Conference: 3rd International Conference. Environment and Natural Resources Management in Developing and Transition Economies

Session: Health and the environment

Title: Farmers' Preferences for Eco-Friendly Nets as an Alternative to Insecticides in Africa

Authors : Vidogbéna Faustin[1]*, Laurent Parrot[2], Anselme Adégbidi[3], Rigobert Tossou[3], Françoise Assogba-Komlan[4], Mathieu Ngouajio[5], Thibaud Martin[6], Serge Simon[2,4], Kerstin K. Zander[7,8]

[1] Regional Agricultural Center for Rural Development of Atlantique-Littoral, Abomey-Calavi, Benin
[2] Cirad, UR Hortsys, Avenue Agropolis, Montpellier, France.
[3] University of Abomey-Calavi, Faculté des Sciences Agronomiques, Cotonou, Benin.
[4] National Agricultural Research Institute (INRAB), Station d'Agonkanmey, Cotonou, Benin
[5] USDA-NIFA, Washington DC, USA.
[6] Icipe, Plant health Department, P.O. Box 30772-00100, Nairobi, Kenya.
[7] The Northern Institute, Charles Darwin University, Darwin, Australia
[8] Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin, Australia
Corresponding author: Vidogbéna Faustin. Email : vifaroho@yahoo.fr. Tel: (+229) 96 03 50 10.

Abstract

Vegetable production in Africa is highly dependent on pesticides with a large proportion of the population involved in farming. We investigate if eco-friendly nets (EFNs) are a viable and accepted alternative to farmer's current practice of extreme use of insecticides in vegetable production. Using a choice experiment, we found that farmers in Benin preferred all of the characteristics of EFNs except the higher labor requirements. The break-even point can vary with the lifespan of EFNs, their purchase price and potential health benefits from avoiding large quantities of insecticides. To break even the nets need to be used for at least two production cycles. To overcome risk-averse farmer's reluctance to adopt EFNs we propose a credit and warranty scheme along with the purchase of the nets. The study's findings can guide the implementation of EFNs in other African countries as part of integrated pest management with global benefits for the environment and health by reducing the use of pesticides.

Keywords: Pesticides; health; Eco-Friendly nets ; farmers; choice experiment; Benin

Introduction

In Sub-Saharan Africa, city food supply is a rising concern for food security in a context of increasing food prices and urban growth (World Bank, 2013). At the same time, productivity and yields need to be improved and follow sustainable pathways of growth (FAO, 2014). This is of particular concern for the subsector of perishable fruits and vegetables in urban and peri urban areas which relies heavily on pesticides (Parrot et al., 2008). Pesticides have the purpose to repel or destroy pests (animals, plants, fungus). Pesticides include a wide range of sub-products: insecticides, herbicides, fungicides, acaricides, nematicides, etc. Pesticides belong to different chemical categories according to their molecular structure and properties.

Africa has the lowest rate of pesticide use in the world but vegetable production may appear as an exception. Vegetable production in Africa is highly dependent on pesticides, not only in sectors where the shift to a cash crop economy such as in East Africa is obvious (Parrot et al., 2008a,b; de Bon et al., 2014). Pests and diseases control is a permanent challenge for fruit and vegetable farmers in Africa. In tropical areas, the lack of cold seasons and the presence of vegetation year round make fruit and vegetables highly vulnerable to pest infestations from non-agricultural land. As a result, the high risk of significant yield reduction or even loss has led farmers to widely use pesticides as a risk adverse strategy.

An increasing literature warns about the impact of pesticides on human health. Exposure to pesticides has been linked to 8 cancer types (non-Hodgkin's lymphoma, leucemia, multiple myeloma, Hodgkin's disease, prostate cancer, testicle cancer, malignant melanomas, and brain tumors), 3 neurodegenerative pathologies (Parkinson, amyotrophic lateral sclerosis, and Alzheimer), cognitive and anxio-depressive disorders, and poor fertility (INSERM, 2013). Health costs have also been assessed in Europe (HEAL, 2014). Exposure to pesticides occurs through dermal exposure, oral intake, or the respiratory system with contaminated air, water and food. Therefore, exposure to pesticides can be direct (manufacturer, farmers) but also indirect through the commodity chains (consumers) or through the environment with the accumulation of pesticides in soils, water, and living organisms. In the case of Guadeloupe for example, the estrogenic insecticide chlordecone was used extensively in the French West Indies, contaminating arable land, staple crops, and the population for more than 30 years; and it resulted in a significant increase in the risk of prostate cancer with increasing plasma chlordecone concentration (Multigner et al., 2010).

Pesticides are also detrimental to the environment, affecting the ecological systems and generating pest resistance in the long term. Some pesticides can bioaccumulate or build up to toxic levels in the bodies of organisms that consume them over time as it is the case of the estrogenic insecticide chlordecone (Multigner et al., 2010). Pest resistance generates a vicious circle of increasing doses applied and a decreasing impact over time (Corbel et al., 2007; de Bon et al., 2014).

The impact of pesticides use in Africa differs from the developed countries for several reasons.

First, the magnitude of the population in Africa involved in agriculture and vegetable is very high and therefore increases the population at direct risk. Considering only urban and peri urban farmers, about 200 million of them produce and trade perishable crops. It represents a quarter of the urban population in African capitals (Orsini et al, 2013: 5 and 8). The number of farmers in towns will increase as prospective studies show that by 2030, 60% of the population in low-and middle-income will reside in cities (Cohen, 2004: 48). In many countries, particularly in sub-Saharan Africa, a majority of the population is involved in agriculture, 70% in Benin (INSAE, 2009: 4; OECD, 2012: 4) or 75% in Kenya.

Second, the prevalence of the informal sector impacts the behavior of farmers and the commodity chains around pesticides. Concerning the commodity chain, the lack of data makes it difficult to draw up any estimates of long-term and induced costs for pollution and health and even any estimated running costs measurements (Ngowi et al. 2007). Conformity between uses and regulations is unknown. Pesticides used in horticulture often take advantage of regulations and practices set up for other crops, resulting in dangerous synergies. A reason is that homologation costs for minor crops as compared to “cash” crops are not profitable for the pesticide industry. For instance, cotton cultivation is the dominant livelihood strategy in West African savannah zones, and increasing concerns exist about pesticide use for this crop in Mali (Mamadou et al. 2001), in Burkina Faso, and in Benin (Tovignan et al. 2001; Pazou et al. 2006). Concerning social impacts, about 95%, 90% and 75 %, respectively, of the workers in Benin, Cameroon and Senegal do not have a formal contract (CES, 2011: 10 & 12; DPS 2004; INS 2005). This situation makes farming and immediate returns a vital necessity. The social impacts of pesticides in such context are much more acute in Africa than in developed countries where healthcare is existent. Panel studies in India and Uganda (Krishna et al., 2006; Krishna, 2006) have shown that a fall in poverty of a household is often caused by a combination of two factors: an illness of the head of the household (e.g., HIV and malaria) and consecutively a loss of employment. In a situation where only the head of a household provides income for the family, one can imagine the catastrophic impacts on the household in a context of a prevalence of the informal sector.

Third, From a farmer perspective, Ajayi and Akinnifesi (2007) cited a number of direct causes for bad practices in pesticide use on farm fields: the absence of instructions, illiteracy among farmers, lack of awareness about the danger of misuse, the difficulty of extrapolating the dosage from a hectare basis to very small areas, unsuitability of the products in respect of the problem source, lack of knowledge of pests and diseases, etc. All these causes are aggravated by the lack of extension services and support from agricultural policies.

At the same time, there is an increasing need to comply with pesticide regulations. The World Bank supports pest control strategies that promote the use of biological or environmental control methods (World Bank, 2011). The European Union has undertaken a program for norms and standards and setting the maximum residual levels for chemicals suitable for use on agricultural products. All imports originating from non-European Union member countries must comply with these new regulatory standards (COLEACP Pesticides Initiative Program, Pesticides File). Therefore, this is a significant challenge in Africa not only for export markets at the present time but for domestic markets in the future. We need to anticipate the future African requirements in biological or environmental control methods.

New agricultural practices are necessary. Integrated pest management IPM has been successfully implemented in a wide range of crops and agroclimatic zones (Matteson 2000; Bajwa and Kogan 2003). It is a holistic approach that views the agro-ecosystem as an interrelated whole and uses a variety of biological, cropping, genetic, physical, and agro-ecological techniques that maintain pests below economic injury levels (de Bon et al., 2014). Another alternative is the use of physical barriers such as greenhouses or plastic tunnels to protect vegetable crops. They have developed significantly worldwide over the past 20 years (Berlinger et al., 1996). This paper focuses on this second alternative.

The aim of this paper is to study one innovative approach for vegetable producers to reduce the use of pesticides with the application of an eco-friendly net (EFN) as a physical barrier to insects. The case study is located in Benin[1]. EFN are made of synthetic or natural fiber, and the mesh of the netting can be varied to suit crop or other requirements such as size of the target pest(s). These nets are regarded as eco-friendly because they reduce the use of pesticides. EFNs proved to be a viable alternative to harmful and unsustainable insecticide application practices in France (Sauphanor et al., 2012) and in tropical countries (Martin et al., 2006, 2010; Licciardi et al., 2008; Gogo et al., 2013; Muleke et al., 2013). In Benin, EFNs were found to reduce pesticide by at least 70%, in some cases by even 100% (Martin et al., 2006). The nets are also profitable even when full labor costs are included and when they are purchased at a full market price (Vidogbèna et al., forthcoming). Moreover there is a strong consumer market potential for food deficit countries such as Benin. From a rational point of view, farmers should be interested in investing in this new technology, as a related study showed that farmers would be better off when using the nets, even with lower yield (Vidogbèna et al., forthcoming).

