Productivity of Pesticides in Vegetable Farming in Nepal

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Abstract

This paper examines the effectiveness of damage control mechanisms to reduce crop losses from agricultural pests. It uses data from a sample of Cole crop (Cauliflower and Cabbage) growing households in the Bhaktapur district of Nepal to study the impact of pesticides on agriculture production. The results suggest that the marginal productivity of pesticides is close to zero for the average farmer, indicating an excessive use of pesticides. While the study estimates the optimal amount of pesticide per hectare of Cole crop to be 680 grams of active ingredients, the average farmer in Bhaktapur uses 3.9 times as much pesticide as this optimal amount. Over 70% of the farmers in the sample use pesticides above the optimal level despite very small increases in yield attributable to pesticide applications. Our results suggest that the time has come to re-examine the current strategy of the National Integrated Pest Management programme and the curriculum of the Farmers' Field School to ensure more efficient use of pesticides in vegetable farming.

Key Words: Pesticide Productivity, Cole Crop, Damage Control, FFS, Nepal

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1. Introduction

Vegetable producers around the world rely heavily on the use of chemical pesticides to ensure pest control. Although pesticides do not directly contribute to agricultural yields, there is evidence to suggest that intensive use of pesticides has significantly increased agricultural production (Brethour and Weersink, 2001). However, pesticide use also poses risks to human health and the environment (Travisi *et al.* 2006). Thus, it is important to examine the trade-offs associated with the costs and benefits of pesticides under different empirical contexts.

Several studies show that there are significant social and environmental costs of pesticide use (Ajayi, 2000; Antle and Pingali, 1994; Antle and Capalbo, 1994, Rola and Pingali, 1993). Some of these studies (Rola and Pingali, 1993; Rahman, 2003) also suggest that indiscriminate pesticide use can lead to larger pest-related yield losses relative to situations where pesticides are not applied. In the absence of pest attacks, pesticide use only results in extra costs and no real benefits. Nevertheless, in the hope of combating the problem of pests, farmers frequently apply high doses and disproportionate combinations of several pesticides, contributing to a pesticide treadmill in certain areas. Farmers in developing countries in particular continue to use pesticides at increasing rates (WRI, 1998).

Pesticides do not enhance productivity directly like other standard factors of production such as land, labor and capital. Rather, they help farmer combat pests that would otherwise reduce agricultural output. Thus, pesticides are a class of damage control agents (Babcock *et al.*, 1992), making them different from other inputs in agriculture (Lichtenberg and Zilberman, 1986). This central issue needs to be recognized in developing a pesticide use policy (Chambers and Lichtenberg, 1994). It is also important for empirical studies that seek to evaluate pesticide use.

Given the damage control role of pesticides, it is useful to examine the empirical evidence on the marginal contribution of pesticides to agricultural yield. Marginal productivity estimates reported in different studies differ sharply. In the case of cotton, Ajayi (2000), for example, estimates the marginal value product (MVP) per CFA[1] of pesticide to be in the range of 0.47 to 4.39 for different functional specifications. A marginal value product *per unit cost of pesticides* greater than unity implies that pesticides are under-utilized and farmers can increase their profitability by increasing the amount of pesticides from the current level (see Figure 3 which illustrates this concept more clearly). In another study, Prabhu (1985) reports the MVP to be less than unity, i.e., Rs 0.13 per rupee cost of pesticide. However, such conclusions on the value of the marginal productivity of pesticides can depend on the functional specification of the model. Fox and

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[1] CFA stands for Communauté Financière Africaine (French-speaking African Financial Community): 550 CFA=1 USD.

Weersink (1995) show that increasing the marginal returns to pesticide use is possible under common damage control specifications, implying that profit-maximizing farmers could opt for either no control or control at the ceiling.

In this study, we examine the use of pesticides in Nepal. The use of pesticide on vegetable crops in Nepal has increased dramatically in recent years (Maharjan *et al.,* 2004). However, it is worth noting that the average use of pesticides in Nepal (which is at 142 g/ha (ADB, cited in Dahal 1995) is rather low in comparison to that of India (500 gm/ha), Japan (12 kg/ha), or Korea (6.6 kg/ha) (Gupta, 2004). This low average is due to an uneven distribution of pesticide applications in Nepal. Pesticides use is heavily concentrated in the cultivation of vegetables, mustard and cotton, and more intensive in the Terai[2] region, Kathmandu valley and its surrounding areas where agriculture is commercialized.

Despite a rapid increase in pesticide use in vegetable farming, no study thus far has evaluated the productivity of pesticides in vegetable farming in Nepal. Two studies that come close in terms of the topic under study are a household survey (Pujara and Khanal, 2002) and a socio-economic study (Shrestha and Neupane, 2002) conducted in the Kavre district of Nepal. These studies have shown that profits from vegetables farming (potato, tomato, bitter gourd and chili) where pesticides are used are higher than from other crops grown in the same area. But these studies have either adopted a production function approach (considering pesticides as a normal yield-enhancing input) or relied on a partial budget analysis. We note that 'productivity' estimates using pesticides as a yield-enhancing input in the production process are questioned because scholars can actually derive the 'productivity' of pesticides only when a crop is infested with pests. Using a conventional production function approach may result in biased estimates of the impacts of pesticides on yields (Lichtenberg and Zilberman, 1986). Thus, the main objective of our paper is to understand the economics of pesticide use in vegetable crops in Nepal under a damage control framework. We use data from a sample of Cole crop[3] growing households in the Bhaktapur district of Nepal for the analysis.

One aspect researchers must take into consideration when studying pesticide use is the integrated pest management (IPM) approach in farming.[4] Many countries promote IPM training, which involves ecological education and information on pesticides. For instance, Irham (2001) and Irham and Mariyono (2001) have found that the IPM programme has significantly reduced the use of pesticides in rice and soybean farming in Indonesia. Similarly, Upadhyaya (2003) reported that the use of pesticides in rice decreased by 40 percent in almost all National IPM programme areas in Nepal. In Nepal, IPM is introduced through the Farmer Field School (FFS) training

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[2] The flat area in the southern part of Nepal from the Churiya Mountain range to the Indian Border is called the Terai.

[3] Cauliflower and Cabbage are the Cole crops we consider in this study. Cauliflower and Cabbage Belong to the same species (Brassica oleracea) of the Brassicaceae family. Both of these crops have more or less similar growing seasons, cultivation practices and pest problems. Farmers apply similar types of plant protection measures for both of these crops.

[4] IPM is a pest management strategy that researchers have developed to educate farmers to limit the use of pesticides. It relies on a combination of biological control and pesticide use methods.

programme of the Department of Agriculture.[5] Our general understanding is that the frequency of pesticide applications by farmers has decreased after attendance at FFS. These findings rely on case studies and individual FFS reports which mainly focus on the rice agro-ecosystem. Therefore, in this study, we examine the effect of IPM training on pesticide use in Cole crop production in addition to the economics of pesticide use.

The paper is organized as follows. Section 2 discusses pesticide use in agriculture, its damage control characteristics and results obtained from previous studies on pesticide productivity. Section 3 provides an overview of the study area and the descriptive statistics of the respondents. Section 4 describes the theoretical foundations of this study and the empirical models used to compute pesticide productivity. Section 5 discusses the empirical results and section 6 concludes with a consideration of policy implications.

