 campaigns or buy it from specialized farmers. The additional income generated by the use of GM seeds 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.

4. Conclusion

In Ghana, the use of GM seed is expected to reduce the use insecticides and labor in spraying to control biotic constraints such as DBM in cabbage, TYLCV in tomato, or fruit and stem borer 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 function 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 due to high costs. The econometric analysis shows that 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 costs of insecticide use through growing GM crops is only likely to affect adoption in cabbage. In addition, the introduction of GM seeds for these crops 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 seeds, despite the technology fee. Variability in price and yield, as well as expected yield losses are the factors that cause the largest changes in rate of returns 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 this 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 post-harvest quality are some attributes demanded in tomato and garden egg. These attributes may be introduced via biotechnology or using conventional selection and enhancement of germplasm. In the long term, vegetable varieties that possess these attributes may represent 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.

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Table 1. Assumptions and distribution used in tomato partial budget simulations

Partial Budget components	**VR Tomato**	**Bt-Cabbage**	**Bt-Garden Egg**
Yield	The yield values were estimated: 1) Best fit distribution adjusted to minimum, mode and maximum yield elicited from each farmer. 2) Average of maximum, mode and minimum values.		
Yield losses	Best fit distribution based 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 costs	For the conventional seed scenario, we use the average costs across observations. For the GM scenario we took an average costs of \$55/Ha	Average costs across observations.	For the conventional seed scenario, we use the average costs across observations. For the GM scenario we used the average costs of the formal seed of tomato (\$55).
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 assume increase seed costs of 50% on average (using the same triangular distribution values as in tomato and cabbage).
Insecticide costs	Best fit distribution based on information collected from farmers		
Insecticide costs 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.		

Table 2. Summary statistics of explanatory variables

Variable	Units	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	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
Yield	kg/Ha	8,807.2	6,997.7	18,670.9	15,802.3	9,998.3	8,126.1
Output price	$/Kg	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

Table 3. Probit Results reporting marginal effects for insecticide use

	Tomato (N=151)			**Garden Egg** (N= 156)		
Variable	**Coef.**	**z**		**Coef.**	**z**	
Age (years)	-0.002	0.00		0.002	1.17	
Education (years)	-0.054	0.05	*	0.005	0.13	
Gender (female =1)	0.009	0.01		-0.008	-1.41	
Crop experience (years)	0.008	0.00	***	0.002	0.77	
Yield Loss (%)	0.125	0.08	*	0.123	2.44	**
Farm Gate Price ($/Kg)	-0.169	0.16		-0.141	-1.50	
Fungicide use ($/Ha)	0.000	0.00		0.000	-0.20	
Fertilizer cost ($/ha)	0.000	0.00		0.000	0.40	
Pesticide use training (dum)	0.066	0.04	*	-0.042	-1.05	
Credit ($/Ha)	0.000	0.00		0.000	0.47	
Pseudo R2		0.45			0.33	
Log likelihood		-37.28			-35.22	

* Fixed effects of district and region were measured by the use of dummy variables which are not presented in this table.

Note: *denotes significances at the 10% level, ** at the 5% level, and *** at the 1% level