However, this technology needs to be adapted not only to different agro-ecological contexts but also to the social and economic context in which farmers evolve. We investigate if eco-friendly nets (EFNs) are a viable and accepted alternative to farmer's current practice of extreme use of insecticides in vegetable production.

[1] Benin and Kenya were covered by Horticulture Collaborative Research Support Program (HortCRSP) project BioNetAgro. Only the results from Benin are displayed in this paper.

The objectives of our study are focused on a farmer perspective: (1) to assess smallholder farmers' preferences for characteristics of different pest control strategies, (2) to test if there is preference variation across farmers and, if so, (3) to reveal the factors determining this variation, and (4) to compare the benefits and costs of EFNs with those associated with pesticides. We do this by applying a choice experiment (CE), a multi-attribute non-market valuation technique. Because the EFNs are not yet on the market, the value of the nets cannot be observed from market transactions. However, non-market valuation techniques make it possible to predict farmers' values for the characteristics of EFNs and hence for the benefit of using EFNs as substitutes for insecticides. From these benefits, expressed as farmers' willingness-to-pay (WTP), the future price of the nets can be inferred as well as the yield that needs to be achieved to make the EFNs commercially viable. A few choice experiments CEs have investigated preferences related to pesticide use by farmers (e.g. Christensen et al., 2011; Richardson et al., 2013) but only a few studies in SSA have looked at the socio-economic implications of decreasing pesticide use, and then mostly at the effects of pesticides on health (e.g. Ngowi et al., 2007; Williamson, 2005; Garming and Waibel, 2009; Atreya et al., 2013).

Material and methods

Benin is a West African country located between the equator and the Tropic of Cancer between Nigeria and Togo. The total population is estimated around 9 million inhabitants in 2011. A major challenge for Benin will be to feed its population. The population is expected to double by 2025. Population densities will double or triple in every provinces by 2030 INSAE (2008). Benin is a low income country, dependent on food import to meet its needs (INSAE, 2009: 583). In 2011, Benin's composite human development index (HDI) stood at 0.427, still below the average of 0.463 for sub-Saharan Africa. More than 95% of the population belongs to the informal sector (CES, 2011: 10 & 12). Between 47.1 and 70% of the workforce is involved in agriculture (INSAE, 2009: 4; OECD, 2012: 4). About half of the population faces food insecurity or a risk of food security (INSAE, 2011: 90). Moreover, its economy is dependent on the agricultural sector for its exports (cotton, fruits) and imports (cereals) and therefore vulnerable to international commodity price volatility and climate constraints. Despite the potential of agriculture (availability of arable land and labor, provided drainage, pastoral resources, etc.), it still faces difficulties: dependence on hazards climate, the limited number of large farms, the low rate of use of specific inputs and agricultural equipment, irrigation deficiencies, low processing of agricultural products, the high rate of post-harvest losses, low market access and the poor state of rural roads paths, insecure land tenure, lack of control of pests and diseases, poor water management, conservation of the difficulties and the low level of organization of farmers and sellers, etc. (MAEP, 2011: 6&7).

Vegetable crops play an important role in the diet of the population and contribute to the prevention of diseases caused by micronutrient deficiencies. However, the current level of production for tomato, pepper, okra, onion and leafy vegetables cannot cover the domestic needs. In addition, some vegetables such as okra, pepper, tomato and onion experience seasonal production which results in high price volatility. About 66% of crop fields in urban areas are under cultivation or fallow (INSAE, 2011: 58). Even in the Littoral Province, defined as urban (Cotonou), about 16.8% of crop fields are under cultivation or fallow (INSAE, 2011: 58 & 60).

Concerning pesticide uses, Ahouangninou et al. (2012) showed in January 2012 that among the 15 pesticides used in Benin market gardens, only two of them, namely lambda-cyhalothrin and acetaprimid, were allowed on vegetable crops in January 2012 by the CNAC because of their toxicity ([National Committee for Approval and Testing of Phytopharmaceutical Products], Republic of Benin); 2 of them were allowed with no crop specificity, namely, cypermethrin and deltamethrin. In Benin, fruit growers used insecticides registered for cotton growing, such as (i) endosulfan, (ii) Calthio DS (lindane+thirame), (iii) Calthio E (endosulfan+thirame), iv) gammalin (lindane), and (v) Apron (metalaxyl + difenoconazole+thiamethoxam) to spray on fruit crops (mango, citrus, papaya, avocado).

Study area

The study was carried out in two geographical zones in Benin, differing in their main soil type and fertility and land use systems. The first zone spreads along the Benin offshore sand bar and comprised five districts: Cotonou, Abomey-Calavi, Ouidah, Comé and Grand-Popo. In this zone trials of EFN use have been implemented by the National Agricultural Research Institute of Benin (INRAB) through the NGO APRETECTRA . The second zone does not border the sea and comprises nine districts: Bopa, Houéyogbé, Lokossa, Athiémé, Dogbo, Aplahoué, Toviklin, Klouékanmè, Lalo. In this zone EFN trials were diffused by the Regional Council of Market Gardeners (CRM-MC: Conseil Régional des Maraîchers du Mono-Couffo). The fourteen districts are spread across four departments: Littoral (Cotonou), Atlantique (Abomey-Calavi and Ouidah), Mono (Comé, Grand-Popo, Bopa, Houéyogbé, Lokossa and Athiémé) and Couffo (Dogbo, Aplahoué, Toviklin, Klouékanmè, Lalo) (Figure 1).

[Figure 1]

All respondents practice urban farming. Soils are poor and infertile in both zones. In the first zone the lack of suitable land for agriculture limits the land size for limited space forces farmers to practice an intensive production system, which is suitable for exotic vegetables production (cabbage, eggplant, lettuce, watermelon, cucumber). Farmers in the second zone have more space and have low-input production systems. They also produce a range of exotic vegetables as well as local ones such as pepper, amaranth and local spinach.

In the two research zones, as in the rest of Benin, the use of insecticides spray is almost ubiquitous and increasing because of growing insecticide resistance (Martin et al., 2006). Access to pesticides is facilitated by government subsidies to purchase these products to boost production, particularly in the cotton sector. Without a thorough knowledge of alternatives, farmers often assume that the only method to control pests is to increase dose and spray frequency (Martin et al., 2006).

Sampling

In order to ensure efficient dissemination of knowledge about EFNs and how to use them, APRETECTRA and CRM-MC haves created farmer networks. Each network consisted of six farmers: one farmer who actively took part in the EFN trials (from here on referred to as ‘participant’) and five farmers who attended the trials during one cycle of vegetable production but who did not adopt the EFNs for their own vegetable production (from here on referred to as ‘observers’).

The list of these farmers was provided by APRETECTRA and CRM-MC, respectively. The reason we sampled only from these farmers is because, in order to adopt a new technology, farmers need some knowledge of and exposure to it (e.g. Dimara and Skura, 2003; Saha et al., 1994; Diagne and Demont, 2007; Kabunga et al., 2012). The sample frame consisted of 90 networks, i.e. in total 540 farmers. Two farmers have abandoned the trials, leaving 538 in the potential sample frame: 76 in the INRAB/APRETECTRA zone and 462 in the CRM-MC zones (Table 1).

[Table 1]

We applied the Moivre-Laplace theorem to determine the number of farmers to be interviewed in each department. For large samples (n> 30) the Moivre-Laplace theorem suggests the sample size (n) is obtained by:

$$n = \mu_{\alpha}^{2} \frac{F_n(1-F_n)}{\delta^2} \quad (1)$$

where μ_α is the 'p-value' of the standard normal distribution (μ_α = 1.96), F_n is the proportion of vegetable growers who took part in the demonstration trials. δ is the half-amplitude of the confidence interval, equal to 0.05 for the selected confidence level. The integration of these data in equation (1) gives a required sample size of 220 (93 participants and 127 observers).

Data collection and questionnaire

Six local people, all having some knowledge in agronomy, were trained to collect the data. The whole study consisted of a pilot survey and two in-depth surveys. The pilot survey took place over ten days in August 2011 and used semi-structured interviews. The outcome was information about choices of crop, yield, and pest control methods including costs of pesticides. This information was used to create attributes and labels and allowed us to design a first draft of the CE. A first in-depth survey with the whole sample (220 farmers) was conducted between October and November 2011. During this survey, using structured questionnaires, socio-economic characteristics of respondents were collected and the CE was piloted. Information collected included household size and composition, level of education and training, wealth status and income generating activities, experience in vegetables cropping and the level of awareness of alternate pest control methods such as EFNs. The second in-depth survey, in which the CE was presented to the 220 farmers, was conducted between January and March 2012.

The choice experiment

In a CE, respondents are presented with a series of choice tasks, known as choice sets, each containing a finite number of options which describe the environmental policy outcome in question (Adamowicz, 2004). The options vary in their level of attributes and respondents are usually asked to choose their most preferred one (Louviere et al., 2000). By making a choice, respondents trade-off the attributes and the associated costs that come with the chosen option. The interpretation of the observed choices is based on Lancaster's characteristics theory of value (Lancaster, 1966) which purports the total value of a product, such as the EFN, as the sum of the values of its characteristics. By observing farmers' choices in a number of choice sets, statistical models of choice can be estimated (see analysis section).

We used choice sets consisting of three options (see Figure 2). Each option showed the same attributes but at different levels. One of the three options was the same across all choice sets and represented the status-quo (SQ). The SQ option reflected the current practice by farmers, which was characterized by high costs because of high use of insecticides, short persistence, low labor requirements, and a long time to be effective. The other two options represented alternative pest control strategies which showed characteristics of insecticide use and EFN use. We opted for an unlabeled design because if we had labeled one option as 'use of EFN', farmers might have shown bias. When the choice sets were presented to respondents, they were asked which one of the three options they preferred for managing one cycle of cabbage production in an area of 12m2. This was the area on which the EFNs were trialed and which all respondents saw, either as participates or observers, and also a plot size that farmers commonly cultivate at home and in public open spaces.

