Do farmers and the environment benefit from adopting IPM practices? Evidence from Kenya

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Abstract:

In this article, we estimate the impacts of a bundle of integrated pest management (IPM) practices on mango yield, mango net income, human health and the environment, using recent household survey data of mango growers in Kenya. We employ multinomial endogenous switching treatment regression model with an ordered probit selection rule to establish counterfactual outcomes, while controlling for potential selection bias. The environmental and human health effects of chemical insecticide use are quantified by employing the environmental impact quotient method. The analysis reveals that, while IPM-adopting farmers have higher mango yields and mango net income, they also use lower quantities of insecticide and cause less damage to the environment and to human health. In addition, switching from one IPM to multiple IPM practices generates even higher economic, environmental and human health benefits. The findings also reveal that variables such as training on insect pest management, exposure to IPM as proxied by the number of adopters within a village, membership of rural institutions, and income share from mango crops positively and significantly influence the probability of a farmer using a bundle of IPM practices. These positive outcomes can be achieved through providing adequate technical support and extension services to farmers.

Acknowledegment: We acknowledge core funding to the International Centre of Insect Physiology and Ecology (icipe) provided by the United Kingdom's Department for International Development (DFID), the Swedish International Development Cooperation Agency (Sida), the Swiss Agency for Development and Cooperation (SDC), the German Federal Ministry for Economic Cooperation and Development (BMZ), and the Kenyan Government. The work on integrated pest management is funded primarily by the European Union, the International Fund for Agricultural Development (IFAD), and the Biovision Foundation. The views expressed herein do not necessarily reflect the official opinion of the donors or icipe.

JEL Codes: I15, C31

#2412

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Abstract

In this article, we estimate the impacts of a bundle of integrated pest management (IPM) practices on mango yield, mango net income, human health and the environment, using recent household survey data of mango growers in Kenya. We employ multinomial endogenous switching treatment regression model with an ordered probit selection rule to establish counterfactual outcomes, while controlling for potential selection bias. The environmental and human health effects of chemical insecticide use are quantified by employing the environmental impact quotient method. The analysis reveals that, while IPM-adopting farmers have higher mango yields and mango net income, they also use lower quantities of insecticide and cause less damage to the environment and to human health. In addition, switching from one IPM to multiple IPM practices generates even higher economic, environmental and human health benefits. The findings also reveal that variables such as training on insect pest management, exposure to IPM as proxied by the number of adopters within a village, membership of rural institutions, and income share from mango crops positively and significantly influence the probability of a farmer using a bundle of IPM practices. These results highlight the need to intensify IPM-adoption efforts and encourage the use of multiple IPM practices. This would not only boost the economy and the health of both producers and consumers, but would also sustain ecosystem services that support livelihoods. These positive outcomes can be achieved through providing adequate technical support and extension services to farmers.

Keywords: economic impact, environmental impact, human health impact, integrated pest management, Kenya, mango

1. Introduction

The mango is an economically important fruit in Kenya, and is traded on domestic, regional and international markets. It provides many smallholders with their principal source of employment and livelihood, while helping the country generate foreign exchange earnings. However, Kenya's mango production is constrained by many problems, with fruit flies being a major threat to food security, poverty alleviation and agricultural livelihoods. Indeed, across Africa, fruit flies are estimated to cause annual losses of US$2.0 billion in fruit and vegetable production (Ekesi et al., 2016). In respect of mango production, the larval stages of fruit flies that feed on the fruit pulp are responsible for direct damage to the produce, causing anything from 30% to 100% loss in the absence of any pest management method (Ekesi et al., 2011, 2014). This not only lowers productivity, but also the quality, marketability and value of the produce (Ekesi et al., 2006; Rwomushana et al., 2008). Fruit-fly infestations also cause indirect damage to the economy by reducing foreign exchange earnings from fruit due to quarantine restrictions and the loss of opportunities to export to global markets (Ekesi et al., 2016; Lux et al., 2003; Ndiaye et al., 2008).

Farmers currently exhibit an over-reliance on synthetic insecticides to manage insect pests; however, insects are developing a resistance to such controls owing to their overuse (Gautam et al., 2017; Pretty and Bharucha, 2015; Vontas et al., 2011). Furthermore, the improper – i.e. excessive or unsafe – use of synthetic pesticides has adverse effects on both human health, as well as on the environment and biodiversity (Asfaw et al., 2010; Gautam et al., 2017; Schreinemachers and Tipraqsa, 2012; Rejesus et al., 2009). These negative consequences are more severe in developing countries, partly because insecticides regulations are less restrictive than in their developed counterparts, and partly because spraying is often conducted manually, without adequate measures to prevent negative effects on human health and the environment (Ghimire and Woodward, 2013). The increased use of insecticides on fruit also reduces its competitiveness, especially on international markets, due to undesirable pesticide residues. (Lux et al., 2003).

Thus, effective alternative pest management is essential to the economic vitality of the horticulture industry in sub-Saharan Africa. To this end, researchers and development partners in the horticulture sector devised an integrated pest management (IPM) approach to suppress and reduce fruit-fly numbers as a more sustainable option to the conventional application of pesticide (Ekesi et al., 2016; Norton et al., 1999). IPM combines pest control practices that minimise the use of synthetic insecticides, are economically and environmentally sustainable, and pose no negative effects on human health (Blake et al., 2007; Pretty and Bharucha, 2015). In Africa, IPM techniques for preventing and managing fruit-fly infestations are developed and promoted by the International Centre of Insect Physiology and Ecology (icipe), in collaboration with its partners. In Kenya, for example, these techniques aim to improve mango production, enhance market access for mango producers, and increase their incomes (Ekesi et al., 2011; Muriithi et al., 2016). An IPM technique is required in Africa because many fruit fly species coexist in individual environments, and their control tends to be species-specific (Ekesi and Billah, 2007).

When one adopts and scales IPM practices, it is critical to measure their impacts across multiple development outcomes, namely their impact on productivity, economic, environment, social and human conditions. Such measurements help policymakers and development partners to understand the scale of what could be gained from designing better policies aimed at disseminating information on IPM practices and encouraging their adoption. As its name implies, IPM involves multiple practices whose integration is expected to enhance the achievement of development objectives. However, empirical evidence on how IPM practices impact the use of insecticides uses, crop yields and household welfare is scant in developing countries, especially in sub-Saharan Africa, and there is a lack of sound evaluation of such impacts (Gautam et al., 2017; Pretty and Bharucha, 2015). For example, Pretty and Bharucha (2015) recently reviewed 85 IPM projects in Africa and Asia and found evidence that such an approach reduced pesticide use. Nonetheless, they concluded (ibid.) that IPM's impact on crop yields was more complex, depending on, among other factors, *the incidence and severity of a pest infestation*. The few existing farm-level impact studies (e.g. Fernandez-Cornejo, 1998; Isoto et al., 2008; Kibira et al., 2015; Sanglestsawai et al., 2015; Sharma and Peshin, 2016) mainly focused on an impact evaluation approach that used binary treatment variables, while ignoring the intensity of IPM adoption. It is vital to take intensity of adoption into account, however, because it could contribute to heterogeneous treatment effects. Furthermore, to our knowledge, no study has so far examined whether IPM that has been developed specifically to suppress and reduce mango fruit-fly infestations is able to help African mango growers reduce the risk effects of insecticides use on human health and the environment. Furthermore, it is well understood that insecticides pose great risk to human health (Athukorala et al., 2012; Okello and Swinton, 2010), water quality (Arias-Estévez et al., 2008), food safety (Liu et al., 1995), aquatic species (Mullen et al., 1997), and beneficial insects (Brethour and Weersink, 2001; Cuyno et al., 2001; Skevas et al., 2013). However, the results from these previous studies are not comparable, as the types of IPM practice considered in the analyses vary.

This paper contributes to the current literature on the impact of IPM and other agricultural technology adoption because, firstly, very few of the existing studies use the multinomial treatment effects evaluation approach. The paper develops a treatment-effects model that can be used to analyse the effects of an endogenous multinomial treatment – when exactly one treatment is chosen from a set of more than two choices – on continuous outcome variables. Specifically, we examine to what extent Kenyan mango farmers on smallholder farms have adopted a bundle of IPM practices developed to suppress mango fruit fly, and how such adoption impacts on their insecticide use, crop yields, mango net income, human health, and the environment. Secondly, the paper contributes to scant empirical data on the impact of IPM adoption on human health and the environment. Thirdly, since IPM is a sustainable crop production intensification technique that does not rely on the increased use of insecticides, its adoption and impact analysis is an important topic: it could potentially allow farmers to increase their mango productivity and incomes, not only without increasing their dependency on frequently unreliable agricultural input such as insecticides, but also, consequently, without increasing their impact on the surrounding environment.

The study reported here begins with an outline of our estimation strategy and model specification in section 2. Section 3 describes the study area and our data, and offers a definition of variables. The empirical results follow in section 4, while the conclusion of the study and its policy implications are presented in section 5.