2. Pesticide Use in Agriculture: A Review

During the last three decades, a number of empirical studies[6] have attempted to measure the productivity of chemical pesticides in agriculture. These studies can be categorized into two broad groups depending upon the methods (Ajayi, 2000). While one group uses the generic Cobb-Douglas production functions, the other uses a variant of it by taking into consideration the unique characteristics of pesticides. We present the findings of some of the studies in Appendix 1. Almost all of the first generation studies (Headley, 1968; Campbell, 1976; Carlson, 1977), which evaluate the economic performance of pesticides within the production function framework using non-linear functional forms, conclude that the value of the marginal product of pesticides exceeds marginal factor costs implying that the current level of pesticide use is lower than the optimum. However, there are reasons to believe that researchers might have overestimated pesticide productivity because of the choice of functional forms used in the study. Lichtenberg and Zilberman (1986), for example, argue that first generation studies may have failed to capture the damage control nature of pesticides in the model specification. Furthermore, Fox and Weersink (1995) explain how corner solutions can arise in the use of damage control inputs, which, among other things, mean that marginal value products may not equal marginal factor costs at optimal use. They also explain why farmers may not be particularly responsive to prices in their use of pesticides.

Lichtenberg and Zilberman (1986) suggest that the contribution of damage control agents to production may be better understood if one conceives of actual (realized) output as a net result of two interdependent components: potential yield and potential loss due to pests. Pesticide use needs to be conceptualized in terms of its role in preventing output losses. While scientists do not as yet know the exact nature of the damage-prevention ability of pesticides, based on biological science it is realistic to assume that the damage control function takes a value in the range of 0 to 1. Lichtenberg and Zilberman (1986) suggested four separate damage control functions for pesticide use in agriculture. These are:

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[5] FFS has now become the model approach for educating farmers in Asia and Latin America (Ponitus et al., 2000). IPM education through FFS focuses on the location-specific issues of agro-ecology; resisting generalization and blanket recommendation of pesticides use (Dilt, 1990).

[6] Headley (1968), Campbell (1976), Carlson (1977), Prabhu (1985), Lichtenberg and Zilberman (1986), Carrasco-Tauber and Moffit (1992), Babcock et al. (1992), Rola and Pingali (1993), Huang et al. (2001), Praneetvatakul and Waibel (2002), and Dung and Dung (1999) are noteworthy among them.

Exponential: $G\ (Xp) = \left(1 - e^{-\lambda X_p}\right)$

Logistic: $G\ (Xp) = \left[1 + e^{\left(\mu - \sigma X_p\right)}\right]^{-1}$

Weibull: $G\ (Xp) = \left(1 - e^{-X_p^C}\right)$

Pareto: $G\ (Xp) = \left(1 - K^{\lambda}\, X_p^{\lambda}\right)$

where G(.) is the damage prevented by pesticide use, X_p is the quantity of pesticide used and λ, μ, σ, c and k are damage control parameters that need to be estimated. These functions are integrated into the production function as $Y = f(X).G(X_p)$, where Y is the output, and X's are standard yield-enhancing inputs.

Carrasco-Tauber and Moffit (1992) and Praneetvatakul and Waibel (2002) compared the conventional approach with these alternative specifications of the damage control function by fitting these to empirical data and found that the exponential abatement function gave the best fit. All other functional specifications provided higher estimates of the marginal productivity of the pesticide. Ajayi (2000) found the Weibull specification of the model more plausible for economic interpretation and more congruent with biological processes. The determination of the most useful specification of the function for the economic analysis will partly depend on the nature of the data.

Shankar and Thirtle (2005) pointed out that most econometric analyses of pesticide productivity are typically handicapped by their failure to incorporate entomological information and detailed, stage-by-stage data on pest infestation and pesticide application. Given this limitation, Shankar and Thirtle (2005) emphasized that Litchenberg and Zilberman's framework provides a more accurate framework for the analysis of pesticide productivity than the traditional production function analysis. Huang *et al.* (2001) employed this framework in the analysis of pesticide productivity in rice production in China. We follow a similar strategy since the non-availability of information on pest incidence is a limitation in our study as well.

3. Study Area and the Data

The data for our study come from a survey of a sample of Cole crop farmers (see Figure 1) in the Bhaktapur district (see Figure 2) which has a vibrant group of commercial and intensive vegetable farmers. Bhaktapur produces the largest amount of vegetables among the three districts (Kathmandu, Bhaktapur and Lalitpur) in the Kathmandu valley (MoAC, 2006). There are 54 vegetable farmer groups in 11 vegetable production pockets.[7] Over the years, some 20 IPM Farmer Field Schools have trained a total of 505 farmers (both male and female). Table 1 provides the pocket-wise cultivated area under Cole crop, the number of Cole crop growing households, and the number of trained farmers in each pocket.

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[7] The production pocket is a prioritized location for the production of a specific commodity such as vegetables, cereals, etc., and is identified under the prioritized production package strategy of the Agriculture Perspective Plan (1995-2015) of Nepal.

We selected five vegetable production pockets for this study where farmers cultivated Cole crops intensively from January to May, 2006. We interviewed a sample of 211 Cole crop farmers (approximately 10 percent of the Cole crop farmers in the area) over the period of January to May, 2006. At first, we prepared an inventory of only those farmers belonging to vegetable farmer groups formed by the government's programme and those planning to grow Cole crop during the study season. We then categorized those farmers into two groups: FFS farmers[8] and Non -FFS farmers. We chose the respondents for this study from these two sub-samples of farmers separately. We chose 67 FFS farmers and 144 Non-FFS farmers randomly from the inventory.[9]

In the first phase, we collected the basic socio-economic and demographic information of the households from a total of 211 households. In the second phase, we collected data related to inputs use and outputs in 3 to 5 rounds of successive interviews to cover the duration from transplanting to harvesting for the Cole crop which varies from 3 to 5 months depending on the variety planted. We collected information on the use of pesticides on every visit from each household in order to improve the reliability of data affected by the length of the recall period.

Table 2 presents the descriptive statistics on the farmer characteristics. Out of the total 211 respondents, 82 percent (173) were male farmers and 18 percent (38) were female farmers. The majority of the respondents were illiterate but 35 percent had studied up to the tenth grade. Most of the respondents, about 94 percent, indicated that farming is their major occupation. The average age of the respondents was 43 years and they had an average landholding size of 6 *ropani*[10] of which they used 3 *ropani* on average in Cole crop farming. The maximum cropping intensity[11] found in the area was 300 percent but the mean intensity was 217 percent. At the end, we were able to use data from only 201 farmers for this study.[12]

4. Theory and Methods

Researchers evaluate the productivity effect of pesticides in terms of the output that a producer obtains due to reduction in potential yield loss from pests. The value of output loss that is prevented by the application of pesticides is a measure of the productivity of pesticide use.

Figure 4 presents graphically the impact of changes in pesticide use on production. Y_{max} is the maximum potential output for a given dose of input use without pest infestation. In reality, complete crop loss due to pest attack (Y=0) is unlikely to occur due to the regulation of pest dynamics by biological and natural processes within the agro ecosystem. As such, the actual minimum level of output that a producer obtains after a pest attack under a natural pest control regime, i.e., without

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[8] FFS Farmers are those farmers who have participated in the season long Farmer Field School to learn the skills of integrated pest management.

[9] There are 2110 Cole crop growing households in Bhaktapur, out of which 670 were FFS trained while 1440 are non-FFS trained. To represent this proportion, we randomly selected 67 farmers with FFS training and 144 farmers without FFS training from the inventory of farmers planning to grow Cole crop during the study season in order to make up the total sample size of 211, which is 10% of 2110.