The attributes used in the choice experimental design were obtained using the first in-depth study. Farmers highlighted five attributes as characteristics of pest control strategies that commonly influence their choices (Table 2). The choice sets were designed using the software Ngene (Institute of Transport and Logistics Studies, 2007). Based on the design's statistical efficiency, we chose the design with the smallest D-error. A low D-error indicates a more efficient design (Scarpa and Rose, 2008). After the pilot study, a Bayesian updated design was employed using priors from responses in the pilot study. The final design yielded 12 choice sets (Figure 2) which we blocked into two versions and each respondent was presented with one of the two versions, i.e. replied to six choice sets each. To overcome the bias that could arise when respondents always chose the first, left-hand, option in a choice set, we randomly varied the order of the options in the choice sets.

[Table 2]

[Figure 2]

Analysis

The random utility theory (McFadden, 1974) is the econometric foundation of statistical models of choice. According to the random utility theory, respondents will choose the alternative that gives them the highest utility with some level of randomness. It is assumed that respondents act rationally and try to maximize their utility and hence would select the option in a choice set which gives them the highest benefit.

We regressed the choice data on the attributes using a series of models. A lot of research has been done on finding the best models for analyzing choice data and, while some models seem to be superior, the evidence is always data specific and it is now common practice to reveal results from a series of models. We, first of all, present results from a mixed logit (MXL) model, for many years the most commonly applied model in environmental economics. The advantages of a MXL model over the basic multinomial logit (MNL) model include relaxation of the assumption about the distribution of error terms , accounting for heterogeneity and a capacity to make use of panel data (repeated choices from each respondent). Recently, however, it has been argued that it is unclear if the revealed heterogeneity is due to taste or due to the scale (e.g. Louviere et al., 2002; Louviere and Meyer, 2008). Scale heterogeneity can arise as an artifact of the survey because some respondents make more errors than others. This variability in error variances can be, for instance, because of different choice task processing strategies or varying degrees of understanding of the choice tasks. Scale and state are perfectly confounded and inseparable in a MXL model. Separating these two is important to avoid making false recommendations. Teasing out 'real' taste heterogeneity can have important implications for targeting a specific market or consumer group. Alternative models such as the scaled multinomial logit (S-MNL) model (Breffle and Morey, 2000), the generalized multinomial logit model (G-MNL) model (Fiebig et al., 2010; Greene and Hensher, 2010) and the WTP-space model (Train and Weeks, 2005) have been proposed. The S-MNL model only accounts for scale heterogeneity whereas the latter two models can jointly model heterogeneity due to taste and due to the scale (Fiebig et al., 2010). Fiebig et al. (2010) found that models accounting for scale heterogeneity performed better than MXL models in 10 out of 10 analyzed data sets. The authors further found that in seven out of the ten analyzed datasets the G-MNL models fitted the data better while in three datasets the S-MNL models performed better. Models with utility estimated in space (WTP-S models) as opposed to preference space models have increasingly been applied (e.g. Scarpa et al. 2008; Scarpa and Willis, 2010; Hensher and Greene, 2011; Hole and Kolstad, 2012; Zander et al., 2013) as a special case of the G-MNL model (Greene and Hensher, 2010). Because the marginal rates of substitution are estimated directly and not through simulations, it was found that the WTP-S model produces more stable welfare (WTP) estimates (e.g. Balcombe et al., 2009). Where the objectives of the study are to obtain welfare estimates, as in our study, WTP-space models are more practical as they offer a more immediate interpretation of the estimated parameters of the utility function (Scarpa and Willis, 2010). Furthermore, Balcombe et al. (2009) and Hole and Kolstad (2012), among others, concluded that the models in WTP-space fit the data better than the model in preference space.

Against this background, we estimated three models: MXL, G-MNL and WTP-S models. For the random parameters we used the normal distribution for all parameters except the cost attribute. Following Greene et al. (2006), we applied a constraint triangular distribution for the random cost parameter in the MXL and G-MNL models to ensure that the sign of the parameter stayed positive. Estimates were obtained using 250 Halton draws (Halton, 1970) to simulate the likelihoods. We further included heterogeneous preferences explaining interaction effects between socio-demographic characteristics of respondents and the SQ option in the models. The cost attribute was linear coded while all other variables were dummy-coded (Louviere et al., 2000). Levels of the SQ were treated as the base levels (see Table 2).

Results

Respondents' socio-demographic characteristics

Out of the 220 interviews obtained, six could not be used, leaving data for 214 respondents. Most of the respondents were male (95%; Table 3) as they were the heads of households. About half of the respondents were middle-aged (between 40 and 60), many (38%) had never attended a formal school or had only attended primary school (41%).

Almost half of the respondents (45%) had an annual income of less than FCFA 800,000 (~ € 1,200), 40% had an annual income between FCFA 800,000 and 3 million and 15% had an annual income of more than FCFA 3 million (~ € 4,600). In terms of income diversification, most farmers pursued only one or two activities, of which vegetable production was one. Most respondents (64%) had fewer than 10 years of experience in vegetable production.

[Table 3]

Results of the choice experiment

Finding the base models and comparison of model results

First of all, we estimated all three models with all attribute levels as random parameters. In a second step we omitted those attribute levels from the model which showed insignificant coefficients in all three models. This concerned only one level of an attribute, 'effect within 5-12 hours'. This means that farmers had the same preference for '5-12 hours' as for 'more than 12 hours' (the base level of the SQ option) time to be effective. The models without the variable '5-12 hours' became our core models (Table 4). The results were very consistent across all three models, the main difference being that in the WTP-S model, the coefficient of 'one month persistence' became insignificant. The cost coefficient was, as expected, negative across all models, implying that farmers, all else being equal, preferred lower costs of pest control options. Across all models, a low labor requirement was preferred over high labor requirement, long persistence (two months) over medium persistence (one month) and short persistence (15 days), immediate effectiveness of measure (within 4 hours) over effect within 5-12 hours and effect after 12 hours, and targeting all damaging insects was preferred over targeting only a few damaging insects and over targeting all insects.

The G-MNL model did not outperform the MXL model (Table 4), as also found by Fiebig et al. (2010). This means that accounting for unobserved individual scale heterogeneity in addition to unobserved individual taste heterogeneity in the preference-space did not result in a better model fit. The WTP-S model also did not fit the data better than the MXL model. The scale parameter (Tau) was not significant in both the G-MNL and WTP-S model, suggesting that there is no scale heterogeneity across the sample. Some unobserved taste heterogeneity did exist, however, as indicated by significant standard deviations of the random parameters, in particular for the attributes labor requirement, time to be effective and target insects. In all three models, the taste preference for attribute persistence did not vary significantly across the sample.

[Table 4]

Factors explaining variations in the likelihood of choosing the SQ

Overall, in 59% of the choices respondents chose the SQ, the remaining 41% choosing either the alternative control option A (17%) or the alternative control option B (24%). However, only 17 respondents (8%) entirely rejected the two alternative control options A and B and chose the SQ in all six choice sets.

We included interaction effects between the SQ option and socio-demographic variables into the core RPL model (model 1). Many variables, such as gender, age, income, education, and farm activities had no significant effect on the likelihood of choosing the SQ option over one of the two other pest control options. Only two variables had a significant impact: the geographical area and the fact that farmers were users as compared to participants in the trial groups (Table 4). The sign of the coefficient of the interaction 'User x SQ' was negative and significant, meaning that being a user as compared to a participant decreased the probability of choosing the SQ option. The sign of the coefficient of the interaction 'Atlantique x SQ' was positive and significant, implying that respondents from this research area had a greater probability of choosing the SQ option than respondents from the other research areas.

Welfare estimates

Because of the similar model fits of the MXL and the WTP-S models, we present welfare estimates derived from both models in Table 5. Welfare estimates from the MXL model were obtained through simulation. For this, numerous draws are taken from the distribution of the coefficients of the attributes and the cost coefficient, and the ratio of the two was calculated for each draw, using 10,000 draws. The mean and variance of the draws of the ratios were used as estimates of the mean and variance of welfare estimates in the sample. The 95% confidence intervals were obtained using the procedure proposed by Krinsky and Robb (1986), with 10,000 draws. The utility coefficients from the WTP-S model can immediately be interpreted as marginal welfare estimates. The welfare estimates from both models did not differ greatly. On average, farmers were willing to pay about FCFA 1,450 (~ € 2.20) for a pest control strategy that requires only one person to implement, FCFA 2,200 (~ € 3.40) for a two month persistence of the measure, and FCFA 1,970 (~ € 1.50) for fast effectiveness of the measure. Farmers would pay the most for the type of organism that the control strategy can target: compared to targeting all insects (damaging ones and harmless ones) they would be willing to pay about FCFA 2,450 (~ € 3.70) to target only a few damaging insects and FCFA 3,600 (~ € 5.50) to target all damaging insects.

[Table 5]

Benefit-cost analysis

Here we present calculations from a benefit-cost analysis for the production of cabbage over four years on a plot of 12m2 with two production cycles per year, i.e. eight production cycles in total. We assumed four scenarios under different pest control strategies. The first scenario describes farmers' current practice (the SQ in the CE), using insecticides exclusively, and the other three scenarios describe the use of EFN of different qualities (in terms of mash size) and lifespan (Table 6).