2. Econometric approach

2.1 Evaluation strategy

An estimation of the impact of technology on development outcomes requires reliable estimate of the counterfactual situation of what would have happened to the technology adopters' development outcomes had they not adopted it. Such estimations are often a challenge in an observational study because adoption of the technology and selection the adopters themselves may not be random. Adopters may differ from non-adopters in terms of unobserved endowments (e.g. managerial ability, ambition, physical strength, and risk preference) and observable characteristics (e.g. resource endowments, proximity to input markets, access to extension, education and training), which simultaneously affect adoption and outcomes of interest. Also, farmers who adopt the technology might be more productive on average than those who do not adopt it because of differences in their endowments. In other words, if one observes higher expected outcomes, they may mistakenly be attributed to technology adoption rather than to individual farmer or farm attributes. Thus, unless corrective measures are taken to account for the non-randomness of adoption, a comparison of adopters with non-adopters is likely to result inconsistent outcomes estimates due to adoption.

We used two approaches to deal with the selection bias and treatment heterogeneity effect. In the first approach, we included a set of explanatory variables that affect both adoption decision and outcome variables. For the second, we developed a multinomial treatment endogenous switching regression (ESR) framework where the multinomial treatment variable was assumed to follow an ordered probit choice model structure. This is a variant of the instrumental variable approach to instrument the endogeneity of adoption using the inverse Mills ratio (Abdulai and Huffman, 2014; Carter and Milon, 2005; Kassie et al., 2017; Teklewold and Mekonnen, 2017). In the ESR framework, separate regressions are respectively estimated for adopters and non-adopters of IPM to estimate true effects of adoption through controlling for the endogeneity of adoption decisions, and through capturing the differential returns to covariates of adopters and non-adopters, and the interaction of adoption variables with regressors in the outcome equations. The separate regressions help to capture the slope effect of IPM adoption in addition to its intercept effect which was ignored in previous studies (Isoto et al. 2008; Fernando-cornejo, 1998; Sharma and Peshin, 2016). The implementation of this framework involves a two-stage econometric model to control for selection bias. The first stage consists of an adoption decision model, which enables one to estimate the combination of IPM practices as well as generate a variable to account for selection bias to be included in the second-stage model. The second stage consists of an impact model to estimate the effects of a bundle of IPM practices on outcomes, after controlling for selection bias and other covariates.

2.1.1 The first stage: Modelling the adoption decision

The multinomial treatment variable arises from the choice of bundles of IPM practices. Each farm household chooses one IPM practice (treatment) from J alternatives in a bundle of IPM practices (Table 1) that yields the highest benefit or utility to him/her. These alternatives are categorised as follows: (i) Category $j = 0$, for mango growers who use none of the IPM practices on their plots; (ii) Category $j = 1$, for mango growers who use only one such practice on their plots; (iii) Category $j = 2$, for mango growers who use a combination of two such practices on their plots; and (iv) Category $j = 3$, for mango growers who use a combination of three or more such practices on their plots. The use of more than three practices on a plot is limited.

As the term *integrated pest management* implies, it involves different practices to control insects and can be adopted to varying degrees. Naturally, the degree of integration can vary among adopters. In the case of multiple IPM practices adoption, defining a cut-off between adopters and non-adopters is a challenge in understanding derivers of intensity of adoption and conduct impact analysis using the continuous treatment impact evaluation approach. For example, it is difficult to use p*ercentage of area under IPM practices*, as is usually done in adoption literature, because many IPM practices (see Table 2) are not amenable to this type of definition. A case in point is that some treatments are applied directly to the mango trees themselves rather than their growth medium, the soil (e.g. traps, sprays and biopesticides), while others, such as burning and burying of infested mangoes and orchard sanitation, cannot be quantified in terms of land area. For this reason, following Teklewold et al. (2013) and Wollni et al. (2010), we use the number of IPM practices employed as our treatment variable to measure the extent of adoption.

Although the Poisson regression model is often applied where the treatment variable is count data, it is only appropriate when all events have the same probability of occurrence (Wollni et al., 2010). This may not apply in our case as the probability of adopting the first IPM practice could differ from the probability of adopting a second or third practice, given that, in the latter case, the farmer has already gained some experience from adopting the first IPM and has been more exposed to information about IPM practices. In this paper, therefore, the number of IPM techniques adopted by farmers is treated as an ordinal variable and used an ordered probit model in the estimation.

The ordered probit model for can be determined form a latent variable model (Wooldridge, 2010). Let I_j^* be the latent variable or utility that the individual farmer will generate with the choice of category $j = 0, \dots, J$. This utility is determined by –

$$I_j^* = X_i\beta_j + e_j,\ j = 0, \dots, J \tag{1}$$

The vector X in Equation 1 represents the set of household- and plot-level variables and location dummy variables with corresponding estimable parameters β; j is a categorical variable that describes choice of J alternative IPM practice bundle by farmers based on utilities I_j^*; and e is a disturbance term. The utility from adoption is not observed, but the decision of the i^{th} household to adopt a bundle of IPM practices (I) is mapped as follows:

$$I_j = \begin{cases} 0,\ if\ I_j{}^* \le c_1 \\ 1,\ if\ c_1 < I_j{}^* \le c_2 \\ \quad\quad . \\ \quad\quad . \\ J,\ if\ I_j{}^* > c_J \end{cases} \tag{2}$$

In Equation 2, c represents unknown cut points or threshold parameters identifying the boundaries of moving through the different levels of IPM practice adoption.

The probabilities that the actual adoption variable Z takes the different possible values conditional on X and the standard normal assumption of e are expressed as follows:

$$prob(I_j = 0|X_i) = \Phi(c_1 - X_i\beta_j) \tag{3a}$$

$$prob(I_j = 1|X_i) = \Phi(c_2 - X_i\beta) - \Phi(c_1 - X_i\beta_j) \tag{3b}$$

$$prob(I_j = 2|X_i) = \Phi(c_3 - X_i\beta) - \Phi(c_2 - X_i\beta_j) \tag{3c}$$

$$prob(I_j = 3|X_i) = 1 - \Phi(c_3 - X_i\beta_j) \tag{3d}$$

The symbol $\Phi(.)$ is the standard normal distribution function. The parameters β and c are estimated using the command “oprobit” available in STATA software.

2.1.2 The second stage: Modelling the impact of IPM on outcomes

The second stage of the econometric model to control for selection bias establishes the relationship between the outcome variables (*mango yield*, *mango net income*, and *insecticide use*) and a set of explanatory variables that include household, plot and location characteristics. The outcome regression models are estimated separately for non-adopters and for the various categories of adopters for each bundle of IPM interventions. The four treatments categories mentioned in section 2.1.1 result in four outcome equations. These are defined as follows for each IPM bundle intervention j:

$$\begin{cases} \text{Regime } 0: \; Y_{i0} = X_{i0}\beta_0 + \hat{\lambda}_{i0}\sigma_0 + \epsilon_{i0}, & if\ I_i = 0 \\ \text{Regime } j: \; Y_{ij} = X_{ij}\beta_j + \hat{\lambda}_{ij}\sigma_{ij} + \epsilon_{ij}, & if\ I_i = j \text{ for } j = 1, 2, 3 \end{cases} \tag{4}$$

The symbol Y represents outcome variables of the i^{th} mango grower for regime or category of j^{th} IPM practice. $j = 0$ refers to the non-adoption of any IPM practice, while $j = 1, 2, 3$ represents the adoption of one, two or three or more IPM practices, respectively. The vector X represents a set of observable explanatory variables comprising household, plot and location characteristics. The variable $\hat{\lambda}$ denotes the inverse Mills ratio for the adoption of each *j* bundle of IPM practices obtained from the estimation of Equation 3, and included in second-stage equations to purge selection bias due to unobservable characteristics. β and σ are parameters to be estimated, while σ is the coefficient that represents the covariance between the error terms of Equations 1 and 4.

Although the second-stage estimates are consistent, they have inefficient standard errors because of the two-stage nature of the estimation procedure. We use the bootstrap method to correct this problem. The other potential problem in the two-stage estimation is that the outcomes equations may not be identified if same set of explanatory variables are used in both stages. The selection correction terms ($\hat{\lambda}$)is non-linear, but it may not be sufficient to identify outcome equations and may lead to multi-collinearity problem. We thus consider additional instrumental variables that influence adoption decisions but not outcome variables. These include number of adopters known by respondents, membership in rural institutions, training on pest management, and availability of IPM, training on IPM and labor for its application are a constraint. We conduct a simple post-estimation test to check the validity of the instruments. The results confirm that, these variables are jointly significant in IPM adoption equation, but they are only weakly significant in one outcome equation out of the twelve outcome equations (See Tables A2-A3).