[10] 20 ropani= 1 hectare

[11] Cropping Intensity = (Total area under crop in 365 days/Total cultivable Area available for 365 days)*100

[12] We left out two respondents because they suffered complete crop failure while we had to drop seven pesticide non-users during the analysis stage.

application of pesticides, is Y_{min}. Y_{min} varies depending on the level of natural enemies of pests present and the effect of other agro-ecological phenomena. The difference between Y_{max} and Y_{min} is the maximum potential yield loss abated by pesticide use. This difference is a measure of the destructive capacity of pests that is eliminated by the application of pesticide quantity $X_{p.}$ It measures the effectiveness of the pesticide $G(X_p)$. We show the optimal use of the pesticide dose in the diagram as Xp*.

4.1 Model Specification

In order to estimate the production impacts of pesticide use, consider a general production function of the vegetable crop as

(1)

where Y is the quantity of crop production and Z is a vector of farm inputs including pesticides. However, to accommodate the unique role of pesticides as damage control agents as described above, we follow Lichtenberg and Zilberman (1986), who specify different non-linear functional forms for the pesticide-yield relationship, and rewrite equation (1) that makes a distinction between pesticides and other inputs as:

(2)

where Z now represents a vector of conventional inputs excluding pesticides and X_p is the amount of pesticides.

Theoretically, the proportion of potential yield loss from pest attacks ranges from zero (i.e., complete loss of the crop) to unity (i.e., perfect control of pests). The value of $G(X_p)$ should be between 0 (meaning no damage abatement) and 1 (meaning 100 percent damage abatement). $G(Xp)$ follows a cumulative probability distribution with respect to the values of $X_{p.}$ Combining the standard Cobb-Douglas production function with a logistic function that estimates the damage avoided due to pesticides use, we estimate the following joint production function that incorporates the damage control function of pesticides:

$$Y = \alpha \prod_{i=1}^{n} Z_i^{\beta_i} . G(Xp) \qquad (3)$$

where *a* is the technological shifter, Z_i are inputs (i = 1 to n) and $G(X_p)$ is the damage control function where $0 < G(Xp) < 1$.

Taking log of both sides in equation (3) gives the following econometric model for estimating pesticide use:

$$\ln Y = \ln \alpha + \beta_i \sum_{i=1}^{n} \ln Z_i + \ln G\left(X_p\right) + u_i \qquad (4)$$

where u_i is an error term with mean zero and constant variance.

We estimate the above equations for three different specifications of the damage control function: Modified Exponential, Logistic and Wiebull; however, we undertake the empirical calculations of optimal pesticide use below only for the Modified Exponential form. For comparison, we also estimate a Cobb-Douglas production function with pesticides treated as a regular input.

Using an exponential specification of the damage function provides the following econometric model:

$$\ln Y = \alpha + \beta_1 \ln(NPK) + \beta_2 \ln(L) + (\beta_3 + \beta_4 (Fc)) \ln(K_o) + \delta_1 (Hail) + \delta_2 (Fc) + \ln\left(1 - e^{\left(-\lambda_1 (X_p) - \lambda_2 (FFS)(X_p)\right)}\right) \qquad (5)$$

where,

Y = Crop yield (kg /ha)
NPK = Total Nitrogen, Phosphorous and Potassium nutrients (Kg/ ha)
L = Labour (mandays /ha)
F_c = 1 if farmers use all three major nutrients (NPK), that is the use of fertilizers in combination, or = 0 otherwise
K_o = Capital (NRs/ha); this includes the cost of compost, seed and land preparation
Hail = 1 if farmers suffered from hailstorm damage, 0 otherwise
FFS = 1 if farmers have participated in farmer field school, 0 otherwise
X_p = Total amount of pesticide used (gram / ha)

$$\left[\frac{P_p}{P_v}\right]$$

We use equation (5) to estimate the yield loss abated by the use of pesticides, and to determine the best or optimum dose of pesticides (Xp). While we consider several alternative specifications of the damage control functions as discussed in section 2, exponential specification provided the best estimates.

4.2 Optimal Level of Pesticide Use

An important issue is to identify the level of pesticide use that would optimize yields. As shown in Figure 4, the pesticide amount X_p* represents the level of pesticide which maximizes producer profit. Equation 6 equates the marginal product (MP) of pesticide (derived from equation 5) to the ratio of the pesticide and Cole crop prices:

$$MPP \left(= \frac{dY}{dX}\right) = \frac{(\bar{Y})\left(e^{-(\lambda_1 + \lambda_2 (FFS))X_p}\right)(\lambda_1 + \lambda_2 (FFS))}{\left[1 - \left(e^{-(\lambda_1 + \lambda_2 (FFS))X_p}\right)\right]} = \qquad (6)$$

Thus, the optimum level of pesticide (X_p*) is given by:

$$X_P^* = \frac{\ln\left((\bar{Y})(\lambda_1 + \lambda_2\, Type) + \left(\frac{P_p}{P_v}\right)\right) - \ln\left(\frac{P_p}{P_v}\right)}{(\lambda_1 + \lambda_2\, Type)} \qquad (7)$$

Where,

$\bar{Y}$ = average crop yield (Kg /ha)

P_p = the unit average price of pesticide (NRs/ gram a.i.)

P_v = the seasonal average farm gate price of Cole crop (NRs/Kg)

It is useful to note that modified exponential specification shows a direct link between the marginal productivity of pesticide use and the participation of farmers in the Farmers' Field School (FFS) training programme, where farmers learn about the judicious use of pesticides and IPM.

4.3 Description of Variables

In estimating equation (5), we use the following variables. Y, the dependent variable, is the quantity (kilograms or kg) of Cole crop harvested per hectare. We take the physical quantity of output as the dependent variable as there is no cross-sectional variation in the price of Cole crops.

Fertilizer use is represented by NPK, which is the sum of the quantity (kg) of major nutrient elements, viz. nitrogen (N), phosphorous (P) and potash (K) per hectare used during the study season. The nutrient content of the commercial chemical fertilizers used by farmers are: Urea (46% N), Dia Ammonium Phosphate (DAP, 18 percent N and 46 percent P) and Murate of Potash (60 percent K). We calculated the quantity of NPK taking this into account.[13]

L is the total labour input (person days) used per hectare. This is the sum of all family and hired labour hours used in all the farm operations from land preparation to harvesting. We convert the labour hours into person days assuming a working duration of 8 hours per day.

K_o is the capital that is measured as the monetary value of inputs other than chemical fertilizer, labour and pesticide. We express it in Nepali Rupee[14] per hectare. This variable encompasses the costs of compost, land preparation and seed or seedling. The cost of compost covers the monetary value of compost either purchased from the market, produced by farmers themselves, or borrowed. Similarly, we valued land preparation input (Tractor) and seed or seedling input, whether it is the farmers' own or bought from the market, at the market price in order to calculate its costs.

X_p is the total quantity (grams) of active ingredient (a.i.)[15] of pesticides per hectare used by a farmer during the study season. Here, pesticide indicates the use of both insecticides and fungicides.

We use three dummy variables in our analyses. *Hail* is the dummy variable that captures the effect of hailstorm that occurred during the study season. We coded the farmers, whose Cole crop was affected by hailstorms, as 1 and others whose crops were not affected by hailstorms as

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[13] NPK = Amount of Nitrogen (N) per hectare + Amount of Phosphorous (P) per hectare + Amount of Potassium (K) per hectare; N per ha = (((Amount of Urea*0.46) + (Amount of DAP*0.18))/Cole crop grown area); P per ha = ((Amount of DAP *0.46)/ Cole crop grown area); K per ha = ((Amount of MoP*0.6)/ Cole crop grown area).

[14] 1 US Dollar($) = 63 Nepali Rupees(NRs)

[15] Active ingredient (a.i.) means the biologically active part of the pesticide.

0. F_c is a dummy variable that captures whether the farmers used all three major nutrients (NPK). It equals 1 for farmers who use all three nutrients in combination and 0 otherwise. *FFS* is a dummy variable which equals 1 for farmers who participated in the Farmer Field School and 0 otherwise.