The cost of scenario 1, the SQ, is solely based on the costs of applying insecticides (costs of insecticides, depreciation cost of the sprayer, costs of the battery and water). The costs of applying insecticides across 12 m2 are about FCFA 6,500 per cycle, i.e. FCFA 52,000 in total.

The current purchase price of a high quality net (0.4 mm mash size) is FCFA 9,220, including the shipping costs from Tanzania, where nets are produced, to Cotonou, custom tax and further transportation costs from Cotonou to the communities 3 (Table 6). We assumed the costs of purchasing a low quality net (0.9 mm mash size) at 70% of those of a high quality net. We further assumed that the low quality net has a lifespan of only two years. It therefore either has to be replaced after two years or farmers have to rely on insecticides after the net has to be removed. Low quality EFNs have to be treated with insecticides to protect against all damaging insects (FCFA 800 per cycle, FCFA 6,400 in total). Over the four years an additional FCFA 16,400 are needed to control other pests within the nets with low doses of pesticides (FCFA 2,050 per cycle) as EFNs only protect against insects.

On the benefit side, we included four elements: yield, potential health benefits, management benefits and environmental benefits (Table 6). For the calculations we assumed that using EFNs will lead to the same annual yield (field experiments to determine yield are currently progressing but EFNs have not yet been used over four years). According to farmers, under current practices (the SQ), the annual yield from two production cycles amounts to FCFA 22,600, i.e. FCFA 90,400 in total.

The health care benefits for the scenarios using EFNs were estimates based on personal communications and rough estimates of annual health care spending of local people. We assumed that farmers would save FCFA 400 per year in which they used EFNs instead of high doses of insecticides.

The management and environmental benefits are derived from the welfare estimates for preferred characteristics, as stated in the choice experiment. For the SQ scenario, the aggregated management benefits of using a high quality EFN over four years would be the lower labor requirement (FCFA 1,454 per cycle or FCFA 11,632 over four years. The management benefits for scenarios 2, 3 and 4 are calculated by aggregating the WTP values for the preferred control strategy characteristics (two months persistence and high effectiveness).

Using EFNs would result in environmental benefits by not targeting harmless insects. For the high quality EFNs (scenario 2) this would amount to FCFA 28,840 over four years (FCFA 3,605 per production cycle; Table 5). For scenarios 2 and 4, the targeting of only a few damaging insects would have an environmental benefit of FCFA 2,449 per cycle (Table 5), and over four years of FCFA 19,592. Scenario 3 would result in environmental benefits of FCFA 9,796 (see footnote).

Applying a high quality EFN for cabbage production on 12m2 over four years has the highest net benefit (FCFA 128,604; Table 6), about 2.5 times the net benefit from farmer's current practice (FCFA 50,032 over four years). Replacing a low quality EFN after two years would result in a 100% higher net benefit and even using a low quality net for two years then returning to the current practice afterwards would yield net benefits of FCFA 79,650, about a third higher than those of the current practice.

[Table 6]

Lifespan of eco-friendly nets

The lifespan of the EFN is crucial for a farmer's decision to adopt netting as a pest control strategy. The relatively high purchase costs of EFNs can be an impediment for risk-averse farmers if they are uncertain whether the expectations of a net lifespan of four years are reliable. Like smallholder farmers in many developing countries, farmers in Benin often invest in low-risk low-return activities and prefer a reliable yield, even if lower, avoidance of costs and losses rather than maximized profits (e.g. Rosenzweig and Binswanger, 1993; Barnett et al., 2008). A sensitivity analysis shows that in order to break even with farmer's current practice, high quality EFNs have to be in place for about a year, or two production cycles. Indeed, if being used for two cabbage cycles, the expected net benefits of EFNs will be already higher (FCFA 25,236 or € 38 (high quality EFN) and FCFA 24,909 or € 37 (low quality EFN) versus FCFA 12,508 or € 19).

Although at the current costs of purchasing EFNs there is a net benefits over pesticides within a year (after two production cycles), there is always the risk that EFNs do not last that long. Given that for farmers with multiple plots of 12m2, the investment and financial risk of erecting EFNs is quite high, we propose that nets carry a one year warranty against structural fault, probably issued by the distributing NGO.

Purchase price of eco-friendly nets

During the trial phase, the nets were distributed at no cost. First estimates showed that the nets will cost about FCFA 9,220 per 12m2 (€ 14). This includes the shipping from Tanzania where the EFNs are produced to Cotonou and further on to the rural areas. This price may decrease if nets can be produced locally but, more likely, the higher production and transportation costs will increase the price. A sensitivity analysis shows that even if the price of EFNs (high and low quality) increases fivefold, the net benefits over four years are still higher when switching to EFNs (Figure 4). For the high quality EFN, the purchase price could even be nine-fold and still result in higher net benefit than the current practice (FCFA 56,444 or € 86 versus FCFA 50,032 or € 76), when used over four years. For a purchase of about FCFA 92,000 per 12m2 (€ 140; ~ ten times the current price), the high quality EFN will become economically unviable when used over four years. Low quality EFNs lose their economic competiveness at a purchase price of about six times the current costs (about FCFA 70,000 or € 107 per 12 m2).

[Figure 3]

[Figure 4]

Health benefits

We assumed (based on farmers' statements during the survey) a very conservative figure for the avoided health damage and related health care costs (savings of about € 0.5 in medical expenses per year). Ngowi et al. (2007) showed that farmers in Tanzania spend between up to € 60 (130,200 Tanzanian shillings) per year on health problems related to pesticides. Williamson (2005) found that in Benin, 81% of pineapple farmers and 43% of vegetable farmers interviewed reported that the effect of pesticides on their health was considerable or noticeable. The author also reported that some farmers lost between 15 and 20 days off work per season because of feeling weak after spraying insecticides. Garming and Waibel (2009) showed that farmers are willing to pay USD 21 (Euros) (median) for low-toxicity pesticides that avoid chronic and acute risks which was added 28% to current pesticide expenditure.

In addition to those directly exposed when spraying are children and women who are not participating in the spraying. In Benin, children under ten years old made up 20% and 30% of poisoning cases recorded in

2000 and 2001 (PAN UK 2003). These people come into contact with pesticides during weeding, pruning, harvesting vegetables (Ngowi et al., 2007).

Discussion

Farmers' attitudes towards eco-friendly nets

Overall, a minority of farmers (8%) would not choose a control strategy other than the SQ. This is promising for future acceptance of an alteration to farmers' current practice. Furthermore, the choices made by farmers as part of the choice experiment revealed that farmers preferred most of the characteristics of a pest control strategy using EFNs over those of the SQ. These include variables that had a direct impact on the productivity of the vegetable cycles, such as long persistence (duration), short time to be effective and 'all damaging insects' as the targeted insects. On the other hand, farmers had a higher value from low labor requirement, an indirect variable of vegetable production, and a characteristic of using insecticides.

The labor requirement and intensity of a pest control strategy are very important to smallholder farmers as time can be used for other income-generating activities. The application of EFNs requires at least two people, the spraying of insecticides only one person. The number of applications per cycle is about the same for both practices. The EFN have to be adjusted almost every day and at least about four times per week. This means 12 to 16 bouts of labor per month during a cycle for moving the nets are required, or, since two people are required, 24 to 32 person bouts. Farmers sometimes also need to apply pesticides up to twice a week, depending on the quality of the net.

Therefore, the number of bouts of labor required for using EFNs compares to the average of 16 times per month that farmers currently need to spray insecticides, which is about half the person hours. One reason for farmer's reluctance to embrace EFNs may thus be the opportunity costs of this extra labor, i.e. money they can earn in the time freed up by pesticides. So the additional person involved in deploying EFNs needs to make as much money as he/she would from other on-farm or off-farm work. Given the increased resilience achieved by farmers who diversify income streams, off-farm employment becomes increasingly important (Barnett et al., 2008; Olale and Henson, 2013). Off-farm employment might also be more available to farmers in urban areas and urban fringes, such as to the Benin vegetable farmers in our study. For households without people employed off-farm, the use of EFNs might be more attractive as the opportunity costs of labor are likely to be lower.

Unsurprisingly farmers like their pest control for as long as possible. The effect of pesticides usually only persists for two weeks, rarely a month and hardly ever two months, so most farmers need to spray each plot once a fortnight. By contrast EFNs exclude insect pests for the whole cycle (three months) before they are removed, i.e. longer than the highest level of this attribute (two months persistence). However they are not effective against all pests and diseases so some spraying continues to be necessary.

Again unsurprisingly, farmers assign a higher value to a pest control strategy that is effective within four hours than to strategies that take longer to take effect. Insect control is usually applied only when farmers notice them attacking the vegetables and so an immediate effect is desired to minimize the damage. Again EFNs, which can be set up in a few hours, are more effective than insecticides which may not take effect until 12 hours have passed, by which time a lot of damage is likely to have occurred.

It is interesting that farmers prefer a pest control strategy that targets only damaging insects over one that targets both damaging and harmless insects, which is the effect of spraying insecticides. This may be a sign that farmers are aware of the negative environmental impacts of pest control. Farmers also assign a positive value to a pest control that targets most of the damaging insects, although this value is lower than for targeting all damaging insects. This lower value could be because of farmer's doubt about whether the few targeted insects are the most damaging ones. Untreated EFNs can only prevent attacks from a few damaging insects, such as moths and butterflies (Plutella and Hellula) but fail to keep out numerous others like aphids and nematode vectors are beyond this control. To target these as well, the nets needs to be treated with deltamethrin. This combination has proved to provide total protection of young plants against the aphid Lipaphis erysimi (Kaltenbach), one of the insects farmers were most concerned about. Although the treatment of nets comes with higher costs for the pesticides, farmers seem to prefer these high quality nets.