2.2 Average adoption effect

The estimation of the average adoption effect requires deriving the expected actual and counterfactual outcomes using Equation 4. The expected actual outcome that is observed from the data is computed for each bundle of IPM practices adopted, as follows:

$$\mathrm{E}(\mathrm{Y}_{\mathrm{i}j} | I_j = j) = \mathrm{X}_{\mathrm{i}j}\beta_j + \sigma_j \hat{\lambda}_{\mathrm{i}j},\ j = 1, 2, 3 \tag{5}$$

The *counterfactual outcome* is defined as what would have been the outcomes of IPM adopters if the returns on their characteristics had been the same as the returns on the characteristics of the non-adopters. The expected value of the counterfactual outcome for each bundle of IPM practices adopted is given as follows:

$$\mathrm{E}(\mathrm{Y}_{\mathrm{i}0} | I_j = j) = \mathrm{X}_{\mathrm{i}j}\beta_0 + \sigma_0 \hat{\lambda}_{\mathrm{i}j,}\ j = 1, 2, 3 \tag{6}$$

In Equation (6), β_0 and σ_0 are the regression coefficients obtained from the outcome equation for the regime $j = 0$ or non-adopters of IPM practices for mango farming (see Equation 4). The average adoption effect (ATT) for each bundle of IPM practices adopted is computed as –

$$\mathrm{ATT}_j = \mathrm{E}(\mathrm{Y}_{\mathrm{i}j} | I_j = j) - \mathrm{E}(\mathrm{Y}_{\mathrm{i}0} | I_j = j) = \mathrm{X}_{\mathrm{i}j}(\beta_\mathrm{j} - \beta_0) + \hat{\lambda}_{\mathrm{i}j}(\sigma_j - \sigma_0),\ \mathrm{j} = 1, 2, 3 \tag{7}$$

In this equation, the terms $\mathrm{X}_{\mathrm{i}j}(\beta_\mathrm{j} - \beta_0)$ and $\hat{\lambda}_{\mathrm{ij}}(\sigma_\mathrm{j} - \sigma_0)$ respectively denote the contribution of observed and unobserved heterogeneities to ATT.

2.3 Measuring the impacts of IPM adoption on the environment and human health

While the change in the volume of insecticide used due to the adoption of IPM is a useful indicator of environmental impact, it is an imperfect measure because it does not capture the differences in specific insecticide products used by farmers in IPM and non-IPM farming systems (Table A4). Clearly, such products may differ in terms of levels of toxicity and persistence. Therefore, to provide a more robust measure of the impact of IPM on human health and the environment, we use the environmental impact quotient (EIQ) developed by Kovach et al. (1992). The EIQ involves three main components: *farm worker/producer*, *consumer*, and *environmental effects*. The EIQ measures the impact of each specific insecticide's active ingredients by assigning an equal weight to each of the three main components (Fernandez-Cornejo, 1998). The EIQ value for each active ingredient of the insecticide ($EIQ_{insecticides}$) is computed as follows:

$$EIQ_{insecticides} = (EIQ_{farm\,worker} + EIQ_{consumer} + EIQ_{environment})/3$$

The *farm worker/producer* component, defined as the effect on the applicators and pickers due to exposure to pesticides, is calculated as follows (Kovach et al., 1992):

$$EIQ_{farmer\,worker} = C * [(DT * 5) + (DT * P)] \quad (8)$$

The *consumer* component is the summation of the consumer exposure potential and the potential groundwater leaching effect of insecticides, measured as follows (ibid.):

$$EIQ_{consumer} = C * [((S + P)/2) * SY + L] \quad (9)$$

The *environmental effect* of insecticide is calculated from its toxicity to fish, birds, bees and beneficial arthropods, leaching and surface loss potential. The ecological effects are measured as follows (ibid.):

$$EIQ_{environmental} = (F * R) + (D * ((S + P)/2 * 3) + (Z * P * 3) + (B * P * 5) \quad (10)$$

The symbol C represents chronic toxicity; DT represents dermal toxicity; P represents plant surface half-life; S represents soil half-life; SY represents systemicity; L represents leaching potential; F represents fish toxicity; R represents surface soil loss potential; D represents bird toxicity; Z represents bee toxicity; and B represents beneficial arthropod toxicity.

To compute the environmental footprint of IPM and non-IPM mango production systems, the field EIQ (FEIQ) was calculated by multiplying the reference EIQ (Equation 10), dose pre unit area and the percent active ingredient (a.i.) defined below:

$$FEIQ = EIQ * \%\,of\ active\ ingredient * dose\ per\ unit\ area \quad (12)$$

The FEIQ values for different active ingredients are summed by IPM adoption status and compared with non-adoption status to measure the IPM impacts on human health and the environment.

3. Data and summary statistics

The data utilised in this study was obtained from four of the major mango-growing counties in eastern Kenya, namely Embu, Machakos, Makueni and Meru (Figure 1). The data collection followed a multi-sampling framework. As a first step, the four-major mango producing counties of the eastern region were purposively selected following icipe's previous dissemination and promotional activities of the mango fruit fly IPM practices. The next step was to select mango-growing wards and villages in each county, in collaboration with the local agricultural extension workers. Thereafter, we conducted a census of mango growers in the selected wards and villages who had ten or more mango trees in each village. Then, well-trained enumerators – who understood the local language and were supervised by an icipe researcher – selected and interviewed a random sample of mango growers proportional to the listed number of such growers in each village. This led to a final sample of 660 mango-growing households being successfully interviewed. After data cleaning, we remain with a sample of 633 mango growers for regression analysis. However, we use the 660 sample for computing the human health and environmental impacts of IPM as all the parameters to compute the field use EIQ are available. Data collection using a semi-structured questionnaire took place in November and December 2016, and referred to the preceding mango season (May 2015–April 2016).

Detailed information on six broad categories of control variables was collected for analysis during the survey. These variables included household socio-economic characteristics, social capital and network, institutional capital, plot characteristics, investment and shocks, technology, and location. Among the socio-economic indicators, livestock ownership, mango income and mango production loss were considered in addition to demographic characteristics such as the age, sex and education of the household head, and family size. The social capital and network variables included membership of rural institutions and associations, and the number of IPM adopters in the village known by respondents that could facilitate access to information and increase farmers' exposure to IPM practices. Institutional capital was captured using questions related to access to different development services (extension, training, credit and markets). Plot characteristics as well as investment and shock variables involved soil fertility indicators; insecticide, fungicide and fertiliser use, among others; the incidence of insects and diseases; and the severity of insect infestations. The technology variables covered the number of IPM practices adopted, farmers' perception of the availability of IPM techniques, and whether insufficient labour and training were constraints to the use of IPM practices. Location dummies were included in the analysis to capture unobserved agro-climatic and socio-economic heterogeneities among the sample counties.

Table 1 lists the definitions and summary statistics for all covariates used in the empirical analysis. The choice of these variables was based on existing agricultural technology adoption and impact studies (e.g. Chaves and Riley, 2001; Fernandez-Cornejo, 1998; Gautam et al., 2017; Isoto et al., 2008; Kassie et al., 2015, 2017; Korir et al., 2015; Sanglestsawai et al. 2015; Sharma and Peshin, 2016; Sharma et al., 2015).

[Table 1 about here]

Regarding adoption variables, as indicated in Table 2, mango growers reported using several IPM practices to suppress fruit-fly infestations and reduce the damage they caused. The dominant practices included fruit-fly traps, food bait spray and burning or burying fallen fruit infested with fruit-fly larvae. About 31% of the sample plots were received neither none of the IPM treatments, while 33%, 24% and 7% of plots had respectively been treated by either one, two, or three or more IPM interventions. The number of plots with more than three IPM interventions were few; therefore, they were merged with plots that had been treated with three IPM interventions. The detailed description and purpose of each IPM practice are available in Ekesi and Billah (2007). Table 2 offers a definition of the outcome and adoption variables, together with their corresponding summary statistics.

[Table 2 about here]

Outcome indicators that represent the economic and environmental benefits and health of farmers include mango yield (pieces of fruit per tree), mango net income (Kenyan Shillings/KSh per tree), insecticide use (litres per tree) and EIQ. Production costs deducted from gross mango revenue comprise fertiliser, pesticides and hired labour. Farmers count mango and make mango transactions in terms of pieces of fruit; thus, the unit for yield is pieces. Also, since farmers' chemical insecticide spray only targets trees, the tree is used as a unit of measure for insecticide use instead of a mango production area. The average number of mango trees per household is about 101. The survey data show that mango growers sprayed their mango trees four times during the 2016 season. On average, mango growers were losing 30% of their mango production due to fruit flies. Given that rigorous analysis is still required, the unconditional statistics nonetheless suggest that IPM adoption seems to generate more benefits when compared with non-adoption (Table 3), and that such benefits are greater at higher levels of IPM adoption.