5. Results and Discussions

This section describes the types of pesticide used in the study area and the estimation of the production function and marginal products of inputs and pesticides.

5.1 Pesticide Use and Farmer Perception

Farmers in Bhaktapur used forty three commercial products from twenty different pesticides. The survey data shows that farmers use 15 commercial products of five different types of fungicide and 28 commercial products of 15 different types of insecticide in Cole crop farming. The most commonly used fungicides are: Carbendazim, Copperoxychloride, Mancozeb, Metalaxy 8 percent plus Mancozeb 64 percent. Similarly, Chlorpyriphos, Cypermethrin, Dichlorvous, Dimethoate, Endosulfan, Fenvelerate, Parathion-methyl and Monocrotophos are the most commonly used insecticides in Bhaktapur for Cole crops. Most of these insecticides fall under World Health Organization (WHO) categories of IB to III, implying that they belong among the extreme to moderately hazardous classifications. FFS trained farmers generally apply well known commercial pesticides rather than less known formulations.

Out of the total amount of pesticide used in Cole crops, 76 percent are insecticides and 19 percent fungicide. As evident from Figure 5, farmers used 2373 gm active ingredient of fungicide and 1963 gm of insecticide per hectare on average. Overall, farmers applied 2633 gm per hectare of pesticides. This finding contradicts the findings of an earlier survey report of PPD (2004), which indicated that farmers applied 1224 gm of insecticides and 1295 gm of fungicides per hectare in cauliflower farming in the Bhaktapur District. Our numbers suggest that average pesticide use is higher than previously estimated.

5.2 Estimation of Pesticide Productivity

Table 2 presents the summary statistics of the variables used in the econometric analyses. In our sample, the average yield per hectare is about 23,000 kilograms. The average pesticide use is 2633 active ingredient grams per hectare. Hailstorms affect approximately 13 percent of farmers and approximately 27 percent farmers use all three major nutrient (NPK) fertilizers in combination.

For the empirical analysis, we estimated four different models: the Cobb-Douglas, the modified Exponential, the Logistic and the Wiebull. We present the results in Table 3. In all specifications (see Table 3), fertilizer use, NPK, and labour coefficients have the expected sign and are highly significant. However, the coefficient for Capital (K_o) is statistically insignificant indicating that the yield is not responsive to capital (compost and land preparation) expenditure.[16] But when

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[16] The coefficient of Ko is â3 + â4 = 0.415 and the standard error is calculated as SE(â3+ â4) = sqrt [(variance(â3) + variance(â4) - 2 covariance(â3, â4)]=0.959. The t-value of Ko is 0.433 which is not significant.

interacted with NPK combination, the coefficient of capital is highly significant and positive indicating that right combination of nutrients is essential in order to get benefits from capital related expenditures. The coefficient for the dummy variable F_c, which shows the use of all three fertilizers (NPK), is negative and statistically significant in all specifications. This suggests that farmers may not be using inorganic fertilizers, viz., Urea, DAP and Murate of Potash in the proper combination. The coefficient of Hailstorm (*Hail*) is negative and significant in all specifications suggesting that hailstorms contribute to crop losses.

The coefficient of pesticide use in different specifications (coefficient of ln(*pesti*) for Cobb-Douglas, λ_1 for exponential, σ for logistic, and c for Weibull) has a positive sign. However, the coefficient for pesticide use (λ_1) is significant only in the exponential form of the production function. In fact, all the parameter estimates of the exponential model are significant at the 1 percent level except for Capital (K_o) and the interaction of FFS with pesticide (λ_2). The R^2 obtained from this model was 0.63. The signs of the estimated input parameters of this model accord well with agronomic facts. The positive but statistically insignificant coefficient of the interaction of FFS with pesticide (λ_2) indicates that the yield is not responsive to FFS training in the case of Cole crop production in the study area.

Figure 6 shows the damage abatement resulting from the different levels of pesticide used in Cole crop production in Bhaktapur based on the modified exponential specification (equation 5). The value of $G(Xp)$ is in the range $0<G(Xp)<1$. The minimum amount of Cole crop (Y_{min}) a farmer can produce without using pesticide is 6703 kg per hectare, which is 35 percent of the average production of Cole crop in Bhaktapur. We provide the results of the calculation of damage abatement and yield increment due to pesticides in Table 4. We present the pesticide productivity curve from this data graphically in Figure 7. The yield loss reduction in Cole crop approaches zero as pesticide use (X_p) increases to above 850 gram per hectare. The maximum attainable yield by using pesticide (Y_{max}) is 20,938 kg per hectare. Thus, the maximum abated yield by pesticide use[17] is 14,235 kg per hectare.

5.3. Marginal Productivity of Pesticides

At the average pesticide application rate of 2633 gram per hectare, we estimate the marginal productivity of pesticides for the modified exponential specification (equation 6) to be close to zero. Thus, this estimate falls below the estimates of Prabhu (1985), Ajayi (2000), and Huang (2001) as mentioned in Appendix 1. Figure 8 shows the significantly declining trend of the marginal value product of the pesticide as its application increases.

Using equation 7, we compute the optimal level of pesticide used to be 680 gram of a.i. for Cole crops in Bhaktapur at the mean of the sample. We base this on the average farm gate price of Cole crop in the season, which was NRs 7.5 per kg, and the average price of a gram of active ingredient of pesticides, which was NRs 0.75.[18] The average application of a pesticide dose in the sample was 2633 gram of active ingredient of pesticides per hectare. This clearly shows that farmers overused about 1953 gram of the active ingredient of pesticides per hectare. In other

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[17] The maximum abated yield by pesticide use = Ymax- Ymin

[18] We base this on the average price of all pesticides used in Cole crops in Bhaktapur in 2006.

words, farmers lose NRs 1465 (1953 X 0.75) per hectare because of inefficient use of pesticides in their Cole crop farming. Farmers were using 3.9 times more pesticides than they should during the survey season. Thus, we can conclude that farmers overuse pesticides substantially on the ground of uncertainty related to effectiveness of the pesticides and the occurrence of the pest problems. It is possible that farmers deliberately apply an overdose of pesticides because they are uncertain of the effectiveness of the dose used and therefore wish through overuse to avert the risk of bigger pest attacks.

It is interesting that the extent of overuse of pesticide differs between farmers trained on IPM at the Farmer Field Schools and farmers not trained in FFS. Estimates show that farmers with FFS use 2.7 times the optimal dose as compared to farmers without FFS who use 4.4 times of the optimal dose.

Table 5 shows that only a small proportion of farmers (3 percent) use the optimal level of pesticides. The majority in Bhaktapur (74 percent) use more than the optimum amount of pesticides and obtain a very small increase (1-4 percent) in yield relative to the average yield.

6. Conclusions and Policy Recommendations

Chemical pesticides play an important role in combating pest problems in agriculture. Increased production and productivity in agriculture in recent years is largely the result of enhanced use of pesticides as well as increased use of nutrients and water. There are, however, growing public objections to the use of chemical pesticides because of their negative externalities on human health and the environment. In order to balance public concern about chemical residues and ecological damage with food security issues, we need to understand better what the trade-offs are between greater and more limited use of pesticides. Accurate, improved and locally-specific information about the productivity of pesticides in agriculture is crucial in the formulation of policy on the issue.

This study investigates the impact of pesticide use on Cole crop production in the Bhaktapur district of Nepal. We evaluate the economic performance of pesticides using a non-linear functional forms. The methods used in this study allow us to estimate the effectiveness of farmer field school (FFS) training on potential yield as well.