Table 4. Testing for endogeneity

Variables	TOMATO				CABBAGE				GARDEN EGG				ALL SAMPLE			
	Cobb-Douglas		Hausman		Cobb-Douglas		Hausman		Cobb-Douglas		Hausman		Cobb-Douglas		Hausman	
	Coef.	**t**	**Coef.**	**t**	**Coef.**	**t**	**Coef.**	**t**	**Coef.**	**t**	**Coef.**	**t**	**Coef.**	**t**	**Coef.**	**t**
Constant	6.83	7.81***	7.05	7.61***	4.64	2.32**	3.97	1.82*	6.57	8.74***	4.67	2.34**	5.91	9.04***	6.13	7.65***
	(0.88)		*(0.93)*		*(2.00)*		*(2.19)*		*(0.75)*		*(2.00)*		*(0.65)*		*(0.80)*	
Age	-0.15	-2.03**	-0.18	-2.14**	-0.05	-0.17	0.02	0.07	0.07	1.25	0.11	1.60	-0.01	-1.16	0.00	-0.69
	(0.07)		*(0.08)*		*(0.27)*		*(0.28)*		*(0.06)*		*(0.07)*		*(0.01)*		*(0.01)*	
Education	-0.03	-0.30	-0.07	-0.64	0.34	1.36	0.36	1.41	0.17	1.89*	0.22	2.15**	0.02	1.52	0.02	1.60
	(0.09)		*(0.11)*		*(0.25)*		*(0.25)*		*(0.09)*		*(0.10)*		*(0.01)*		*(0.01)*	
Gender	-0.22	-1.25	-0.12	-0.54	0.67	0.98	1.02	1.23	0.03	0.20	0.10	0.60	-0.03	-0.23	0.08	0.40
	(0.18)		*(0.22)*		*(0.69)*		*(0.83)*		*(0.15)*		*(0.16)*		*(0.14)*		*(0.20)*	
Crop experience	0.11	0.99	0.06	0.52	0.13	0.53	0.10	0.40	-0.06	-0.70	-0.05	-0.62	0.01	1.45	0.01	0.52
	(0.11)		*(0.12)*		*(0.24)*		*(0.25)*		*(0.08)*		*(0.08)*		*(0.01)*		*(0.01)*	
Insecticide	0.08	1.25	0.36	0.93	0.34	2.85***	0.61	1.60	0.07	1.41	0.42	1.23	0.16	3.72***	0.53	1.08
	(0.06)		*(0.39)*		*(0.12)*		*(0.38)*		*(0.05)*		*(0.34)*		*(0.04)*		*(0.49)*	
Labor	0.41	4.08***	0.34	2.48***	0.14	0.61	-0.04	-0.12	0.19	2.12**	0.25	2.33**	0.29	4.09***	0.23	2.12**
	(0.10)		*(0.14)*		*(0.23)*		*(0.34)*		*(0.09)*		*(0.11)*		*(0.07)*		*(0.11)*	
Land	0.10	0.54	0.09	0.50	0.08	0.15	0.29	0.49	0.19	2.11**	0.21	2.26**	0.13	1.34	0.18	1.54
	(0.19)		*(0.19)*		*(0.51)*		*(0.58)*		*(0.09)*		*(0.09)*		*(0.10)*		*(0.12)*	
Seed	0.01	0.05	0.00	0.03	0.31	1.20	0.35	1.34	0.10	1.44	0.10	1.51	0.08	1.20	0.09	1.25
	(0.11)		*(0.11)*		*0.26*		*(0.26)*		*(0.07)*		*(0.07)*		*(0.07)*		*(0.07)*	
Residual			-0.28	-0.73			-0.31	-0.76			-0.36	-1.02			-0.38	-0.77
			(0.39)				*(0.41)*				*(0.35)*				*(0.49)*	
No. of obs		151		151		76		76		156		156		360		360
R-sq		0.36		0.36		0.26		0.27		0.53		0.53		0.35		0.35
Adj R-sq		0.30		0.30		0.15		0.14		0.48		0.48		0.32		0.32

* Fixed effects of district and region were measured by the use of dummy variables which are not presented in this table.