[Table 3 about here]

4. Results and discussion

4.1 Factors that influence the adoption of IPM

The results of the first stage ordered probit model are presented in table 4. The findings suggest that the most crucial factors in deriving the use of IPM practices are as follows: (1) the number of adopters that respondents know in their vicinity, (2) membership of rural institutions, and (3) participation in insect pest management training. These factors point to the knowledge-intensive nature of IPM techniques. The result on the role of information in enhancing adoption of IPM practices is in line with previous studies (Allahyari et al., 2016; Chaves and Riley, 2001; Kabir and Rainis, 2015; Timprasert et al., 2014).

[Table 4 about here]

Furthermore, as the explanatory variables in table 4 show, the likelihood of adoption increases when farmers have a higher income share from mango production, and when the severity of fruit-fly infestation increases. We also find plot distance from the respondent's residence and a lack of training in IPM reduces the probability of using IPM practices.

The fact that access and exposure to information shape IPM adoption tendencies implies that policies aimed at enhancing information delivery mechanisms could make a difference in farmers' success in terms of adopting such practices.

4.2 Impacts of IPM technologies

4.2.1 Impacts on mango yield and mango net income

For brevity's sake, the second stage regressions results are not discussed here; they can, however, be consulted in the Appendix presentations (Tables A1–A3).

Table 5 summarises the results on how each bundle of IPM practices adopted impacts on mango yield and mango net income. IPM-adopting farms have higher mango yields and incomes, which both increase with the intensity of adoption. Thus, the adoption of one, two, or three or more IPM practices provides yield gains of 6.3%, 28.9% and 100%, respectively. These percentages are obtained by dividing ATT by the average counterfactual yield. The impact on income shows a similar trend as that exposed by the yield results. These findings agree with the descriptive statistics results (Table 3) as well as previous studies that have provided evidence of increasing yield and income due to IPM adoption (Fernandez-Cornejo, 1996; Muriithi et al., 2016; Owusu and Kakraba, 2015).

[Table 5 about here]

4.2.2 Impacts on human health and the environment

For the sake of brevity again, details of the data associated with this section are available in the Appendix. Appendix Table A4 provides the different insecticides' active ingredients along with their trade names used in mango production, while Table A5 presents the EIQ values of the active ingredients.

The data analysis shows that the estimated change in insecticide use registers at 68.1% for the adoption of one IPM practice, 65.1% for the adoption of two, and 89.3% for the adoption of three or more IPM practices. The change is revealed when one compares how much insecticide respondents used while applying one or more IPM techniques with how much they would have used if they had not applied any of the IPM components (Table 5). Owing to pesticide toxicity, fewer insecticide applications per tree are assumed to result in concomitantly lower negative impacts on human health, the environment and food safety. Our results are consistent with those of Fernandez-Cornejo (1998), Rejesus et al. (2009) and Sanglestsawai et al. (2015), where IPM adoption was also shown to reduce pesticide use.

In terms of insecticide toxicity levels, the analysis reveals that about 8% of mango plots were treated with pesticides that were highly hazardous, while 81% received treatment with moderately hazardous ones (Table 6). Pesticides in these two categories impose greater human health and environmental problems than any of the other categories listed (Jeyaratnam, 1990; Krishna and Qaim, 2008). Of all the mango plots treated with insecticide from the two most hazardous categories, fewer occurred among those where IPM was adopted – except in the case of plots adopting only one IPM practice.

[Table 6 about here]

Lower insecticide quantities and hence, lower levels of insecticide toxicity are reflected in a significantly lower FEIQ value on IPM plots (Table 7). The FEIQ value decreased by 35%, 30% and 40% for the respective adoption of one, two, or three or more IPM practices (Table 7). Looking at the FEIQ value, the impact insecticide use, notably associated with no IPM techniques being employed, was highest on the environment, then on farm workers' health and, after that, consumers' health (Table 7). Insecticides' environmental impact can be expected to take its toll on agricultural productivity, which will aggravate farmers' food insecurity.

[Table 7 about here]

5. Conclusion and policy implications

Mango fruit-fly infestation is a major threat to the fruit production farming system in sub-Saharan Africa because it undermines food security and poverty reduction efforts. However, the synthetic insecticides being used by farmers to reduce such infestations are causing environmental and human health problems, and pests are developing resistance to these toxins. An alternative infestation control strategy being employed is the integrated pest management (IPM) approach, which involves reducing the use of synthetic pesticides. The IPM approach offers enhanced economic benefits to farmers, while improving food safety and minimising risks to human health and the environment. However, there is limited rigorous study on the economic impacts of IPM in the context of Africa, and to our knowledge no study to date has analysed the environmental and human health impacts of IPM adoption targeting the mango fruit fly. This article examines the impacts of different combinations of IPM practices on mango yield, insecticide use, mango net income from mango farming, human health, and the environment. A multinomial treatment switching regression model was used to address any selection bias that could have arisen from both observed and unobserved heterogeneities, while an environmental impact quotient was employed to assess the impacts of IPM on human health and the environment.

Our findings confirm the significant role that IPM adoption plays in controlling mango fruit fly, namely that mango yields and incomes are improved, insecticide use is reduced, and the human health and environmental risks effect of insecticide use is ameliorated. These positive outcomes increase substantially as farmers progress from using one to multiple IPM practices. The study findings reinforce the need for governments and their development partners to encourage and support smallholder farmers to adopt a bundle of IPM practices that not only enhance mango production, but do so at less cost to the environment and human health.

Moreover, the discovery that exposure to IPM practices – as measured by the number of IPM adopters that farmers know in their vicinity, membership of rural institutions, and training in pest management as well on IPM – has such positive and significant effects suggests that strengthening existing and establishing further information delivery mechanisms are essential for facilitating and scaling up IPM adoption.

Nonetheless, despite the interesting positive impact stories of IPM adoption, the current study has some limitations that could be tackled in future research. Firstly, the study is based on cross-sectional data which may not capture the cyclical nature of pest invasion and in relation to the dynamics of IPM adoption and outcomes. Secondly, a tree's mango yield depends on its age; in our case, however, we used only two age categories: young trees that had not yet begun producing, and mature trees that had already begun. However, it is important to further disaggregate matured trees by age interval to capture mango yield data more accurately.

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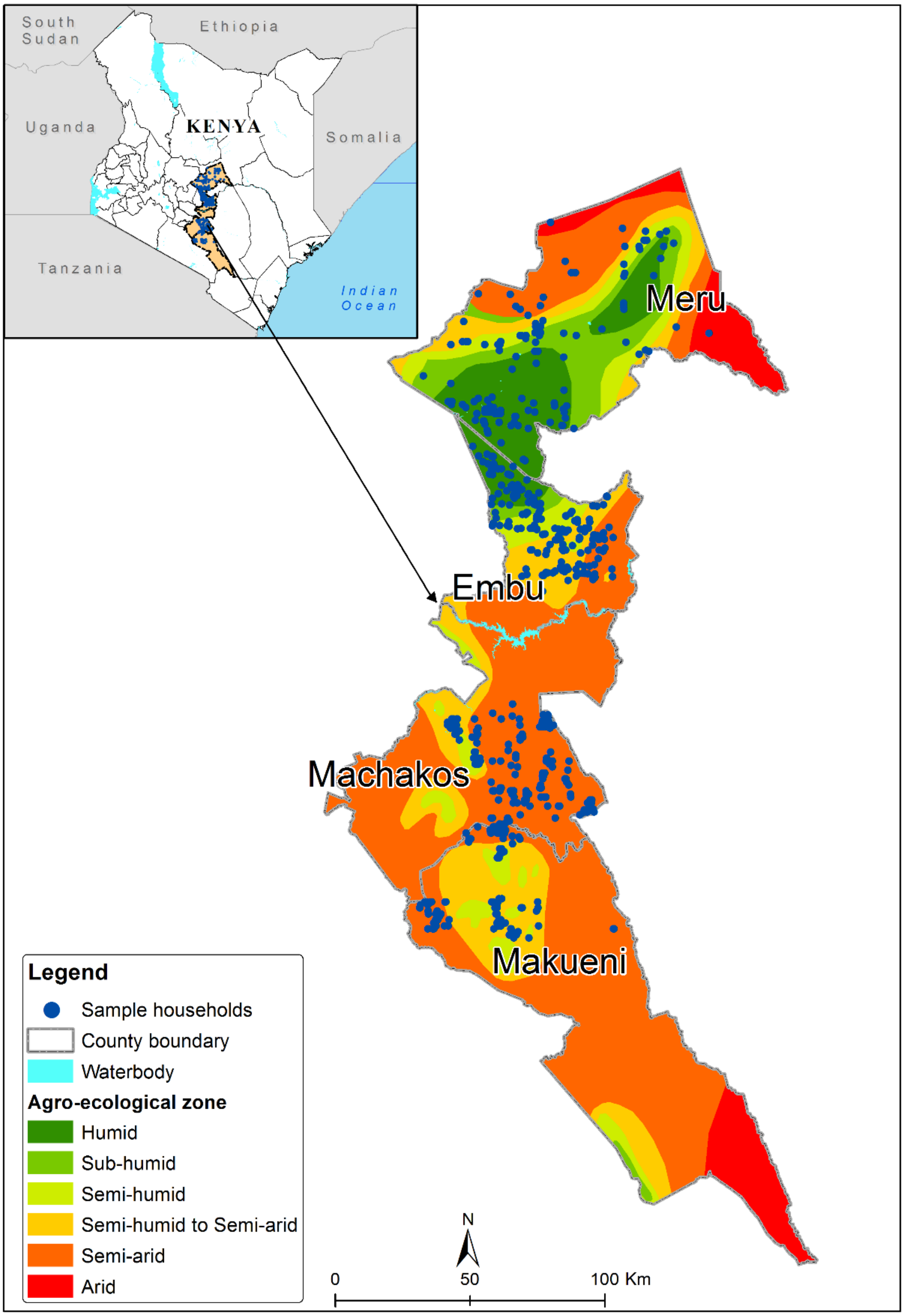