We find that pesticides significantly contribute to Cole crop production by limiting yield losses. As expected, the marginal contributions of pesticide use declines with increased use of pesticides. What is interesting is that the marginal contribution of pesticides is close to zero at the average level at which Cole crop growers currently use pesticides. In the study area, farmers apply pesticides at more than at their profit maximizing or optimum level. The optimal or profit maximizing amount of pesticide per hectare for Cole crop production is 680 grams while the average farmer uses pesticides in Cole crops at about four times this optimal level. This is happening despite a perception among a majority of farmers that pesticides are harmful to human health as well as to beneficial organisms prevalent in the vegetable ecosystem (Jha and Regmi, 2009). Our results indicate that reduction in pesticide use from the current level would not decrease yields significantly.

Wilson and Tisdell (2001) propose four reasons for the overuse of pesticides: (i) ignorance regarding the sustainability of pesticide use; (ii) the lack of alternatives to pesticides; (iii) underestimation of the short and long term costs of pesticide use; and (iv) weak enforcement of laws and regulations. These reasons seemed to be equally valid in the case of our study.

Both farmers trained in integrated pest management and those who are not trained overuse pesticides. However, farmers trained in the farmer field schools tend to use lesser amount of pesticides. Policy makers and planners need to review the IPM programme in Nepal and revise the FFS curriculum. The FFS programme should be designed in such a way that it empowers farmers to make decisions suitable for a locally-specific vegetable production system. This ultimately leads to the adaptation of alternative technologies for growing healthy crops.

The study sheds some light on discrepancies between claims by agriculturists and economists regarding pesticide productivity. Though we cannot make general recommendations based on such a small-scale study, the results are still relevant for regulatory decisions. Further empirical studies are required on a wider scale to understand pesticide productivity across Nepal's diverse agro-ecosystems. It would be useful to study the correlations between farmers' perceptions of risk and pesticide use levels as well as the implications of any training they may have on integrated pest management.

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TABLES

Table 1: Vegetable Production Pocket-wise Distribution of Cultivated and Cole Crop Area in Bhaktapur

Production Pockets	Total Cultivated Area (ha)	Cole Crop Cultivated Area (ha)	No. of Households Growing Cole Crop
Bode	323	40	150
Sipadole	401	25	225
Nakhel	905	25	125
Kharipati	778	30	90
Dadhikot	652	35	85
Bhaktapur N.P	414	30	433
Katunje	382	20	153
Balkumari	155	30	287
Balkot	385	25	104
Jhaukhel	523	20	301
Duwakot	476	20	157
Total	**5394**	**300**	**2110**

Source: Information obtained from Plant Protection Officer of District Agriculture Development Office, Bhaktapur (2004)

Table 2: Summary Statistics of the Variables

Variables	N	Min	Max	Mean	S.D
Age of Respondent (Years)	201	16.0	85.0	43.0	13.1
Vegetable farming experience(Years)	201	0.0	50.0	14.1	10.3
Cole Crop cultivated area (*ropani*)	201	0.4	13.0	2.6	2.0
Total landholdings (*ropani*)	201	1.0	17.0	6.0	3.1
Cropping intensity (%)	201	133.3	300.0	217.1	42.2
Production (Kg / ha)	201	450.0	60000.0	23203.7	10285.6
NPK nutrients (Kg / ha)	201	92.0	1135.0	529.0	254.8
Labour (Mandays / ha)	201	240.0	718.8	427.8	105.7
Capital (NRS / ha)	201	7000.0	79000.0	20793.7	11598.9
Pesticide (a.i. gram/ha)	201	53.3	22650.0	2632.8	3571.3
Type of participant (*FFS*)	201	0.0	1.0	0.3	0.5
Hail storm damage (*Hail*)	201	0.0	1.0	0.13	0.3
User of NPK in combination (*Fc*)	201	0.0	1.0	0.27	0.4

Source: Primary Survey (2006)

Table 3: Results from the Non–linear Estimation of Various Production Functions

Variables	Cobb-Douglas	Damage Control Specifications		
		Modified Exponential	Logistic	Weibull
Intercept	6.424*** (5.607)	7.163*** (6.20)	7.097*** (6.117)	7.176*** (6.167)
In *(NPK)*	0.174*** (2.849)	0.165*** (2.796)	0.165*** (2.776)	0.160*** (2.665)
In *(L)*	0.349*** (2.645)	0.406*** (3.11)	0.382** (2.916)	0.383*** (2.932)
In *(Ko)*	0.050 (0.750)	-0.050 (-0.683)	-.029 (-0.392)	-0.033 (-0.458)
In *(Ko)*Fc*		0.465*** (2.780)	0.431*** (2584)	0.434*** (2.613)
In *(Pesti)*	0.005 (0.196)			
Hail	-1.514*** (-15.412)	-1.492*** (-15.430)	-1.516*** (-15.660)	-1.514*** (-15.68)
Fc	-0.130* (-1.755)	-4.693*** (-2.852)	-4.364*** (-2.661)	-4.392*** (-2.690)
λ_1		0.012*** (2.844)		
λ_2		0.048 (0.279)		
μ			1.394 (0.064)	
σ			0.061 (0.163)	
c				0.218 (1.50.131)
R^2	0.61	0.63	0.63	0.63
N	201	201	201	201

Note:

- Absolute values of asymptotic *t*-statistics (for the damage control specification) and *t*-statistics (for the Cobb- Douglas specification) are shown in parenthesis.

- λ_1 and λ_2 are coefficients of pesticide use and the interaction of FFS with pesticide use in the modified exponential model; μ and σ are coefficients of pesticide use in the Logistic model; c is the coefficient of pesticide use in the Weibull model.

Table 4: Computation of Damage Abatement and Yield Increment due to Pesticide Use (Modified Exponential Functional Specification)

Pesticide amount used (gm a.i /ha) (Xp)	Damage abatement function G(Xp)	Cumulative yield increment (Kg/ha)	Yield loss reduction (Kg/ha)
50	0.4408	9229.3	5161.5
100	0.6872	14390.8	2886.6
150	0.8251	17277.3	1614.3
200	0.9022	18891.6	902.8
250	0.9453	19794.4	504.9
300	0.9694	20299.3	282.4
350	0.9829	20581.7	157.9
400	0.9904	20739.6	88.3
450	0.9946	20827.9	49.4
500	0.9970	20877.3	27.6
550	0.9983	20904.9	15.4
600	0.9991	20920.3	8.6
650	0.9995	20929.0	4.8
700	0.9997	20933.8	2.7
750	0.9998	20936.5	1.5
800	0.9999	20938.0	0.8
850	0.9999	20938.9	0.5
900	1.0000	20939.3	0.3
950	1.0000	20939.6	0.1
1000	1.0000	20939.7	0.1
1050	1.0000	20939.8	0.0
1100	1.0000	20939.9	0.0
1150	1.0000	20939.9	0.0
1200	1.0000	20939.9	0.0

Note:

- Yield loss reduction (Kg/ha) by X_p amount of pesticide used is calculated as given in exaples below.

Example:

Yield loss reduction (Kg/ha) at X_{50} = (cumulative yield increment at $X_{50} - Y_{min}$).

Yield loss reduction (Kg/ha) at X_{100}= (cumulative yield increment at X_{100}-cumulative yield increment at X_{50})

- Y_{min} = 6703 kg per hectare (The minimum amount of Cole crop a farmer can produce at X_0).