Note: *denotes significances at the 10% level, ** at the 5% level, and *** at the 1% level

Table 5. Estimated damage abatement functions

	Tomato				Cabbage				Garden Egg			
	Quadratic		Damage Framework		Quadratic		Damage Framework		Quadratic		Damage Framework	
	Coef.	**t**	**Coef.**	**t**	**Coef.**	**t**	**Coef.**	**t**			**Coef.**	**T**
Constant	4792.19	1.44	6,772.44	1.53	9,285.10	0.98	25572.69	1.60	-9,363.54	-1.92 *	-14,302.40	-1.73 *
Household characteristics												
Age	-23.19	-0.41	-27.8	-0.38	-126.81	-0.79	23.44	0.07	-63.57	-1.02	-139.54	-1.38
Gender (fem =1)	108.87	0.08	69.73	0.04	-95.38	-0.02	-3748.52	-0.32	518.42	0.32	11.64	0
Education	-141.63	-0.97	-217.71	-1.14	127.15	0.32	439.50	0.64	147.83	0.80	343.58	1.04
Crop exp.	184.65	2.52 **	229.23	2.1**	52.39	0.21	-373.39	-0.74	18.81	0.20	25.78	0.16
Growth Inputs												
Credit									31.30	3.00 ***	-15.15	-0.83
Sq. Credit									-0.03	-2.52 ***	0.00	0.13
Labor	7.91	1.96 **	11	2.12**	-2.85	-0.39	-69.68	-2.50 **	4.93	1.68 *	6.50	1.31
Sq. Labor	0.00	-1.65 *	0	-1.72**	0.00	0.61	0.05	3.09 ***	0.00	-1.21	0.00	-0.79
Land	-16.65	-0.49	1.39	0.03*					125.45	1.45	312.37	2.2 **
Sq. Land	0.07	1.08	0.04	0.48					-0.68	-0.89	-1.95	-1.81 *
Seed	-110.14	-1.56	-151.13	-1.6	132.26	1.77 **	439.13	3.16 ***	101.21	1.95 **	142.53	1.63 *
Sq. Seed	0.83	1.57	1.15	1.65*	-0.41	-1.59	-1.37	-2.95 ***	-0.61	-2.10 *	-0.89	-1.76 *
Fertilizer	19.76	1.90 *	27.1	1.97**	5.11	0.15	-45.02	-0.83	45.73	2.26 **	63.04	1.69 *
Sq. Fertilizer	-0.01	-0.98	-0.01	-1.17	-0.04	-0.79	0.02	0.23	-0.09	-1.86 *	-0.13	-1.42
Water	-48.18	-1.31	-74.55	-1.53	-31.54	-1.45	-43.42	-1.11	-15.62	-0.40	-27.15	-0.38
Sq. Water	0.14	0.76	0.26	0.93	0.02	1.05	0.03	0.77	0.04	0.38	0.08	0.4
Insecticide	34.27	0.51			8.35	0.33			2.11	0.03		
Sq. Insecticide	0.28	0.37			-0.03	-1.49			-0.10	-0.16		
Interaction Insect * Labor					0.03	2.31 *						
Damage Abatement												
μ			-0.37	-0.71			0.88	2.16 **			0.06	0.14
σ_1 (Insecticides)			0.06	1.12			0.02	4.79 ***			0.0014	0.31
σ_2 (Interac Labor/Insect.)							-0.00001	-4.46 ***				
σ_3 (Credit)											0.06	0.86
R2		0.28	0.84		0.51		0.81		0.41		0.77	
Adjusted R2		0.18	0.79		0.38		0.76		0.31		0.74	
VMP Insecticide					7.56		39.58					