Figure 2: Study areas and sample households' distribution

Table 1: Definition and summary of variables (mean)

Variables	Description	Full sample	non-IPM adopters	One IPM adopters	Two IPM adopters	Three or more IPM adopters
Family size	Number of family members in a household	4.76	5.17	4.74	4.64	3.99
Sex	1 if household head is male; 0 otherwise	0.92	0.90	0.91	0.94	0.95
Age	Household age in years	57.67	56.87	57.14	58.77	58.86
Education	Education, in years, of household head	9.66	9.45	9.85	9.59	9.66
Livestock	Livestock ownership in tropical livestock units	3.16	3.49	3.48	2.96	1.84
Occupation	1 if main household occupation is farming; 0 otherwise	0.73	0.65	0.75	0.74	0.78
Extension visits	1 if household was visited by an extension officer in the last three years; 0 otherwise	0.52	0.38	0.49	0.64	0.68
Training on insect pest management	1 if household received training on insect pest management; 0 otherwise	0.67	0.48	0.68	0.80	0.82
Membership	Number of rural institutions to which household belongs	2.41	2.21	2.42	2.43	2.80
Number of adopters	Number of IPM adopters known by respondents in a village	9.33	2.38	6.51	9.73	11.77
Fungicide use	1 if mango plot received fungicide; 0 otherwise	0.53	0.58	0.56	0.50	0.43
Insecticide use	1 if mango plot received insecticide; 0 otherwise	0.85	0.91	0.84	0.80	0.78
Insecticide unit price	Insecticide unit price (KSh/liters)		3200.47	3607.60	3380.27	3729.95
Unavailability of IPM	1 if unavailability of IPM technology is a constraint; 0 otherwise	0.73	0.51	0.81	0.81	0.74
Insufficient training a constraint	1if insufficient training on IPM is a constraint; 0 otherwise	0.43	0.41	0.55	0.36	0.89
Insufficient labour a constraint	1 if insufficient labour for IPM application is a constraint; 0 otherwise	0.12	0.08	0.17	0.12	0.11

Variables	Description	Full sample	non-IPM adopters	One IPM adopters	Two IPM adopters	Three or more IPM adopters
Intercropping	1 if mango plot intercropped with other crops; 0 otherwise	0.81	0.80	0.79	0.81	0.89
Distance to plot	Plot distance from residence in walking minutes	6.07	6.91	5.56	6.06	5,57
Land quality	1 = Good, 2 = Medium, 3 = Low	1.64	1.76	1.68	1.50	1.46
Mango income	Proportion of mango income to annual household income	20.37	18.87	20.80	22.58	27.17
Mango loss	Proportion of mango production loss	30.00	28.84	31.95	27.89	24.72
High fruit-fly infestation (reference dummy)	1 if farmer reports fruit-fly infestation is high; 0 otherwise	0.56	0.63	0.62	0.49	0.39
Medium fruit-fly infestation	1 if farmer reports fruit-fly infestation is medium; 0 otherwise	0.24	0.16	0.23	0.24	0.43
Low fruit-fly infestation	1 if farmer reports fruit-fly infestation is low; 0 otherwise	0.19	0.19	0.15	0.27	0.19
Disease infestation	1 if farmer reports mango disease; 0 otherwise		0.96	0.96	0.95	0.97
Machakos (reference dummy)	1 if Machakos County; 0 otherwise	0.26				
Embu	1 if Embu County; 0 otherwise	0.28	0.12	0.23	0.42	0.51
Meru	1 if Meru County; 0 otherwise	0.24	0.13	0.29	0.26	0.35
Makueni	1 if Makueni County; 0 otherwise	0.22	0.40	0.22	0.11	0
Observations		633	182	219	158	74

Table 2: Adoption of fruit fly IPM practices for suppression of fruit fly at plot level

Individual IPM practice	Number of plots treated with IPM	Percentage of plot treated with IPM (%)
Fruit-fly traps/male annihilation technique	394	52.39
Food bait spray	105	13.96
Biopesticides	18	2.39
Burning or burying fallen infested fruits	291	38.7
Orchard sanitation using an augmentorium	10	1.33
Fruit-wrapping bags	19	2.53
Biological control via parasitoids	14	1.86
Smoking repellent herbs/spraying traditional concoction	56	7.45
Adoption of a bundle of IPM practices		
Non-adoption	235	31.25
Adoption of one IPM practice	247	32.85
Adoption of two IPM practices	181	24.07
Adoption of three or more IPM practices	65	8.64

Source: Households Survey 2016

Table 3: Outcome variables (mean)

Variables	Total sample	Non-adoption of IPM practices	Adoption of one IPM practice	Adoption of two IPM practices	Adoption of three or more IPM practices
Mango yield (piece per tree)	148.92 (125.09)	133.11 (118.91)	145.72 (124.20)	157.26 (126.70)	179.51 (134.43)
Mango net income (KSh per tree)	1126.09 (1125.70)	1009.07 (986.82)	1105.08 (1020.99)	1148.51 (1003.45)	1428.235 (1133.81)
Insecticide use (litres per tree)	0.033 (0.083)	0.040 (0.087)	0.023 (0.044)	0.045 (0.122)	0.024 (0.052)
Field EIQ	14.32 (36.63)	22.65 (1.22)	14.74 (0.93)	15.77 (1.14)	13.53 (1.31)
Number of observations	633	182	219	158	74

Note: Standard deviation in parentheses

Table 4: Factors that influence the adoption of a bundle of IPM practices: Ordered probit results

Variable	Coefficient
Family size	-0.01
	(0.024)
Sex	-0.13
	(0.244)
Ln(Age)	0.13
	(0.230)
Education	0.01
	(0.013)
Livestock	-0.02
	(0.017)
Occupation	-0.05
	(0.112)
Extension visits	0.11
	(0.100)
Training on pest management	0.26**
	(0.105)
Ln(Membership)	0.06*
	(0.035)
Ln(Number of adopters)	0.21***
	(0.023)
Insecticide use	-0.03
	(0.125)
Unavailability of IPM	0.10
	(0.119)
Insufficient training a constraint	-0.33***
	(0.099)
Insufficient labour a constraint	0.15
	(0.133)
Intercropping	0.22*
	(0.117)

Variable	Coefficient
Plot distance	-0.01***
	(0.003)
Ln(Mango income)	0.11**
	(0.044)
Ln(Mango loss)?	-0.09
	(0.069)
Fruitflies_infestation2	-0.38***
	(0.144)
Fruitflies_infestation3	-0.02
	(0.146)
Embu	0.83***
	(0.134)
Meru	0.47***
	(0.134)
Makueni	-0.28*
	(0.149)
Joint significance of instruments, chi2	128.30p=000)***
Wald chi^2(23)	259.94***
Pseudo R^2	0.2024
Observations	633

Note: Robust standard errors in parentheses; * p<0.1, ** p<0.05, *** p<0.01

Table 5: Mango yield and income effect of IPM adoption

Adoption status	Outcome	Mango yield (pieces/tree)	Insecticide use (litre/tree)	Net mango income (KSh/tree)
One IPM practice	$\mathrm{E}(\mathrm{Y}_{i1}\|j=1)$	103.01	0.023	1105.08
	$\mathrm{E}(\mathrm{Y}_{i0}\|j=1)$	96.91	0.072	1018.17
	$ATT=\mathrm{E}(\mathrm{Y}_{i1}\|j=1)-\mathrm{E}(\mathrm{Y}_{i0}\|j=1)$	6.10 (5.15)	-0.049 (0.005)***	86.91 (42.21)**
Two IPM practices	$\mathrm{E}(\mathrm{Y}_{i2}\|j=2)$	114.99	0.045	1148.51
	$\mathrm{E}(\mathrm{Y}_{i0}\|j=2)$	89.24	0.129	872.01
	$ATT=\mathrm{E}(\mathrm{Y}_{i2}\|j=2)-\mathrm{E}(\mathrm{Y}_{i0}\|j=2)$	25.75 (7.37)***	-0.084 (0.013)***	276.50 (73.61)***
Three ?or more? IPM practices	$\mathrm{E}(Y_{i3}\|j=3)$	142.91	0.024	1428.24
	$\mathrm{E}(\mathrm{Y}_{i0}\|j=3)$	71.22	0.233	596.13
	$ATT=\mathrm{E}(\mathrm{Y}_{i3}\|j=3)-\mathrm{E}(\mathrm{Y}_{i0}\|j=3)$	71.68 (13.09)***	-0.208 (0.025)***	832.10 (145.76)***