Furthermore, the results of the choice experiment reveal differences in farmers' preferences for variables impacting on vegetable production. Respondents living in 'Atlantique' (the department comprising the two districts Abomey-Calavi and Ouidah Comé in research zone 1) had a greater probability of choosing the SQ option than respondents from the other research areas. The reason could be because farmers in these two districts are very close to the main markets in Cotonou and pesticides are one of the main exchange means. Farmers in these districts were in close contact with middlemen who sell pesticides for whom promotion of EFNs is against their interest. This has been found in other African countries, in which farmers have been 'locked in' to the system of pest control technology that ''entrapped'' them in pesticides (Wilson and Tisdell, 2001).

Variation in the likelihood to choose EFN as a preferred control strategy also exists between 'users' and 'observers'. The fact that those farmers who were already using EFNs on their farm as part of the trial phase ('users') were less likely to choose the SQ (current practice) is not surprising. Involvement of the users in the trial implies some level of commitment and acceptance of substituting insecticides for EFNs, and hence lowering the probability of choosing the SQ. The farmers may also have been influenced by their positive experience of the EFNs in the short time the trials had been running before the choice experiment was conducted.

Net benefits of different pest control strategies

Assuming the same yield, using a high quality EFN over four years should lead to an increase in net benefits of more than 100% compared with just pesticides. For the net benefits to be the same, yield under the high quality EFN would have to be 87% lower than under farmer's current practice (a pesticide regime) because of lower costs and potential management and health benefits. Using a low quality net with replacement after two years would require yield to be 66% lower than farmer's current practice to result in the same net benefits over four years. A vegetable pest control strategy with a low quality net without replacement after two years would require a yield 33% lower than under farmer's current practice. Results for all three alternative pest control scenarios show clear evidence that the use of EFNs is economically superior to farmers' current practice. Producing the same returns in a shorter time can help buffer farmers against sudden and unforeseen natural hazards such as storms, droughts, pests and diseases, particularly if the frequency of these increases under a changing climate.

Outlook and limitations

Vegetables are suitable for urban agriculture. The link between urban agriculture and food security has been recognized for many years (Shackleton et. al., 2009) and urban agriculture can contribute significantly in combating urban hunger and malnutrition by providing increased and more consistent access to fresh, nutritional food at lower cost than market purchases (Drechsel and Dongus, 2010; Orsini et al., 2013).

However, the abuse of pesticides can have worse impacts in cities than rural areas with more people in direct or indirect contact with potential contamination.

EFNs could be a sustainable solution to boost the production of city food. Our results, showing that the net benefits under the EFN strategy exceeds farmers' current practice after only two production cycles, can be used for future marketing of the nets and implementation in countries other than Kenya and Benin in which urban agriculture is a common phenomenon. Once a distributing agency has been established (ideally offering credits and insurance/warranty with the purchase of the nets), EFNs could become a pivotal part of IPM across Africa. Preliminarily assessments of yield using EFNs suggest that yield over four years (for a plot of 12m2) might be as high as FCFA 172,800 or € 263 (FCFA 21,600 or € 33 per cycle), which would be almost double the yield of farmers' current practices. Further field experiments are currently being undertaken (see Martin et al., 2013) but if these preliminary results are verified, this would mean that farmer's concern about the two-fold labor requirements for EFNs (two instead of one person) can be allayed by a doubling of yield).

Together with introducing EFN, farmers' concerns have to be addressed to 'release' them from the pesticide trap (see Wilson and Tisdell, 2001). Ignoring the 'real' costs of pesticides in formulating regulations and agricultural policies or programs has been a common practice, together with minimizing awareness and knowledge transfer to farmers about the negative effects of pesticides (Wilson and Tisdell 2001). To increase production efficiently and sustainably, farmers need to understand under what conditions agricultural inputs (seeds, fertilizers and pesticides) can either complement or contradict biological processes and ecosystem services that inherently support agriculture (Royal Society, 2009; Pretty et al., 2011). The identification of factors that can help to increase the rate of adopting EFNs and improving farmer's knowledge and capacity (see e.g. van den Berg and Jiggins, 2007) is inevitable and needs further research if EFNs are to replace insecticides in the long-term.

Finally, we would like to bring to attention two limitations to our study. Firstly, while we performed a sensitivity analysis on the net benefits under different purchase prices of EFNs, required yield and lifespan, we did not investigate the consequences of variations in insecticide prices. We do not know if the price will go further down should supply increase and markets and access to markets improve or if it will go up because of, for instance, higher production costs or supply shortages.

Secondly, while in the survey only 7% of farmers rejected the new technology, this might be more in reality. There are strong incentives among farmers to wait until others have tried the nets. A farmer can choose what seems to work, with less risk of failure and therefore lower costs. However, the incentive to adopt a new technology first is then low, resulting in zero innovation. The underlying problem can be described by the public good dilemma (Collier and Dercon, 2014). Therefore those who have not personally experienced benefits from EFNs, may reject them because they are not convinced of their relative advantage (Saha et al., 1994; Rogers, 2003). To counter this reluctance there may be benefits from providing discounts for the purchase of EFNs for first time (additional to the warranty), or to issue credits for those farmers for whom nets are initially unaffordable.

Conclusion

Farmers in Benin increasingly provide vegetables to urban markets to meet the growing food demand of urban centers. Farmer's current practice to maximize yield is the excessive use of pesticides, mainly insecticides. This has negative effects on peoples' health and the environment. The use of eco-friendly nets for vegetable production has been trialed with smallholder farmers in Benin and Kenya. While the implementation costs of the nets are relatively high, the net benefits exceed those of insecticide use after only a year. In this trial phase the nets were distributed to farmers for free but for a sustainable use, they will be sold to farmers in future. The lifespan of the eco-friendly nets is estimated at four years and over this time period the net benefit would almost triple that of the current practice of insecticide use (€ 196 versus € 76 for 12m2).

Apart from reduced costs of pesticides, the benefits of the nets include potential health care savings and management costs which we estimated through a choice experiment. Farmers' responses to the choice experiment revealed that they prefer most aspects of using eco-friendly nets for pest control, such as their immediate effectiveness, their persistence without needing input and their capacity to target the most damaging insects. Farmers disliked a pest control strategy that aims at all insects (damaging and harmless ones), which is the case when insecticides are applied excessively. The only benefit farmers felt they gained from pesticides was the lower requirement for labor. The opportunity costs from engaging two persons instead of one for controlling vegetable pests might be too great a disincentive, particularly for households with income from off-farm work and no spare labor for farm work.

A few factors determined farmers' preferences: Those who have actually used the nets themselves were more likely to choose the pest control strategies involving the use of a net than those who only attended demonstrations of the use of nets. Farmers in the department Atlantique (Abomey-Calavi and Comé districts) which borders the sea were more likely to choose the use of insecticides over the use of nets than farmers in the other regions, which we speculate was because of closer relationships with pesticide salespeople.

Switching to eco-friendly nets will improve smallholder farmers' livelihoods when used for at least two production cycles. Shorter lifespan of eco-friendly nets will leave farmers worse-off as the purchase price of the nets is relatively high. An insurance scheme could address this shortfall and convince risk-averse farmers to substitute the use of large quantities of insecticides with eco-friendly nets. We conclude that eco-friendly nets are an economically viable alternative to the single insecticide spray assuming the two strategies produce the same yield. If the use of eco-friendly nets should provide higher yields, as suggested by first field experiments, farmers using them would be even better off.

From an economic policy perspective, if farmers are convinced of the comparative advantages of eco-friendly nets, a crucial step has been achieved. Additional research is needed along the commodity chain in order to implement a complete an agricultural policy promoting alternatives to pesticides. Additional research is required at the consumer level as there is a rising awareness among the consumers about food safety. Studies in Benin reveal that vegetable consumers are aware of the heavy use of chemicals on vegetables (Coulibaly et al., 2011: Assogba-Komlan et al., 2007). Additional research is also needed at the collective level among farmers (farmer groups, farmer association) and extension services in order to study the perspective of support and diffusion of such innovations.

Acknowledgement

This study was made possible by the generous support of the American people through the U.S. Agency for International Development (USAID) under Award No. EPP-A-00-09-00004, with additional support by Michigan State University and the Cirad-Agricultural Research for Development. The contents are the responsibility of Horticulture Collaborative Research Support Program (HortCRSP) project BioNetAgro investigators and do not necessarily reflect the views of USAID or the U.S. Government. We also acknowledge our project partners: the Kenya Agricultural Research Institute (KARI) and the International

Centre of Insect Physiology and Ecology (Icipe) in Kenya; A to Z Textile Mills in Tanzania; University of Abomey Calavi, Institut National des Recherches Agricoles du Bénin (INRAB), and Association des Personnes Rénovatrices des Technologies Traditionnelles (APPRETECTRA) in Benin for their support.

References

Adamowicz, W.L., 2004. What's it worth? An examination of historical trends and future directions in environmental valuation. Australian Journal of Agricultural and Resource Economics 48, 419-443.

Ahouangninou, C., Martin, T., Edorh, P., Siddick, S., Bio-Bangana, S., Dion, S., Samuel, S., St-Laurent, L., Boko, M., Simon, S., Fayomi, B. 2012. Characterization of health and environmental risks of pesticide use in market-gardening in the rural city of Tori-Bossito in Benin, West Africa. Journal of Environmental Protection, 3, 241-248.

Ajayi, O.C., Akinnifesi, F.K., 2007. Farmers' understanding of pesticide safety labels and field spraying practices: a case study of cotton farmers in northern Cote d'Ivoire. Sci. Res. Essays 2, 204-210.