Table 5: Cole Crop Production Using Different Levels of Pesticide by Farmer

Participant Category	Level of Pesticide Use	Proportion of Participants	Production Level (Kg/ha)	
			Mean(Y_l)	Difference(D)
Non-FFS farmers	Below Optimal	21%	20891.96	-11%
	Optimal	**4%**	**19610.71**	-16%
	Above Optimal	74%	24276.49	4%
FFS Farmers	Below	25%	22012.94	-4%
	Optimal	**2%**	**23600**	3%
	Above	73%	23157.45	1%
Overall	Below Optimal	22%	21290.53	-8%
	Optimal	**3%**	**20180.61**	-13%
	Above Optimal	74%	23923.51	3%

Note :

- Production level difference (D) is calculated as: $\frac{\left(Y_l - \bar{Y}\right)}{\bar{Y}} \times 100\%$

- Mean yield ($\bar{Y}$) of non-FFS farmers, FFS farmers and Overall is 23355, 22878, and 23203 (Kg/ha) respectively.

FIGURES

Figure 1: Map of Bhaktapur District and Study Locations

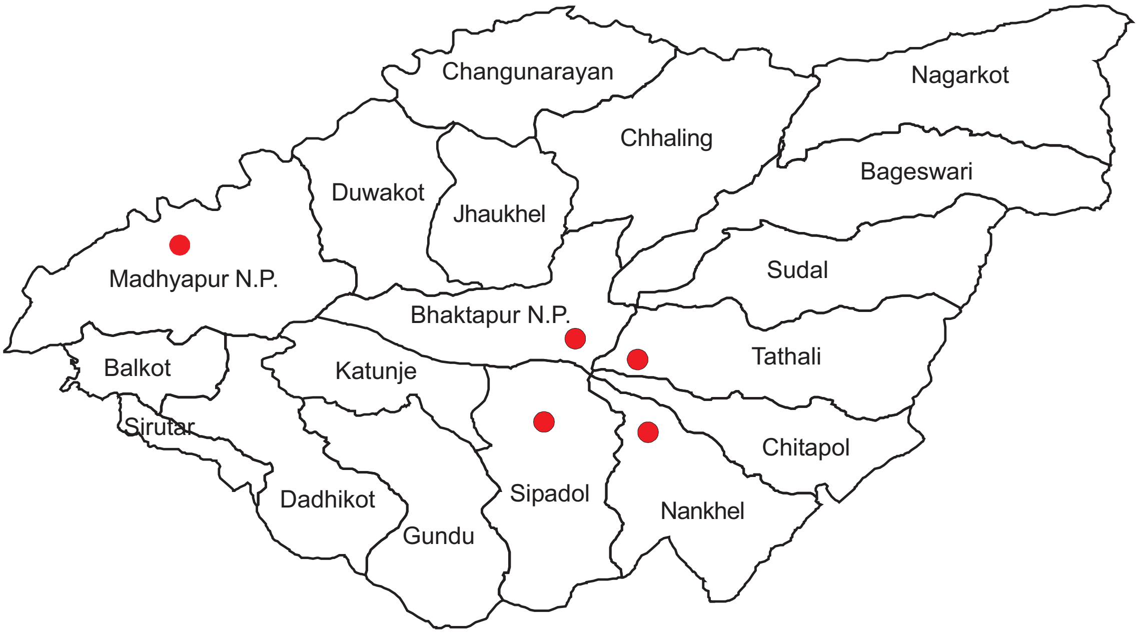
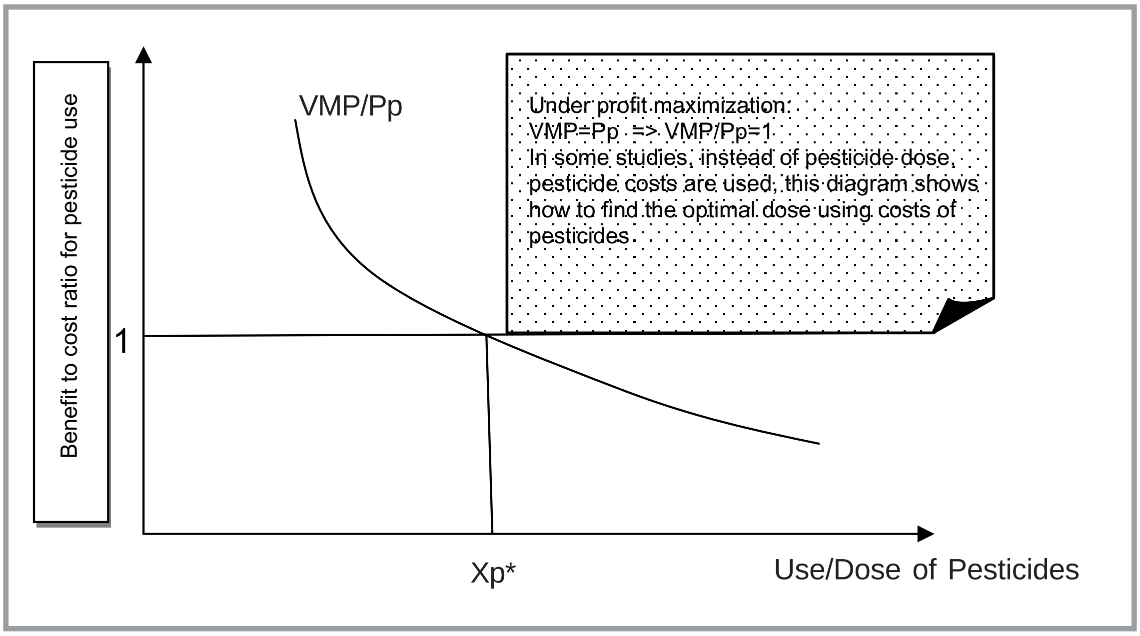


Figure 2: Location of Bhaktapur in the Territory of Nepal

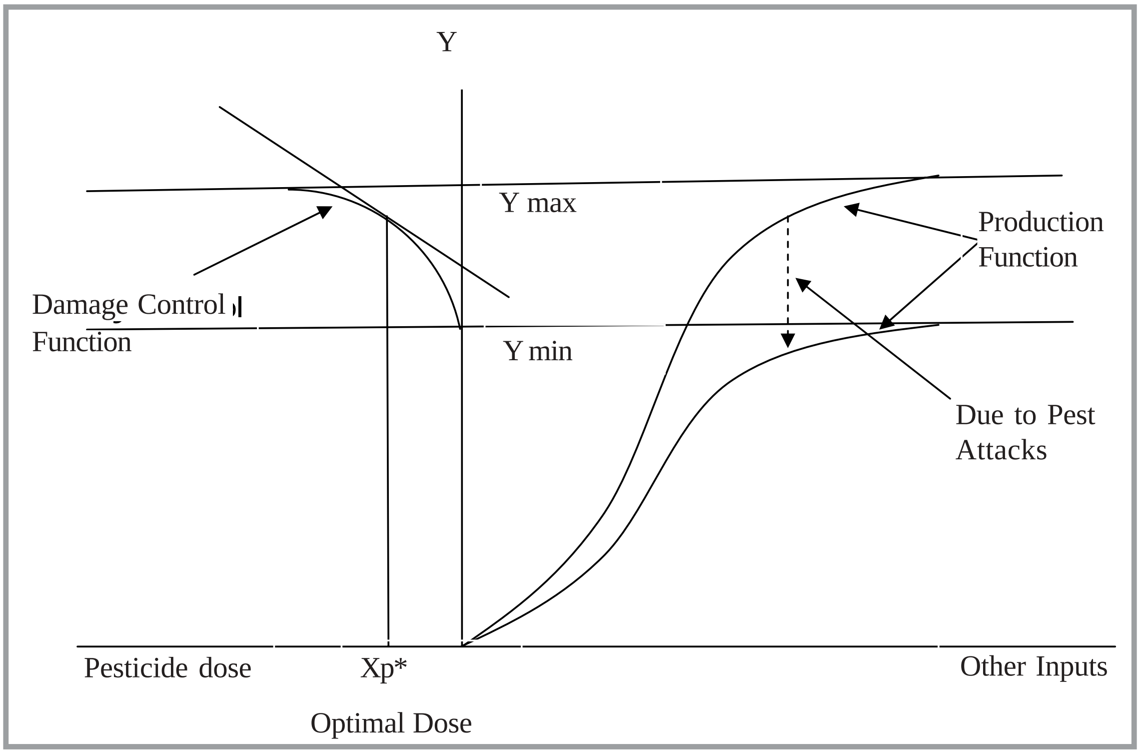
Figure 3: Optimal Use of Pesticides



Under profit maximization:
VMP=Pp => VMP/Pp=1
In some studies, instead of pesticide dose, pesticide costs are used; this diagram shows how to find the optimal dose using costs of pesticides