Note: Standard errors in parentheses; ** *p*<0.05, *** *p*<0.01; Y denotes mango yield, income and insecticide use; KSh = Kenyan Shilling

Table 6: Distribution of mango plots by level of adoption and class of insecticide toxicity

World Health Organization (WHO) class of insecticide toxicity	Non-adoption of IPM	Adoption of one IPM practice	Adoption of two IPM practices	Adoption of three or more IPM practices	Total
Extremely hazardous (Ia)	–	–	–	–	–
Highly hazardous (Ib)	1.31	4.48	1.87	0.56	8.21
Moderately hazardous (II)	25.93	26.68	19.59	8.96	81.16
Slightly hazardous (III)	–	0.37	0.19	0.19	0.75
Unlikely to present acute hazard in normal use (U)	0.93	0.37	0.19	0.56	2.05

Note: WHO (2010) classification adopted

Table 7: Estimates of the impact of IPM adoption on human health and the environment

Number of IPM practices adopted	FEIQ	Risk effect (%)	Consumers	Risk effect (%)	Farm workers	Risk effect (%)	Environment	Risk effect (%)
0	22.65	-	4.53	-	7.31	-	56.09	-
1	14.73	-34.96	4.50	-0.66	4.78	-34.61	34.90	-37.78
2	15.77	-30.38	4.19	-7.51	4.95	-32.28	38.16	-31.97
3+	13.53	-40.26	3.57	-21.19	4.25	-41.86	32.76	-41.59

Note: Risk effect is computed by dividing the difference between the EIQ values for adopters and non-adopters by non-adopters EIQ value.

Appendix

Table A1: Estimates of determinants of mango yield (dependent variable – Ln(Pieces per tree))

Variables	Non-adoption of IPM practices	Adoption of one IPM practice	Adoption of two IPM practices	Adoption of three or more IPM practices
Family size	0.04	0.03	-0.03	0.13*
	(0.037)	(0.042)	(0.067)	(0.070)
Sex	0.33	-0.18	-0.25	-1.27***
	(0.260)	(0.296)	(0.427)	(0.452)
Ln(Age)	-0.94***	-0.26	-0.09	0.16
	(0.345)	(0.346)	(0.446)	(0.720)
Education	-0.08***	-0.01	0.00	-0.06
	(0.025)	(0.021)	(0.026)	(0.040)
Hired labour	-0.07	-0.14	0.14	-0.28
	(0.198)	(0.161)	(0.210)	(0.314)
Ln(Distance to village market)	-0.28***	-0.03	0.00	0.12
	(0.106)	(0.095)	(0.124)	(0.216)
Livestock	-0.01	0.01	0.04	0.17*
	(0.029)	(0.026)	(0.028)	(0.097)
Foliar fertiliser use	-0.03	0.25	0.13	0.19
	(0.186)	(0.179)	(0.244)	(0.275)
Insecticide use	0.40	0.02	0.02	-0.08
	(0.349)	(0.228)	(0.247)	(0.399)
Fungicide use	-0.26	-0.15	-0.02	0.34
	(0.185)	(0.192)	(0.214)	(0.273)
Land quality	0.36**	0.01	-0.18	-0.03
	(0.159)	(0.135)	(0.192)	(0.249)
Intercropping	0.15	-0.37**	-0.49**	-0.56
	(0.272)	(0.158)	(0.189)	(0.522)
Plot distance	0.00	-0.01	-0.02*	-0.01
	(0.004)	(0.005)	(0.011)	(0.013)
High fruit-fly infestation	-0.13	-0.04	0.06	0.45

Variables	Non-adoption of IPM practices	Adoption of one IPM practice	Adoption of two IPM practices	Adoption of three or more IPM practices
	(0.233)	(0.229)	(0.195)	(0.473)
Medium fruit-fly infestation	-0.38	0.01	-0.16	0.62
	(0.298)	(0.228)	(0.254)	(0.373)
Plot suffered from diseases	0.86*	0.36	-0.48	-1.52**
	(0.499)	(0.455)	(0.342)	(0.593)
County dummies	Yes	Yes	Yes	Yes
Inverse Mills ratio	Yes	Yes	Yes	Yes
Constant	-89.60	-374.92**	175.07	-404.09
	(310.239)	(172.848)	(148.476)	(1,378.212)
Joint significance of instruments, F-test	1.12(p=0.355)	1.71(p=0.109)	0.96(p=0.463)	0.62(p=0.735)
Observations	182	219	158	74
R-squared	0.22	0.19	0.20	0.30

Note: Robust standard errors in parentheses; * p<0.1, ** p<0.05, *** p<0.01

Table A2: Estimates of determinants of mango net income (KSh per tree)

Variables	Non-adoption of IPM practices	Adoption of one IPM practice	Adoption of two IPM practices	Adoption of three or more IPM practices
Family size	-4.76	12.16	48.53	94.80
	(33.007)	(44.215)	(55.229)	(85.739)
Sex	161.28	-335.01	-283.88	-1,396.92**
	(212.928)	(245.377)	(431.752)	(588.578)
Ln(Age)	-785.57**	-209.10	151.04	242.81
	(327.907)	(381.883)	(414.503)	(871.477)
Education	-56.83***	-8.18	4.82	-81.15*
	(19.857)	(19.082)	(25.234)	(43.146)
Ln(Distance to village market)	-193.19**	-36.57	19.32	90.43
	(86.444)	(100.667)	(125.408)	(248.522)
Livestock	8.44	-4.84	0.30	291.24**
	(22.647)	(24.874)	(30.249)	(129.158)
Foliar fertiliser use	-81.20	309.54*	108.02	166.28
	(158.310)	(180.912)	(199.404)	(333.213)
Insecticide use	108.77	-107.14	-124.30	-492.21
	(306.731)	(206.933)	(208.129)	(388.938)
Fungicide use	-241.75	-161.20	-87.31	354.61
	(176.556)	(184.475)	(201.785)	(319.452)

Variables	Non-adoption of IPM practices	Adoption of one IPM practice	Adoption of two IPM practices	Adoption of three or more IPM practices
Land quality	247.38	-69.57	-100.04	-89.63
	(151.435)	(129.682)	(174.096)	(305.651)
Intercropping	-90.60	-168.55	-422.20*	-630.47
	(204.964)	(164.345)	(217.785)	(599.190)
Plot distance	-0.82	-3.85	-8.81*	-27.10*
	(3.533)	(3.424)	(4.912)	(13.704)
Ln(Proportion of mango income loss)	-108.29	-38.66	-99.17	-141.50
	(120.432)	(104.511)	(123.393)	(209.616)
High fruit-fly infestation	-91.81	-56.74	270.85	787.01
	(260.490)	(223.260)	(219.309)	(635.681)
Medium fruit-fly infestation	-82.48	-33.17	235.72	1,117.07**
	(288.841)	(238.621)	(214.010)	(489.004)
Plot suffered from diseases	642.65*	593.96**	-349.86	-1,785.95***
	(336.592)	(229.527)	(375.003)	(563.514)
County dummies	Yes	Yes	Yes	Yes
Inverse Mills ratio	Yes	Yes	Yes	Yes
Constant	-110,371.31	-412,303.43**	244,351.34	-1847733.57
Joint significance of instruments, F-test	1.18(p=0.316)	1.95(0.064)*	1.16(p=0.329)	0.88(p=0.527)
	(298,079.086)	(167,246.460)	(156,536.186)	(159,948.781)

Variables	Non-adoption of IPM practices	Adoption of one IPM practice	Adoption of two IPM practices	Adoption of three or more IPM practices
Observations	182	219	158	74
R-squared	0.18	0.17	0.20	0.34

Note: Robust standard errors in parentheses; * p<0.1, ** p<0.05, *** p<0.01

Table A3: Estimates of determinants of insecticide use

Variables	Non-adoption of IPM practices	Adoption of one IPM practice	Adoption of two IPM practices	Adoption of three or more IPM practices
Family size	-0.00	-0.00	-0.01**	0.00
	(0.003)	(0.002)	(0.005)	(0.003)
Sex	-0.00	0.01	-0.01	0.01
	(0.016)	(0.007)	(0.033)	(0.018)
Ln(Age)	0.01	-0.01	-0.05	-0.02
	(0.025)	(0.018)	(0.061)	(0.027)
Education	0.00	0.00	0.00	0.00
	(0.002)	(0.001)	(0.003)	(0.002)
Livestock	-0.00***	-0.00***	-0.00	-0.01
	(0.002)	(0.001)	(0.004)	(0.005)
Ln(Distance to pesticide dealer)	0.01	0.01*	-0.00	0.02**
	(0.006)	(0.005)	(0.007)	(0.008)
Foliar fertiliser use	0.02	0.00	-0.01	-0.00
	(0.019)	(0.009)	(0.020)	(0.012)
Ln(Insecticide unit price)	0.00	0.00***	0.00*	0.00**
	(0.001)	(0.001)	(0.002)	(0.001)
Intercropping	0.03**	0.01**	-0.01	0.03
	(0.013)	(0.007)	(0.026)	(0.023)