Assogba-Komlan F., Anihouvi P., Achigan E., Sikirou R., Boko A., Adje C., Ahle V., Vodouhe R., Assa A. (2007). Pratiques culturales et teneur en éléments anti nutritionnels (nitrates et pesticides) du Solanum macrocarpum au sud du Bénin. African Journal of Food Agriculture Nutrition and Development, Vol. 7, No. 4.

Atreya, K., Johnsen, F.H. and Sitaula, B.K., 2013. Health and environmental costs of pesticide use in vegetable farming in Nepal. Environment, Development and Sustainability 14, 477-493.

Balcombe, K., Chalak, A. and Fraser, I., 2009. Model selection for the mixed logit with Bayesian estimation. Journal of Environmental Economics and Management 57, 226-237.

Barnett, B.J., Barrett, C.B. and Skees, J.R., 2008. Poverty traps and index-based risk transfer products. World Development 36, 1766-1785.

Berlinger MJ, Lebiush-Mordechai S, Rosenfeld J (1996) State of the art and the future of IPM in greenhouse vegetables in Israel. IOBC/WPRS Bull 19:11–14

Breffle, W.S. and Morey, E.R., 2000. Investigating preference heterogeneity in a repeated discrete-choice recreation demand model of Atlantic salmon fishing. Marine Resource Economics 15, 1-20.

de Bon, H., Parrot, L., Moustier, P., 2010. Sustainable urban agriculture in developing countries. A review. Agron. Sustain. Dev. 30, 21-32.

de Bon, H., Huat, J., Parrot, L., Sinzogan, A., Martin, T., Malézieux, E., Vayssières, J.-F., 2014. Pesticide risks from fruit and vegetable pest management by small farmers in sub-Saharan Africa. A review. Agronomy for Sustainable Development, 1-14.

CES (2011) : Le secteur informel au Bénin: Problématique et perspective de contribution à l'économie nationale. Conseil Economique et Social. Commission de l'économie et des finances. 25 pages.

Christensen, T., Pedersen, A.B., Nielsen, H.O., Mørkbak, M.R., Hasler, B. and Denver, S., 2011. Determinants of farmers' willingness to participate in subsidy schemes for pesticide-free buffer zones - a choice experiment study. Ecological Economics 70, 1558-1564.

Cohen, B., 2004. Urban Growth in Developing Countries: A Review of Current Trends and a Caution Regarding Existing Forecasts. World Development 32, 23-51.

Collier, P. and Dercon, S., 2014. African agriculture in 50 years: smallholders in a rapidly changing world? World Development. doi:10.1016/j.worlddev.2013.10.001.

Corbel, V., N'Guessan, R., Brengues, C., Chandre, F., Djogbenou, L., Martin, T., Akogbeto, A., Hougard, J.M., Rowland, M., 2007. Multiple insecticide resistance mechanisms in Anopheles gambiae and Culex quinquefasciatus from Benin, West Africa. Acta Tropica 101, 207-216.

Coulibaly, O., T. Nouhoheflin, et al. (2011). "Consumers' perceptions and willingness to pay for organically grown vegetables."International Journal of Vegetable Science 17(4): 349-362.

Diagne, A. and Demont, M., 2007. Taking a new look at empirical models of adoption: Average treatment effect estimation of adoption rates and their determinants. Agricultural Economics 37, 201-210.

Dimara, E., and Skora, S., 2003. Adoption of agricultural innovations as a two-stage partial observability process. Agricultural Economics 28, 187-196.

DPS, 2004. L'emploi, le chômage et les conditions d'activité dans l'agglomération de Dakar. Agence Nationale de la Statistique et de la Démographie.

Drechsel, P., and Dongus, S., 2010. Dynamics and sustainability of urban agriculture: examples from sub-Saharan Africa. Sustainability Science 5, 69-78.

FAO, 2014. Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks 1990-2011 Analysis. FAO Statistics Division, Working Paper Series, ESS/14-02. 76 pages.

Fiebig, D.G., Keane, M.P., Louviere, J. and Wasi, N., 2010. The Generalized Multinomial Logit Model: accounting for scale and coefficient heterogeneity. Marketing Science 29, 393-421.

Garming, H. and Waibel, H. 2009. Pesticides and farmer health in Nicaragua: a willingness-to-pay approach to evaluation. European Journal of Health Economics 10, 125-133.

Gogo E.O., Saidi M., Itulya F. M., Martin T., Ngouajio M., (2013). Eco-friendly nets and floating row covers reduce pest infestation and improve tomato (Lycopersicon esculentum) yield for small holder farmers in East Africa. Biological Agriculture & Horticulture.

Greene, W.H., Hensher, D.A. and Rose, J. 2006. Accounting for heterogeneity in the variance of unobserved effects in mixed logit models. Transportation Research Part B 40, 75-92.

Greene, W.H. and Hensher, D.A., 2010. Does scale heterogeneity across individuals matter? A comparative assessment of logit models. Transportation 37, 413-428.

Halton, J.H., 1970. A retrospective and prospective survey of the Monte Carlo method. SIAM Review 12, 1-63.

HEAL, 2014. Health costs in the European Union, how much is related to EDCs? Health and Environment Alliance (HEAL). UK. 25 pages.

Hensher, D.A. and Greene, W.H., 2011.valuation of travel time savings in WTP and preference space in the presence of taste and scale heterogeneity. Journal of Transport Economics and Policy 45, 505-525.

Hole, A.R. and Kolstad, J.R., 2012. Mixed logit estimation of willingness to pay distributions: a comparison of models in preference and WTP space using data from a health-related choice experiment. Empirical Economics 42, 445-469.

INS, 2005. Enquête sur l'Emploi et le Secteur Informel au Cameroun en 2005. Institut National de la Statistique, Yaoundé.

INSERM, 2013. Pesticides, Effets sur la santé. Collection Expertise collective. Éditions Inserm, juin 2013. 161 pages.

INSAE, 2008. Projections départementales 2002-2030. Institut National de la Statistique et de l'Analyse Economique. 137 pages.

INSAE (2009) : Annuaire statistique 2005 – 2007. Institut National de la Statistique et de l'Analyse Economique. 607 pages.

INSAE (2011) : Enquête Modulaire Intégrée sur les Conditions de Vie des ménages (EMICoV). Enquête de suivi 2010. Principaux indicateurs. Institut National de la Statistique et de l'Analyse Economique. 124 pages.

Kabunga, N.S., Dubois, T. and Qaim, M., 2012. Heterogeneous information exposure and technology adoption: the case of tissue culture bananas in Kenya. Agricultural Economics 43, 473-486.

Keys, E., McConnell, W.J., 2005. Global change and the intensification of agriculture in the tropics. Global Environmental Change Part A 15, 320-337.

Krinsky, I. and Robb, A., 1986.On approximating the statistical properties of elasticities. Review of Economics and Statistics 68, 715-719.

Krishna, A., 2006. Pathways out of and into poverty in 36 villages of Andhra Pradesh, India. World Development 34, 271-288.

Krishna, A., Lumonya, D., Markiewicz, M., Mugumya, F., Kafuko, A., Wegoye, J., 2006. Escaping poverty and becoming poor in 36 villages of Central and Western Uganda. Journal of Development Studies 42, 346-370.

Lancaster, K., 1966. A new approach to consumer theory. Journal of Political Economy 84, 132-157.

Licciardi S., F. Assogba-Komlan, I. Sidick, F. Chandre, JM Hougard and T. Martin. A temporary tunnel screen as an eco-friendly method for small-scale growers to protect cabbage crop in Benin. International Journal of Tropical Insect Science, 27, 152-158. http://dx.doi.org/10.1017/S1742758407883184

Louviere, J., Hensher, D.A., Swait, J.D. and Adamowicz, W., 2000. Stated choice methods: analysis and applications. Cambridge University Press, Cambridge.

Louviere, J., Street, D., Carson, R., Ainslie, A., Deshazo, J.R., Cameron, T., Hensher, D., Kohn, R. and Marley, T., 2002. Dissecting the random component of utility. Marketing Letters 13, 177-193.

Louviere, J.J. and Meyer, R.J., 2008. Formal choice models of informal choices: what choice modeling research can (and can't) learn from behavioral theory. Review of Marketing Research 4, 3-32.

MAEP (2011) : Plan Stratégique de Relance du Secteur Agricole, Ministère de l'Agriculture de l'Elevage et de la Pêche. 107 pages.

Mamadou C., Fadimata H, Abdramane T (2001) Etudes socioéconomiques de l'utilisation des pesticides au Mali. Les monographies sahéliennes, INSAH 12, Bamako.

Martin T., Ochou O.G., Djihinto A., Traore D., Togola M., Vassal J. M., Vaissayre M., Fournier D, 2005. Controlling an insecticide-resistant bollworm in West Africa. Agriculture, Ecosystems and Environment, 107, 409–411.

Martin T., Assogba-Komlan F., Houndete T., Hougard J.M. and Chandre F. (2006). Efficacy of mosquito netting for sustainable small holders' cabbage production in Africa. Journal of Economic Entomology, 2006, 99, 450-454.

Martin, T., Palix, R., Kamal, A., Delétré, E., Bonafos, R., Simon, S. and Ngouajio, M., 2013. A repellent net as a new technology to protect cabbage crops. Journal of Economic Entomology 106, 1699-1706.

McFadden, D., 1974. Conditional logit analysis of qualitative choice behaviour. In: Zarembka, P. (ed.), Frontiers in Econometrics. Academic Press, New York.

Muleke E. M., Saidi M., Itulya F. M., Martin T., and Mathieu N. (2013). Enhancing Cabbage Seed Germination and Seedling Quality Using Eco-Friendly Nets.Agronomy 3, 2. (www.mdpi.com/journal/agronomy).