Where,
MVP = Marginal value product
P_p = Unit price of pesticide
X_p* = Optimal dose of pesticide

Figure 4: Impact of Pesticide on Yield Loss Reduction in a Production System



Where,

Y_{max} = Maximum attainable yield by using pesticide
Y_{min} = Minimum yield without pesticide use
Xp = Use of pesticide
Xp* = Optimal level of pesticide

Figure 5: Average Amount of Pesticides Used on Cole Crop (grams a.i./ ha)

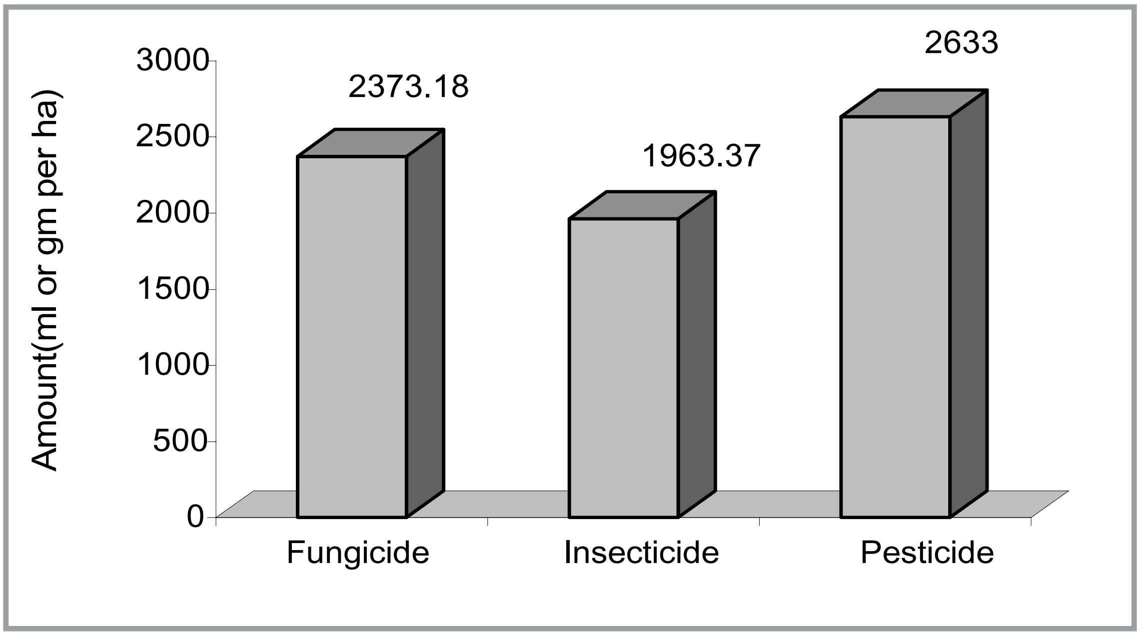
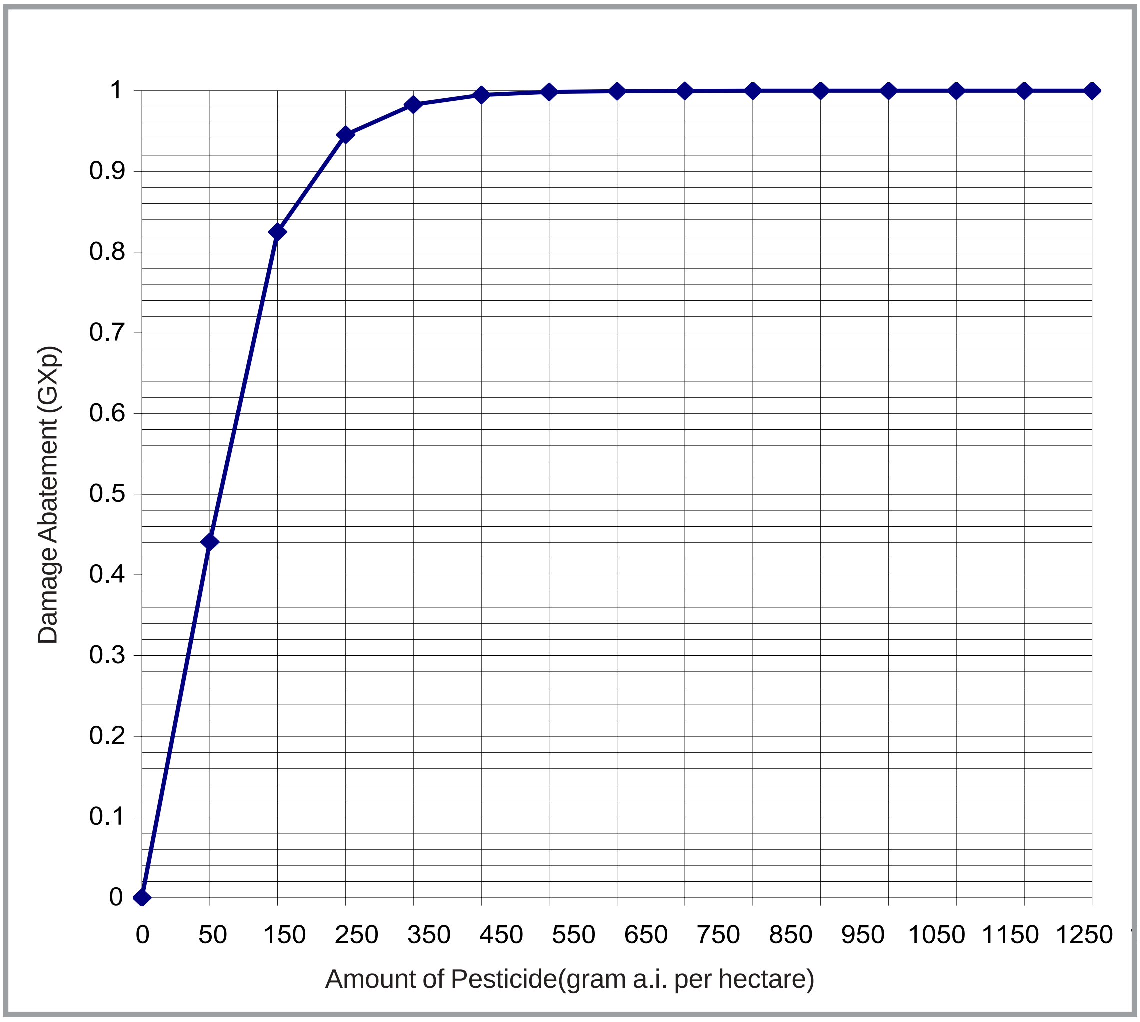


Figure 6: Resultant Damage Abatement Function of Pesticides



Note:
We based this graph on the modified exponential functional specification. We evaluate all variables at mean values.