Variables	Non-adoption of IPM practices	Adoption of one IPM practice	Adoption of two IPM practices	Adoption of three or more IPM practices
Plot distance	0.00	-0.00	0.00	0.00
	(0.000)	(0.000)	(0.001)	(0.001)
High fruit-fly infestation	-0.05**	-0.02**	0.03	-0.02
	(0.021)	(0.007)	(0.022)	(0.027)
Medium fruit-fly infestation	-0.03	-0.00	0.02	-0.03
	(0.031)	(0.012)	(0.024)	(0.024)
Plot suffered from diseases	-0.02	0.00	-0.04*	0.04
	(0.016)	(0.014)	(0.021)	(0.028)
County dummies	Yes	Yes	Yes	Yes
Inverse Mills ratio	Yes	Yes	Yes	Yes
Constant	22.37	-2.86	-16.58	25.49
	(31.493)	(5.542)	(19.830)	(56.399)
Joint significance of instruments, F-test	0.46(=0.859)	1.15(0.332)	1.08(p=0.379)	0.95(p=0.479)
Observations	182	219	158	74
R-squared	0.19	0.16	0.14	0.27

Note: Robust standard errors in parentheses; * p<0.1, ** p<0.05, *** p<0.01

Table A4: Active ingredient and trade names of the insecticide used by mango growers

Active ingredient	Trade names
Abamectin	DYNAMEC, NOCBECTIN, ROMECK
Acephate	ORTHENE
Acetamiprid	ASCESTRIM AMIRAN, KINGCODE, ELIDE, TRIGGER, TWIGA EYES
Alfacypermethrin	AFLA CYPER, ALBAZ, ALPHA GUARD, ALPHA KILL, ALPHA SCOP, BESTON, BESTOX, TATA ALFA
Beta-Cyfluthrin	BATAFOSE, BULL DOCK
Carbaryl	SEVIN
Carbendazim	CHARIOT, ZYBAN
Carbosulfan	MARSHAL
Chlorpyrifos	AGRO-PYRIFOS, DASPAN, DASPAN, DUST PAN, DUSTPAN, MURSDAN, RANGER, RANGER, SULBAN
Cypermethrin	CYCLON, NURELLE
Deltamethrin	ATOM, DESIS
Diazinon	DIAZOL
Dicofol	ACARIN
Difenoconazole	SCORE
Dimethoate	DIMEKIL, DIMETHOATE
Endosulfan	THIONEX
Fenitrothion	SUMITHION
Imidacloprid	CONCORD 20SL, EMERALD, THUNDER
Lambdacyhalothrin	DUDUTHRIN, HALOTHRINE, JACKPOT, KARATE, PENTAGON, VENDEX
Malathion	OSHOTHION
Mancozeb	OSHO, RIDOMIL
Methomyl	AGRINATE
Omethoate	FOLIMAT
Profenofos	POLYMART, POTRIN P, PROFILE 440EC
Propamocarb hydrochloride	PLANTON
Pyriproxyfen	PROFANE
Thiamethoxam	ACTARA, ENGEO
Triadimefon	BAYLETON
Trifloxystrobin	NATIVO

Table A5: Insecticide used and environmental impact quotient (EIQ) results per IPM-adopter category

Active ingredient	Base EIQ[1]	Application rate (lb/acre)	Percentage of active ingredient (%AI)	Total field EIQ (per acre-$FEIQ_i$)	Field EIQ components (per acre)			Area applied (acre-A_i)	Area applied (%-W_i)
					Consumer ($CFEIQ_i$)	Worker ($WFEIQ_i$)	Environmental ($EFEIQ_i$)		
NON-ADOPTERS OF IPM PRACTICES									
Abamectin	34.7	0.78	1.80	0.50	0.10	0.20	1.20	4.25	1.27
Acephate	24.9	0.66	97.00	16.00	8.00	9.60	30.30	1.00	0.30
Acetamiprid	28.7	3.20	20.00	18.40	4.40	4.70	46.10	4.00	1.19
Alfacypermethrin	36.4	5.66	3.84	7.90	1.30	3.00	19.40	74.41	22.19
Azadirachtin	12.1	n/a	n/a[2]	n/a	n/a	n/a	n/a	n/a	n/a
Beta-Cyfluthrin	31.6	16.33	2.50	12.90	1.00	2.80	34.80	12.38	3.69
Carbaryl	22.7	1.62	85.00	31.20	7.60	20.60	61.60	1.10	0.33
Carbendazim	50.5	0.50	50.00	12.50	10.00	6.20	21.30	2.00	0.60
Carbosulfan	47.3	1.51	35.00	24.90	4.40	3.60	66.80	8.50	2.54
Chlorpyrifos	26.9	11.66	48.00	150.20	11.20	36.60	405.90	9.00	2.68
Cypermethrin	36.4	5.53	10.00	20.10	3.30	7.60	49.40	62.83	18.74

[1] The base EIQ values for individual active ingredients were derived from the newly calculated values available on the New York State Integrated Pest Management (NYSIPM) Program website (https://nysipm.cornell.edu/eiq/calculator-field-use-eiq, last accessed on 20-Dec-2017). The field EIQ and its components (Farmer/worker, Consumer and Ecological for individual active ingredients per acre were obtained using the method explained in section 2.3 as well as the automatic calculator available on the NYSIPM website. The weighted average field EIQ for each category of IPM adopters is the sum of the total and each component field EIQ and multiplied by the weighing factor (W_i). For instance, the weighted average field-use EIQ for total field EIQ is computed as $\sum_i(FEIQ_i * W_i)$, where *i* represents the individual active ingredients and W_i is the weighing factor ($A_i/\sum_i A_i$).

[2] n/a denotes the active ingredient was not used.

Active ingredient	Base EIQ[1]	Application rate (lb/acre)	Percentage of active ingredient (%AI)	Total field EIQ (per acre-$FEIQ_i$)	Field EIQ components (per acre)			Area applied (acre-A_i)	Area applied (%-W_i)
					Consumer ($CFEIQ_i$)	Worker ($WFEIQ_i$)	Environmental ($EFEIQ_i$)		
Deltamethrin	28.4	0.12	2.50	0.10	0.00	0.10	0.20	3.75	1.12
Diazinon	44	5.04	60.00	133.10	7.40	20.90	371.20	7.00	2.09
Dicofol	29.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Difenoconazole	41.5	2.04	25.00	21.10	12.00	7.60	43.80	8.25	2.46
Dimethoate	33.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Endosulfan	38.5	26.46	35.00	357.00	50.90	250.00	770.10	0.50	0.15
Fenitrothion	39.6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Imidacloprid	36.7	2.99	14.50	15.90	4.50	3.00	40.30	50.98	15.20
Lambdacyhalothrin	44.2	4.93	4.58	10.56	0.80	4.70	24.50	25.00	7.46
Malathion	23.8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Mancozeb	25.7	5.20	72.00	96.40	30.50	75.90	182.80	5.00	1.49
Methomyl	22	3.39	90.00	67.20	33.60	18.30	149.60	6.02	1.80
Profenofos	59.5	0.82	40.00	19.40	1.00	2.60	54.60	0.75	0.22
Propamocarb hydrochloride	23.9	0.29	72.20	5.10	2.60	2.60	10.00	1.50	0.45
Pyriproxyfen	14.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Thiamethoxam	33.3	2.74	25.00	22.80	8.30	7.10	53.20	24.58	7.33
Triadimefon	27	8.82	25.00	59.40	33.40	26.80	118.10	0.50	0.15
Trifloxystrobin	29.8	0.06	30.00	0.50	0.20	0.20	1.20	22.00	6.56