Multigner, L., Ndong, J.R., Giusti, A., Romana, M., Delacroix-Maillard, H., Cordier, S., Jegou, B., Thome, J.P., Blanchet, P., 2010. Chlordecone Exposure and Risk of Prostate Cancer. Journal of Clinical Oncology 28, 3457-3462.

Ngowi, A.V.F., Mbise, T.J., Ijani, A.S.M., London, L., Ajayi, O.C., 2007. Smallholder vegetable farmers in Northern Tanzania: Pesticides use practices, perceptions, cost and health effects. Crop Protection 26, 1617-1624.

OECD, 2012, Economic Outlook – Benin, 14 pages.

Olale, E. and Henson, S., 2013. The impact of income diversification among fishing communities in Western Kenya. Food Policy 43, 90-99.

Oliva, A., Spira, A., Multigner, L., 2001. Contribution of environmental factors to the risk of male infertility. Human Reproduction 16, 1768-1776.

Orsini F., Kahane R., Nono-Womdim R., Gianquinto G., 2000. Urban agriculture in the developing world: a review. Agronomy for Sustainable Development, 1-26.

Parrot, L., Dongmo, C., Ndoumbé, M., Poubom, C., 2008a. Horticulture, livelihoods, and urban transition in Africa : Evidence from South-West Cameroon. Agricultural Economics 39n.2, 245-256.

Parrot, L., Tatong Dongmo, C., Nkeng, M.N., Poubom, C., 2008b. Horticulture, livelihoods and pesticides in Africa : Evidence from south-West Cameroun, Conference Endure: Diversifying Crop Protection, 12-15 octobre 2008, La Grande Motte, France. [4] p.

Pazou AEY, BokoM, Van Gestel CAM, Ahissou H, Lalèyè P, Akpona S, van Hattum B, Swart K, van Straalen NM (2006) Organochlorine and organophosphorous pesticide residues in the Ouémé river catchment in the republic of Benin. Environ Int 32:616–623. doi:10.1016/j.envint.2006.01.007.

Pretty, J., Toulmin C. and Williams, S., 2011. Sustainable intensification in African agriculture. International Journal of Agricultural Sustainability 9, 5-24.

Richardson, R.B., Kellon, D., Leon, R.G. and Arvai, J., 2013. Using choice experiments to understand household tradeoffs regarding pineapple production and environmental management in Costa Rica. Journal of Environmental Management 127, 308-316.

Rogers, E.M., 2003. Diffusion of innovations. 5th Edition. Free Press, New York.

Rosenzweig, M. and Binswanger, H.P., 1993. Wealth, weather risk and the composition and profitability of agricultural investments. Economic Journal 103, 56-78.

Royal Society of London, 2009. Reaping the benefits: science and the sustainable intensification of global agriculture. Royal Society, London.

Saha, A., Alan Love, H. and Schowart, R., 1994. Adoption of emerging technology under uncertainty. American Journal of Agricultural Economics 76, 836-846.

Sauphanor, B., G. Severac, et al. (2012). "Exclusion netting may alter reproduction of the codling moth (Cydia pomonella) and prevent associated fruit damage to apple orchards." Entomologia Experimentalis et Applicata 145(2): 134-142.

Scarpa, R. and Rose, J.M., 2008. Design efficiency for non-market valuation with choice modelling: how to measure it, what to report and why. Australian Journal of Agricultural and Resource Economics 52, 253-282.

Scarpa, R., Thiene, M. and Train, K., 2008. Utility in willingness to pay space: a tool to address confounding random scale effects in destination choice to the Alps. American Journal of Agricultural Economics 90, 994-1010.

Scarpa, R. and Willis, K., 2010. Willingness-to-pay for renewable energy: primary and discretionary choice of British households' for micro-generation technologies. Energy Economics 32, 129-136. Tovignan S, Vodouhé SD, Dinham B (2001) Cotton pesticides cause more deaths in Benin. Pestic News 52:12–14.

Shackleton, C.M.M., Pasquini, M.W. and Drescher, A.W. (Eds), 2009. African Indigenous vegetables in urban agriculture. Earthscan, London.

United Nations, 2006. World Urbanization Prospects - The 2005 Revision. United Nations Population Division, Department of Economic and Social Affairs, New York, p. 210 pages.

van den Berg, H. and Jiggins, J., 2007. Investing in farmers—the impacts of farmer field schools in relation to integrated pest management. World Development 35, 663-686.

Williamson, S., 2005. Breaking the barriers to IPM in Africa: evidence from Benin, Ethiopia, Ghana and Senegal. In: The Pesticide Detox: towards a more sustainable agriculture, Ed. J Pretty, Earthscan, London, pp.165-180.

Wilson, C. and Tisdell, C., 2001. Why farmers continue to use pesticides despite environmental, health and sustainability costs. Ecological Economics39, 449-462.

World Bank, 2011. Making the grade, Smallholder Farmers, Emerging Standards, and Development Assistance Programs in Africa A Research Program Synthesis. Washington. 184 pages.

World Bank, 2013. Urban Agriculture. Urban Development Series Knowledge papers. Washington. 104 pages.

Zander, K.K., Signorello, G., De Salvo, M., Gandini, G. and Drucker, A.G., 2013. Assessing the total economic value of threatened livestock breeds in Italy. Ecological Economics 93, 219-229.

TABLES

Table 1: Distribution of the sample frame across different stakeholders operating in different research areas

Stakeholders facilitating and implementing trials in research area	Farmers who use the EFN at least once	Farmers participating at least once in the trial implementation	Sample frame
INRAB-APRETECTRA (Hort CRSP- USAID)	16	60	76
CRM-MC (FAFA)	77	385	462
Total	93	445	538

Source: Own survey (August 2011)

Table 2: Attributes and levels used in the choice experiment (translated from French)

Attribute	Description	Pest control option A & B	Status-quo option
Labor requirement	Labor is one of production inputs for which farmers often face constraints because of seasonal fluctuations. Additionally, high labor spending for pest control can reduce agricultural and livelihood diversification as well as social responsibilities. The setting up of the EFNs and the handling during day time requires at least two people while spraying can be done by one person.	■ 1 person ■ More than 1 person	1 person
Persistence of technology	The longer the duration of a pest control measure the less frequent farmers need to apply it. Referring to farmer's current practices the levels can be defined as: 15 days, 1 month and 2 months.	■ 15 days ■ 1 month ■ 2 months	15 days
Time for technology to be effective	Farmers have to act quickly once damaging insects have attacked the vegetables. Control measures that become effective within a short time from application can help to minimize the damage. The attribute has three levels: 4 hours, 5 – 12 hours and more than 12 hours.	■ Within 4 hours ■ 5 – 12 hours ■ After 12 hours	After 12 hours
Target insects	The pilot survey revealed that respondents distinguished between two broad types of insect groups: 1) fully or mostly harmless insects, and 2) damaging insects. The levels in the choice experiments relate to for which of these insects the chosen pest control is effective.	■ Most of the damaging insects ■ All damaging insects ■ All insects (damaging and harmless)	All insects
Costs of applying technology (in FCFA)[+]	If the nets are to be acquired by the farmers, a certain starting capital is needed. Per production cycle, the costs are (according to APRETECTRA): FCFA 1,000, 1,600 and 2,800 (€1.53, €2.44 and €4.27). These costs do not take into account the maintenance costs of using the nets, and also do not account for the fact that the nets have a lifespan of about four years. The cost attribute of the SQ option is the highest costs level (FCFA 2,800) as this is equivalent to the cost of insecticides required for a standard plot of vegetables ($12m^2$).	■ 2,800 ■ 1,600 ■ 1,000	2,800

[+] € 1 = FCFA 656

Table 3: Respondents' socio-economic and demographic characteristics (N=214)

Characteristics	N	Percentage
Gender:		
Male	204	95
Female	10	5
Age:		
20 to 39 (young)	82	38
40 to 60 (middle-aged)	108	51
> 60 (older)	24	11
Education (number of years in schooling):		
No formal schooling	81	38
Finished Primary school (year 6)	44	21
Finished 4 years of secondary school (year 10)	37	17
Finished 7 years of secondary school (year 13)	51	24
Any level of university	1	<1
Total income per year (€ 1~ FCFA 656)		
< 200,000	22	10
200,000 to 400,000	45	21
400,001 to 800,000	30	14
800,001 to 1,500,000	56	26
1,500,001 to 3,000,000	30	14
3,000,001 to 5,000,000	10	5
> 5000,000	21	10
Number of important activities (in terms of cash flow):		
1	118	55
2	93	44
3	3	1
Experience in vegetable growing (years):		
1-10	138	64
11-30	71	43
> 30	5	2

Table 4: Choice experiment results from different models: Mixed logit (MXL) model, generalized multinomial logit (G-MNL) model and willingness-to-pay in space (WTP-S) model. All models were estimated at 1284 observations from 214 respondents. Estimates from the WTP-S model can be directly interpreted as welfare estimates (see also Table 5).