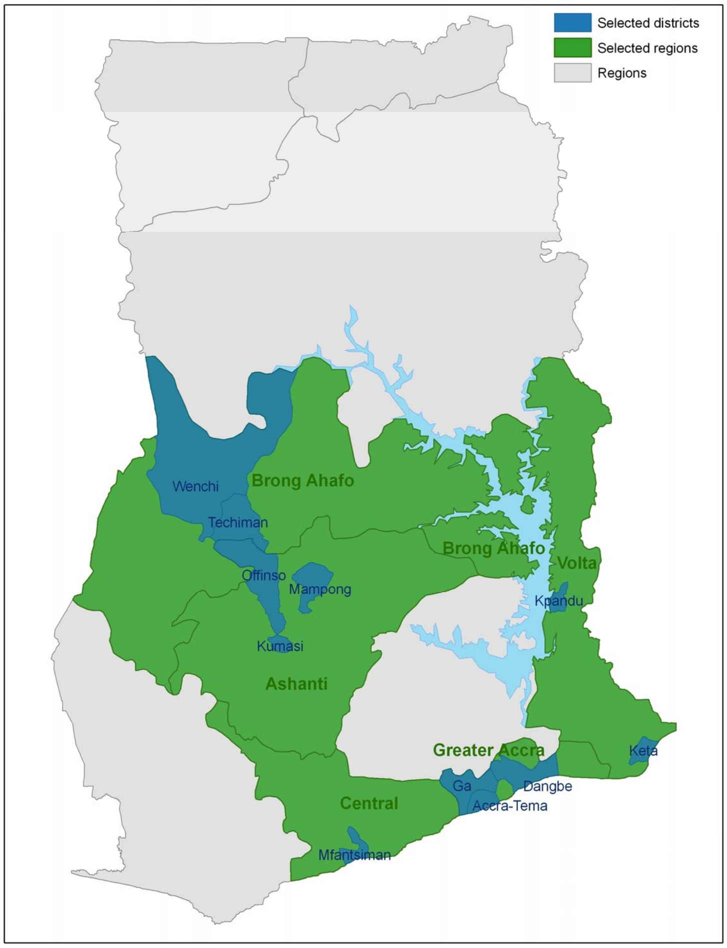
* Fixed effects of district and region were measured but are not presented in this table.

Note: *denotes significances at the 10% level, ** at the 5% level, and *** at the 1% level

Table 6. 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 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**

Figure 1. Study sites in Ghana



Map: M. Benza (IFPRI)