Active ingredient	Base EIQ[1]	Application rate (lb/acre)	Percentage of active ingredient (%AI)	Total field EIQ (per acre-$FEIQ_i$)	Field EIQ components (per acre)			Area applied (acre-A_i)	Area applied (%-W_i)
					Consumer ($CFEIQ_i$)	Worker ($WFEIQ_i$)	Environmental ($EFEIQ_i$)		
Weighted average field-use EIQ	n/a	n/a	n/a	22.65	4.53	7.31	56.09	n/a	n/a
ADOPTERS OF ONE IPM COMPONENT									
Abamectin	34.7	0.84	1.80	0.50	0.10	0.20	1.30	12.50	3.55
Acephate	24.9	1.72	97.00	41.60	20.90	25.10	78.80	13.60	3.87
Acetamiprid	28.7	2.45	16.00	11.20	2.90	2.70	28.20	20.60	5.86
Alfacypermethrin	36.4	4.12	5.85	8.70	1.40	3.30	21.50	89.55	25.46
Azadirachtin	12.1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Beta-Cyfluthrin	31.6	3.31	4.88	5.10	0.40	1.10	13.80	55.00	15.64
Carbaryl	22.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Carbendazim	50.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Carbosulfan	47.3	1.10	35.00	18.30	3.20	2.70	48.90	0.20	0.06
Chlorpyrifos	26.9	8.97	48.00	115.60	8.60	25.80	312.30	0.68	0.19
Cypermethrin	36.4	3.40	10.00	12.40	2.00	4.70	30.40	41.30	11.74
Deltamethrin	28.4	10.45	2.50	7.40	0.50	4.70	17.00	6.94	1.97
Diazinon	44	1.47	60.00	38.80	2.20	6.10	108.30	0.30	0.09
Dicofol	29.9	7.94	28.50	67.90	10.60	23.40	168.90	1.50	0.43
Difenoconazole	41.5	0.76	25.00	7.90	4.50	2.90	16.30	15.85	4.51
Dimethoate	33.5	4.46	40.00	59.60	20.50	18.40	139.90	2.50	0.71

Active ingredient	Base EIQ[1]	Application rate (lb/acre)	Percentage of active ingredient (%AI)	Total field EIQ (per acre- $FEIQ_i$)	Field EIQ components (per acre)			Area applied (acre- A_i)	Area applied (%- W_i)
					Consumer ($CFEIQ_i$)	Worker ($WFEIQ_i$)	Environmental ($EFEIQ_i$)		
Endosulfan	38.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Fenitrothion	39.6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Imidacloprid	36.7	4.07	14.98	22.46	6.30	4.20	56.60	37.70	10.72
Lambdacyhalothrin	44.2	2.41	3.86	4.10	0.30	1.90	10.10	14.27	4.06
Malathion	23.8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Mancozeb	25.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Methomyl	22	3.50	90.00	69.30	34.60	18.90	154.30	16.00	4.55
Profenofos	59.5	0.53	40.80	12.60	0.60	1.60	35.50	8.75	2.49
Propamocarb hydrochloride	23.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Pyriproxyfen	14.5	1.47	10.80	2.30	0.30	1.00	5.70	1.50	0.43
Thiamethoxam	33.3	1.44	24.98	12.00	4.30	3.70	27.80	12.68	3.61
Triadimefon	27	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Trifloxystrobin	29.8	2.65	30.00	23.60	8.10	9.60	53.10	0.25	0.07
Weighted average field-use EIQ	n/a	n/a	n/a	14.73	4.50	4.78	34.90	n/a	n/a
ADOPTERS OF TWO IPM COMPONENTS									
Abamectin	34.7	1.50	1.80	0.90	0.10	0.40	2.30	10.56	4.85
Acephate	24.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Active ingredient	Base EIQ[1]	Application rate (lb/acre)	Percentage of active ingredient (%AI)	Total field EIQ (per acre-$FEIQ_i$)	Field EIQ components (per acre)			Area applied (acre-A_i)	Area applied (%-W_i)
					Consumer ($CFEIQ_i$)	Worker ($WFEIQ_i$)	Environmental ($EFEIQ_i$)		
Acetamiprid	28.7	2.79	20.00	16.00	4.10	3.10	40.20	3.25	1.49
Alfacypermethrin	36.4	7.70	5.00	14.00	2.30	5.30	34.40	52.47	24.08
Azadirachtin	12.1	1.93	0.03	0.00	0.00	0.00	0.10	2.00	0.92
Beta-Cyfluthrin	31.6	5.66	2.50	4.50	0.30	1.00	12.10	8.50	3.90
Carbaryl	22.7	0.44	85.00	8.50	2.10	5.60	17.90	1.00	0.46
Carbendazim	50.5	4.41	50.00	111.40	89.30	55.10	189.60	0.50	0.23
Carbosulfan	47.3	2.28	35.00	37.80	6.70	5.50	101.30	5.49	2.52
Chlorpyrifos	26.9	2.85	48.00	36.70	2.70	8.20	99.20	3.75	1.72
Cypermethrin	36.4	1.54	10.00	5.60	0.90	2.10	13.80	28.30	12.99
Deltamethrin	28.4	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Diazinon	44	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Dicofol	29.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Difenoconazole	41.5	3.31	25.00	34.20	19.40	12.40	71.00	1.00	0.46
Dimethoate	33.5	5.90	40.00	79.00	27.20	24.40	185.50	3.00	1.38
Endosulfan	38.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Fenitrothion	39.6	0.88	37.25	n/a	n/a	n/a	n/a	0.25	0.11
Imidacloprid	36.7	2.66	14.50	14.20	4.00	2.70	35.80	28.70	13.17
Lambdacyhalothrin	44.2	5.27	4.38	10.20	0.80	4.80	25.00	29.13	13.37

Active ingredient	Base EIQ[1]	Application rate (lb/acre)	Percentage of active ingredient (%AI)	Total field EIQ (per acre-$FEIQ_i$)	Field EIQ components (per acre)			Area applied (acre-A_i)	Area applied (%-W_i)
					Consumer ($CFEIQ_i$)	Worker ($WFEIQ_i$)	Environmental ($EFEIQ_i$)		
Malathion	23.8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Mancozeb	25.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Methomyl	22	0.93	90.00	18.40	9.20	5.00	41.00	13.20	6.06
Profenofos	59.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Propamocarb hydrochloride	23.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Pyriproxyfen	14.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Thiamethoxam	33.3	3.66	24.98	30.40	11.00	9.50	70.80	26.77	12.29
Triadimefon	27	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Trifloxystrobin	29.8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Weighted average field-use EIQ	n/a	n/a	n/a	15.77	4.19	4.95	38.16	n/a	n/a
ADOPTERS OF THREE OR MORE IPM COMPONENTS									
Abamectin	34.7	0.22	1.80	0.10	0.00	0.10	0.30	2.10	1.80
Acephate	24.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Acetamiprid	28.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Alfacypermethrin	36.4	11.10	3.62	14.60	2.40	5.50	35.90	31.26	26.73
Azadirachtin	12.1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Beta-Cyfluthrin	31.6	0.33	2.50	0.30	0.00	0.10	0.70	20.00	17.11

Active ingredient	Base EIQ[1]	Application rate (lb/acre)	Percentage of active ingredient (%AI)	Total field EIQ (per acre-$FEIQ_i$)	Field EIQ components (per acre)			Area applied (acre-A_i)	Area applied (%-W_i)
					Consumer ($CFEIQ_i$)	Worker ($WFEIQ_i$)	Environmental ($EFEIQ_i$)		
Carbaryl	22.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Carbendazim	50.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Carbosulfan	47.3	0.88	35.00	14.60	2.60	2.10	39.10	0.25	0.21
Chlorpyrifos	26.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Cypermethrin	36.4	2.51	10.00	9.10	1.50	3.50	22.40	6.50	5.56
Deltamethrin	28.4	0.03	2.50	0.00	0.00	0.00	0.00	0.25	0.21
Diazinon	44	0.98	60.00	25.80	1.40	4.00	71.90	3.38	2.89
Dicofol	29.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Difenoconazole	41.5	0.44	25.00	4.60	2.60	1.70	9.50	2.00	1.71
Dimethoate	33.5	5.25	40.00	70.20	24.20	21.70	164.70	6.00	5.13
Endosulfan	38.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Fenitrothion	39.6	2.74	37.25	n/a	n/a	n/a	n/a	11.25	9.62
Imidacloprid	36.7	1.59	15.11	8.80	2.50	1.60	22.20	17.43	14.90
Lambdacyhalothrin	44.2	1.59	3.75	2.60	0.20	1.20	6.50	4.15	3.55
Malathion	23.8	2.00	50.00	23.80	4.50	9.00	57.90	2.21	1.89
Mancozeb	25.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Methomyl	22	7.35	90.00	145.50	72.80	39.70	324.10	0.30	0.26
Profenofos	59.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00

Active ingredient	Base EIQ[1]	Application rate (lb/acre)	Percentage of active ingredient (%AI)	Total field EIQ (per acre-$FEIQ_i$)	Field EIQ components (per acre)			Area applied (acre-A_i)	Area applied (%-W_i)
					Consumer ($CFEIQ_i$)	Worker ($WFEIQ_i$)	Environmental ($EFEIQ_i$)		
Propamocarb hydrochloride	23.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Pyriproxyfen	14.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Thiamethoxam	33.3	4.15	25.00	34.50	12.50	10.70	80.40	7.75	6.63
Triadimefon	27	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00
Trifloxystrobin	29.8	0.62	30.00	5.60	1.90	2.30	12.50	2.10	1.80
Weighted average field EIQ	n/a	n/a	n/a	13.53	3.57	4.25	32.76	n/a	n/a