Figure 7: Pesticide Productivity Curve

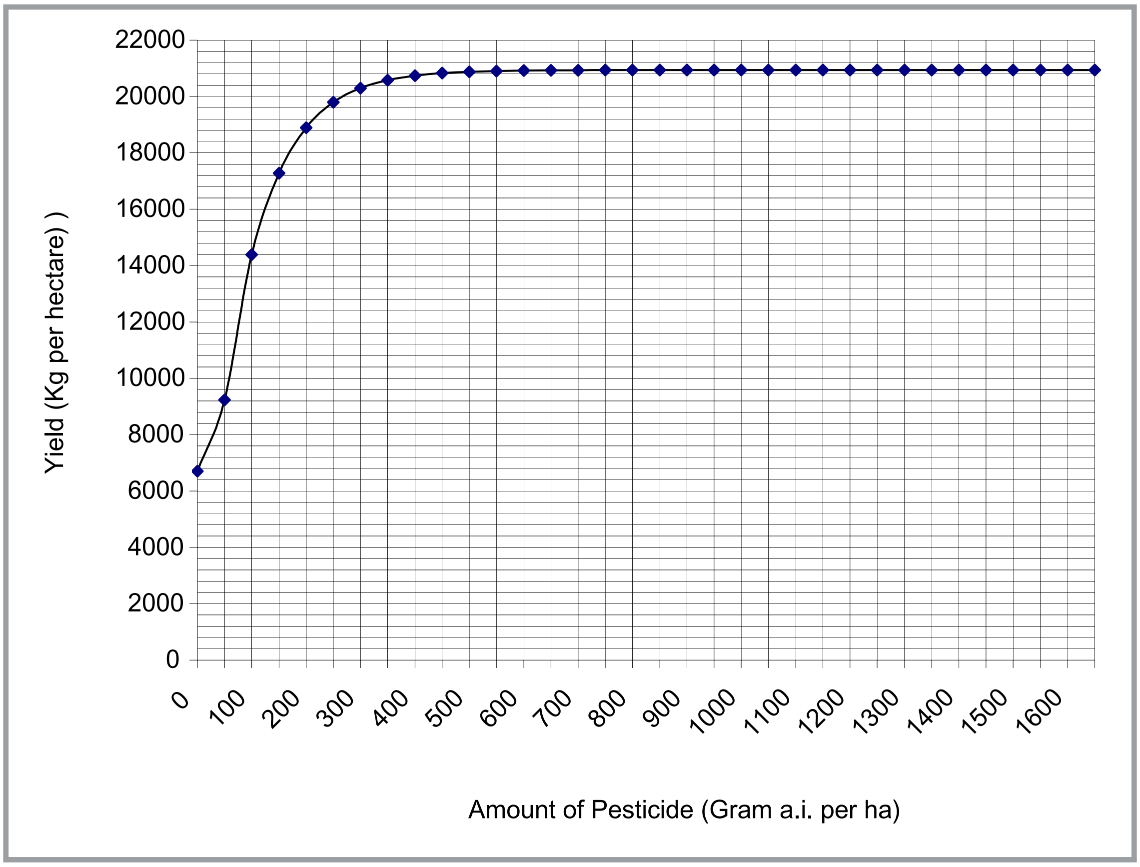
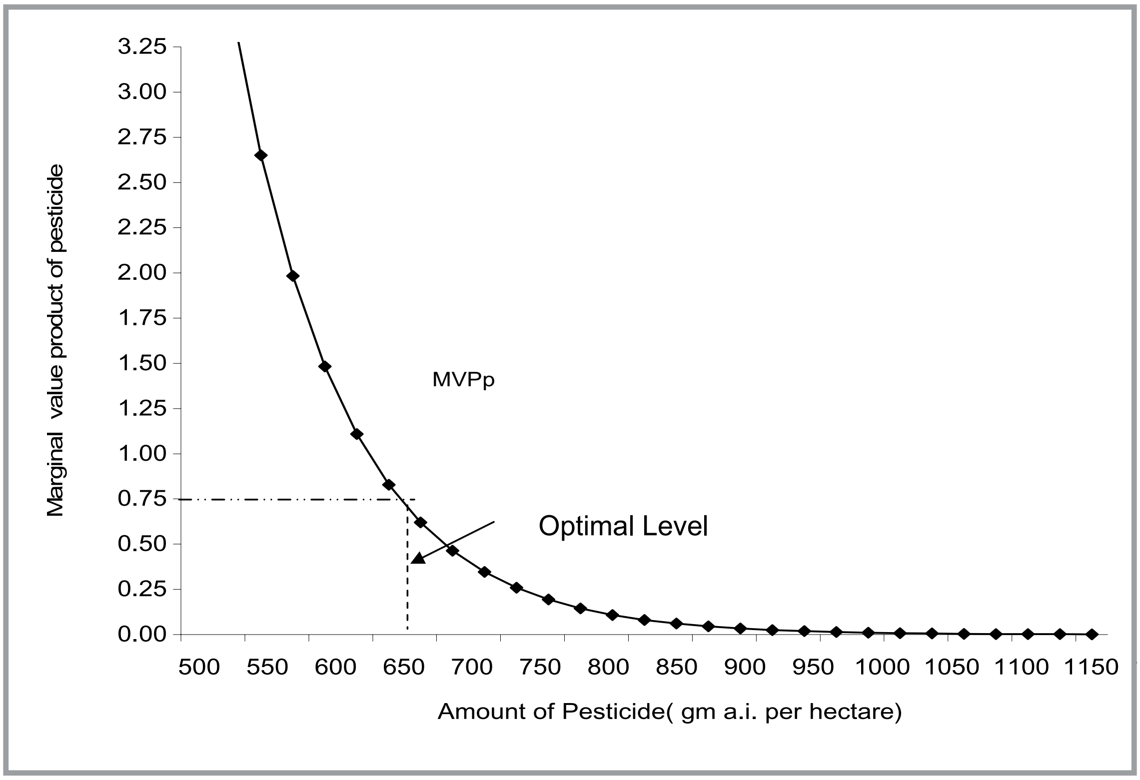


Figure 8: Marginal Value Product of Pesticide Use in Cole Crop Production



Note:
We base this graph on the modified exponential functional specification. We evaluate all variables at mean values.

Appendix 1 : Empirical Findings of Pesticide Productivity Estimation Works

Source	Functional Specification	Finding
Headely (1968)	Cobb-Douglas Function	The marginal value of one dollar expenditure for chemical pesticides is approximately $4.0
Campbell (1976)	Cobb-Douglas Function	The marginal dollar's worth of pesticides input yielded around $ 12 worth of output.
Prahbu (1985)	Cobb-Douglas Function with some modifications	The marginal value product of pesticide was less than unity, that is, 0.13.
Carrasco-Tauber and Moffit (1992)	Cobb-Douglas Function compared with Damage Function Specifications	All functional specification indicates high marginal productivity of pesticides except the exponential specification.
Ajayi (2000)	Cobb-Douglas Function compared with Damage Function Specifications	The marginal value product per unit cost of insecticides is greater than unity in the Cobb-Douglas model and all the alternative LZ damage specification except Weibull specification.
Huang *et al.* (2001)	Exponential Damage Control Specification	The marginal product of pesticide was only 0.07 Kg.
Praneetvatakul and Waibel (2002)	Cobb-Douglas Function compared with Damage Function Specifications	The abatement function, "the exponential form," gave the best fit to the empirical data of rice.
Dung and Dung (1999)	Cobb-Douglas Function	10 percent increase in total dose of pesticides will contribute to a micro increase of 0.346 percent of rice yield.