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

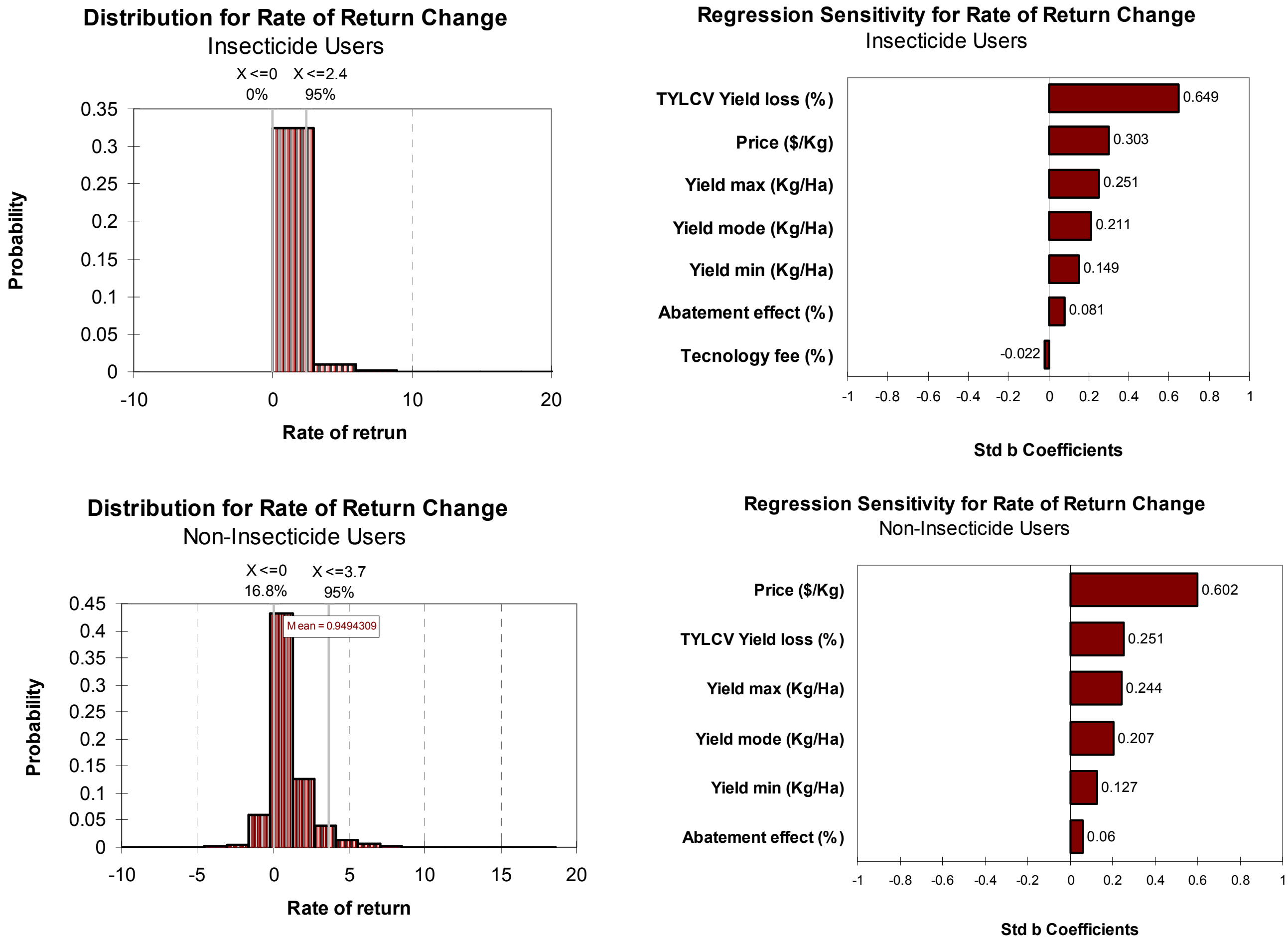


Figure 3. Regression sensitivity and distribution of rate of return change for cabbage

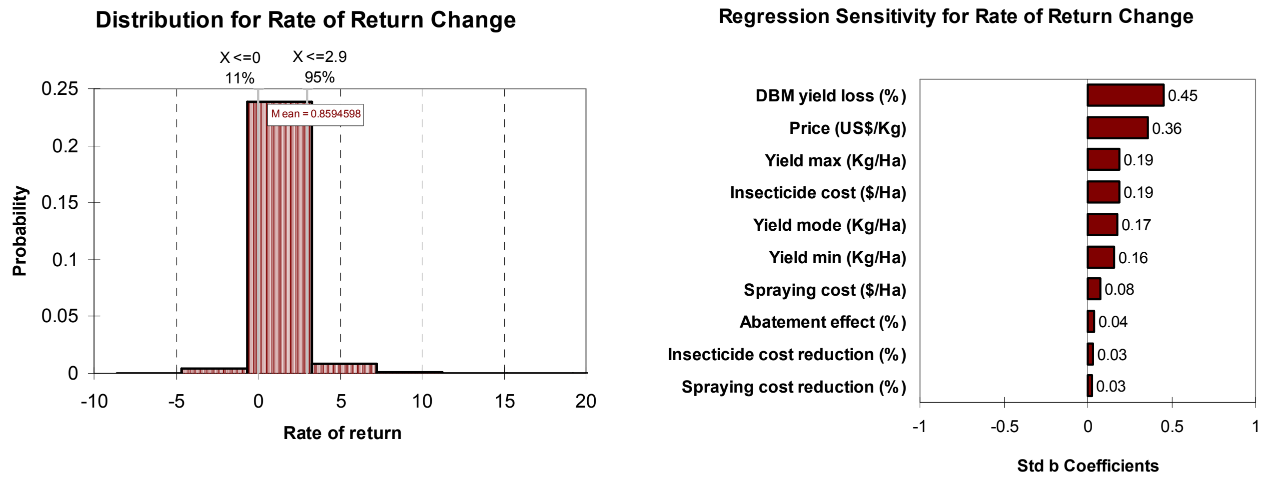


Figure 4. Regression sensitivity and distribution of rate of return change for garden egg