	MXL		**G-MNL**		**WTP-S**	
	Estimate	SE	Estimate	SE	Estimate	SE
Labor requirement: 1 person	0.588***	0.127	0.586***	0.142	1454***	498
Persistence: 2 months	0.879***	0.165	0.882***	0.189	2203***	731
Persistence: 1 month	0.392**	0.179	0.416**	0.198	979	600
Time to be effective: 4 hours	0.789***	0.149	0.794***	0.167	1970***	521
Target insects: few damaging	0.976***	0.180	0.984***	0.188	2449***	731
Target insects: all damaging	1.448***	0.177	1.455***	0.181	3605***	979
Costs	-0.0004***	0.0001	-0.0004***	0.0001		
User x SQ	-0.303**	0.146	-0.303**	0.150	-0.300**	0.147
Atlantiquex SQ	3.651***	0.254	3.666***	0.254	3.687***	0.247
Standard deviations of random parameters						
Labor requirement: 1 person (n)	0.427**	0.213	0.451**	0.199	1155**	522
Persistence: 2 months (n)	0.104	0.376	0.112	0.883	90	4875
Persistence: 1 month (n)	0.518	0.353	0.550	0.367	1387	979
Time to be effective: 4 hours (n)	0.696***	0.229	0.706**	0.279	1787**	758
Target insects: few damaging (n)	0.743***	0.177	0.733***	0.196	1871***	602
Target insects: all damaging (n)	0.534**	0.267	0.538	0.342	1469*	861
Costs (t)	0.0004***	0.0001	0.0004***	0.0001		
Scale (Tau)			0.029	0.236	0.031	0.262
McFadden R^2		0.21		0.21		0.21
Log likelihood		-1113.36		-1113.09		-1112.76
AIC		2256.7		2258.2		2257.5

*** 1% significance level; ** = 5% significance level; * = 10% significance level

SE = Standard error; SQ = Status-quo option

Table 5: Welfare estimates, derived from two models: mean and 95% confidence interval (CI) (in FCFA)

	MXL		WTP-S	
Attribute	Mean	95% CI	Mean	95% CI
Labor requirement: 1 person	1513	462 - 2524	1454	478 - 2431
Persistence: 2 months	2194	804 - 3531	2203	770 - 3635
Persistence: 1 month	1213	492 - 1906	not significant	
Time to be effective: 4 hours	2051	785 - 3268	1970	949 - 2992
Target insects: few damaging	2539	423 - 4574	2449	1016 - 3882
Target insects: all damaging	3731	1025 - 6333	3605	1687 - 5524

Note: € 1 = FCFA 656

Table 6: Benefits and costs of cultivating a cabbage plot ($12m^2$) over four years with two production cycles per year under different scenarios

	Scenario 1: SQ (exclusive use of insecticides)	Scenario 2 (high quality net)	Scenario 3 (low quality net without renewal)	Scenario 4 (low quality net renewed after 2 years of use)
Costs of net purchase	0	9,220	6,454	12,908
Net maintenance costs	0	16,400	8,200	16,400
Costs of pesticide use	52,000	0	29,200	6,400
Yield (Income)	90,400	90,400	90,400	90,400
Management benefits	11,632	33,384	22,508	33,384
Environmental benefits	0	28,840	9,796	19,592
Health care savings	0	1,600	800	1,600
Net benefits over 4 years (FCFA)	50,032 (€ 76)	128,604 (€ 196)	79,650 (€ 121)	109,268 (€ 167)
Net present value over 4 years discounted at 5%	44,083	113,312	70,179	96,276
Required % change in yield for same net benefit than SQ		-86.9%	-32.8%	-65.5%

FIGURES

Figure 1: Research area, indicated by blue stars (the red line defined Hort CRSP Zone)

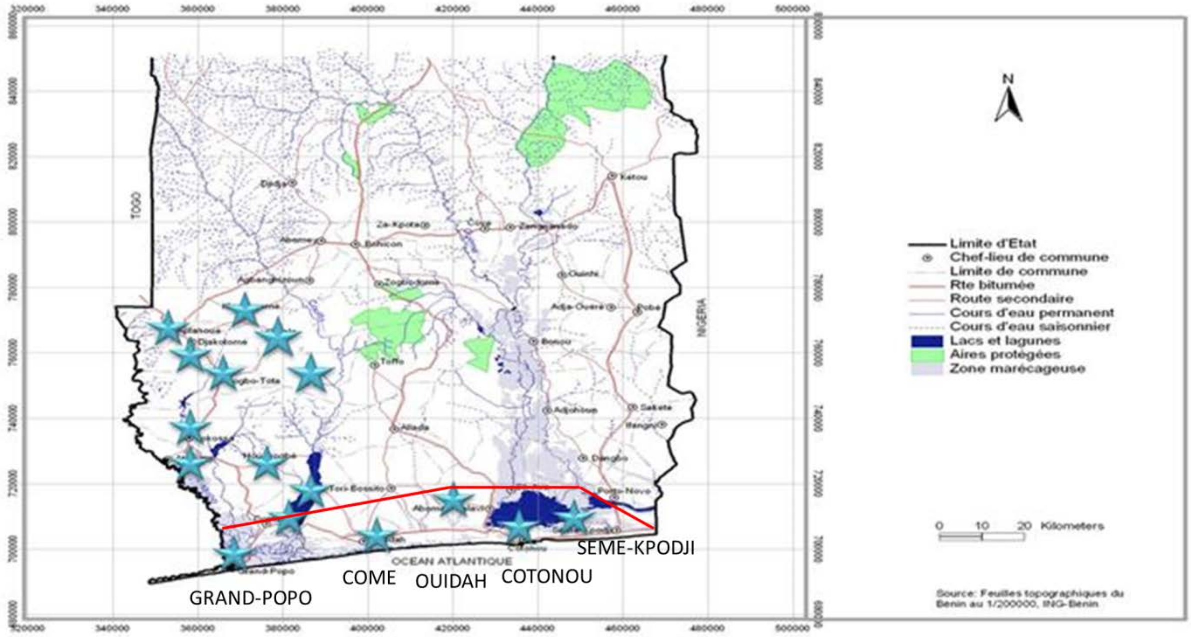
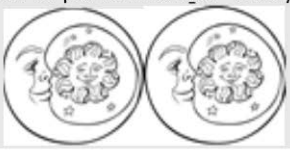
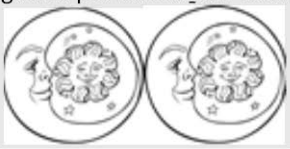
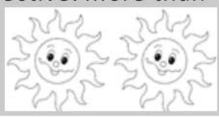


Figure 2: Example of a choice set used in the survey (the original sets were in French). It shows three options and the farmers chose their most preferred one. The option on the right hand was always the same, the status-quo option which shows farmers' current pest control strategy, characterized by high quantities of insecticides. The other two options (A and B) imply alternative pest control strategies.

Pest control option A	Pest control option B	Status-quo
Labour requirement: 1 person 	Labour requirement: more than 1 person 	Labour requirement: 1 person 
Length of performance: 2 days 	Length of performance: 1 day 	Length of performance: 2 days 
Time to be effective: 4 hours 	Time to be effective: more than 12 hours 	Time to be effective: 4 hours 
Target organisms: all damaging insects 	Target organisms: all insects 	Target organisms: all insects 
Costs: 2800	Costs: 1000	Costs: 2800

Note: FCFA 2800 ~ € 4.30; FCFA 1,000 ~ € 1.50

Figure 3: Net benefits of using insecticides, a high quality eco-friendly net (EFN) and a low-quality EFN over 1 to 6 years, assuming the same annual yield under all three methods.

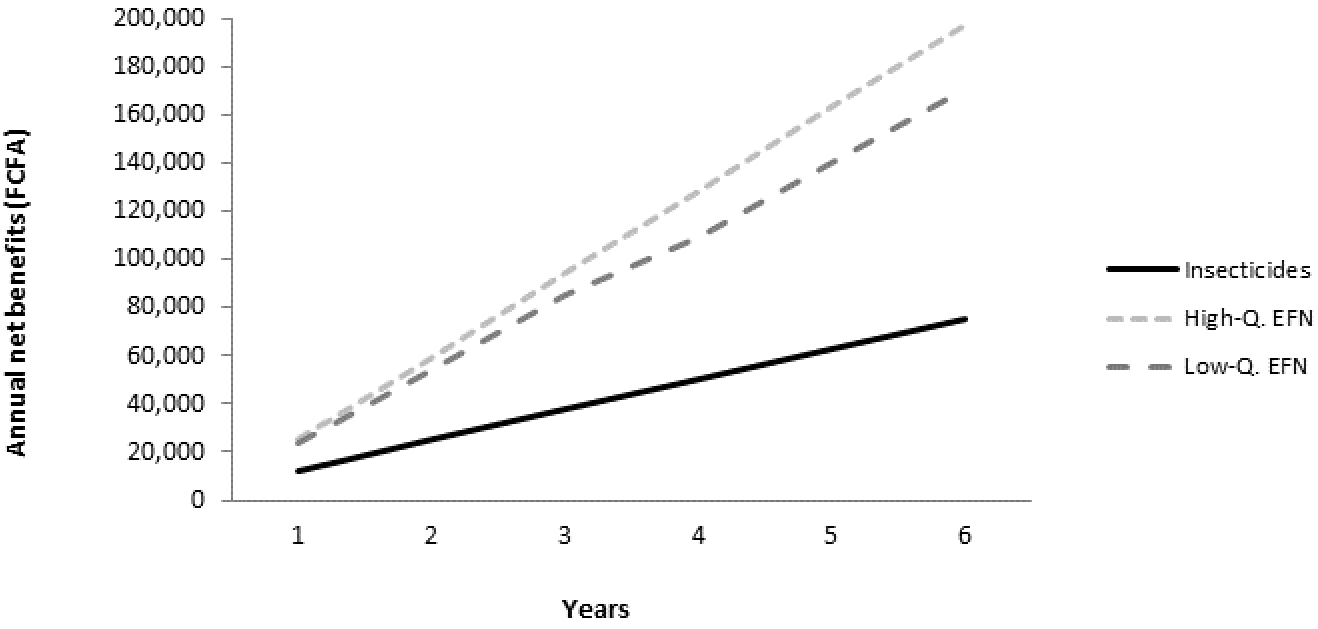


Figure 4: Net benefits of using insecticides, a high quality eco-friendly net (EFN) and a low-quality EFN over 4 years with different EFN purchase prices (as a multiple of the current price).