



## Control of vegetable pests in Benin – Farmers' preferences for eco-friendly nets as an alternative to insecticides



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### ARTICLE INFO

#### Article history:

Received 5 March 2014

Received in revised form

4 September 2014

Accepted 8 September 2014

Available online

#### Keywords:

Benefit–cost analysis

Choice experiment

Integrated pest management

Pesticides

Insect net

Stated preference

Urban agriculture

West Africa

### ABSTRACT

We investigated if eco-friendly nets (EFNs) are a viable and acceptable alternative to extremely high levels of insecticide use in vegetable production. Using a choice experiment, we found that vegetable producing farmers in Benin preferred all of the characteristics of EFNs except the higher labor requirements. The nets had been distributed in a trial phase for free but in the long run farmers would need to purchase the EFNs. The break-even point for investing in nets was found to 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 human health.

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### 1. Introduction

Continuing growth in human population and consumption means that the global demand for food will increase for at least another 40 years (Godfray et al., 2010) and that the world need 70–100% more food by 2050 (World Bank, 2008). More than one in seven people today still do not have access to sufficient protein and energy from their diet, and even more suffer from some form of micronutrient malnourishment (Barrett, 2010). Increasing urbanization and climate change aggregates food insecurity. The urban population expansion is more pronounced in developing countries

as a result of rural-to-urban migration and natural population growth (FAO, 2007). By 2030, over half of Africa's population will reside in urban areas, augmenting the 'invisible crisis' of urban food security (Crush and Frayne, 2010).

Smallholder farmers can play an important role in supplying urban markets and meeting the food demand of growing urban centers (FAO, 2007, 2012). In Sub-Saharan Africa (SSA) vegetables have been growing in importance both as food for city dwellers and for generating and diversifying income for smallholder farmers (Weinberger and Lumpkin, 2007; World Bank, 2008). In urban areas farmers use public open spaces (e.g. along roads, power lines, drains and streams) to cultivate vegetables commercially for the local market (Drechsel and Dongus, 2010; Crush et al., 2011; Dossa et al., 2011; FAO, 2012; Probst et al., 2012a), often in groups, though not necessarily working together (Jacobi et al., 2000). However, fruit and vegetable consumption in SSA remains low and currently

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contributes at most 82%, and sometimes as low as 22%, of the daily intake recommended by the World Health Organization and Food and Agricultural Organization (Nair and Ngouajio, 2010).

One impediment to boosting vegetable production in SSA is, besides the competition for fertile land, water and energy, high exposure to pests and diseases (MEA, 2005; Waterfield and Zilberman, 2012). Globally, food estimated to feed an additional one billion people is lost to pests (Birch et al., 2011). In Benin, for instance, insects cause an average yield loss of 30–40% (Matthews, 2008).

To counter pests, farmers in Benin rely heavily on synthetic pesticides to reduce the risk of harvest and income loss, particularly to protect exotic crops like cabbage and lettuce (Williamson et al., 2008; Lund et al., 2010; Ahouangninou et al., 2012, 2013). Such heavy pesticide use not only results in high levels of human exposure and poisoning (Williamson, 2005; Ntow et al., 2006) but also reduces the quality of aquatic and terrestrial ecosystems, contaminating drinking water and food crops (Pimentel et al., 1992; van der Werf, 1996). Smallholder farmers often use pesticides with little understanding of their impact on human health and the environment (Matthews, 2008) and inappropriate knowledge on safe handling, storing and applying pesticides (Williamson, 2005; Ngowi et al., 2007; Ahouangninou et al., 2012; Amoabeng et al., 2014; de Bon et al., 2014). Farmers also often ignore, or are unaware of, regulations issued by the Benin government for the distribution and use of pesticides (Présidence de la République du Benin, 1991) and assume that the only solution to pest control is to increase dose and spray frequency (Martin et al., 2006). Such overuse of hazardous pesticides both increases resistance of pests and destroys beneficial predators (Clarke, 1997; Wilson and Tisdell, 2001; Ntow et al., 2006; Lund et al., 2010; Probst et al., 2012b).

According to Probst et al. (2012a), without changing pest control strategies and efficient governmental control mechanisms, urban vegetable production in the cities will remain in a state of “systemic rigidity”. A potential means to break the reliance on pesticides is a form of sustainable and integrated pest management (IPM) that is affordable and accessible to all farmers (Tokannou and Quenum, 2007; Houngué and Kindomihou, 2009) combined with practices that intensify production through carefully managed inputs of fertilizer and water (Herrero et al., 2010).

One approach to IPM can be physical exclusion of pests using eco-friendly nets (EFNs). EFNs were introduced to farmers in Benin in 2010 with the aim of reducing the use of pesticides, mainly insecticides, while increasing both yield and quality. Initially the EFNs were trialed on cabbage production first in Benin (Martin et al., 2006; Licciardi et al., 2008) then in Kenya as part of an IPM project funded through USAID and Cirad ([www.bionetagro.com](http://www.bionetagro.com)). In Benin the EFNs were allocated to participating farmers at no cost through a non-governmental organization (NGO). However, the free allocation of EFNs cannot be sustained after the trial phase so it is important to understand the characteristics of the nets farmers prefer, and the yield to cost ratio compared to pesticides.

The objectives of our study are (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' preferences and values for the characteristics of EFNs and hence for the benefit of using EFNs as substitutes for insecticides. These benefits are measured

through farmers' changes in welfare that come with the change from their current farming practice to the use of EFNs and are expressed as their willingness-to-pay (WTP). The welfare estimates can be used in a benefit-cost analysis and, by aggregating farmer's welfare estimates for each of the characteristics of the EFNs, we can make recommendations about the future price of the nets as well as the yield that needs to be achieved to make the EFNs economically viable. A few 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).

## 2. Materials and methods

### 2.1. Study area

The study was carried out in two geographical zones, differing in soil type, 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 (Fig. 1). In this zone trials of EFN use have been implemented by the National Agricultural Research Institute of Benin (INRAB) through the NGO APRETECTRA.<sup>1</sup> The second zone does not border the sea and comprises nine districts: Bopa, Houéyogbé, Lokossa, Athiéme, 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 de Comé), Mono (Comé, Grand-Popo, Bopa, Houéyogbé, Lokossa and Athiéme) and Couffo (Dogbo, Aplahoué, Toviklin, Klouékanmè, Lalo) (Fig. 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 and the relatively high population density limits the land size for 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 African eggplant ‘gboma’, 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., 2005). Access to pesticides in the research area is further facilitated by government subsidies to purchase these products to boost production.

### 2.2. Sampling

In order to ensure efficient dissemination of knowledge about EFNs and how to use them, APRETECTRA and CRM-MC have 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 ‘user’) 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

<sup>1</sup> Association des Personnes Rénovatrices des Technologies Traditionnelles (Association for the renewing of traditional technologies).

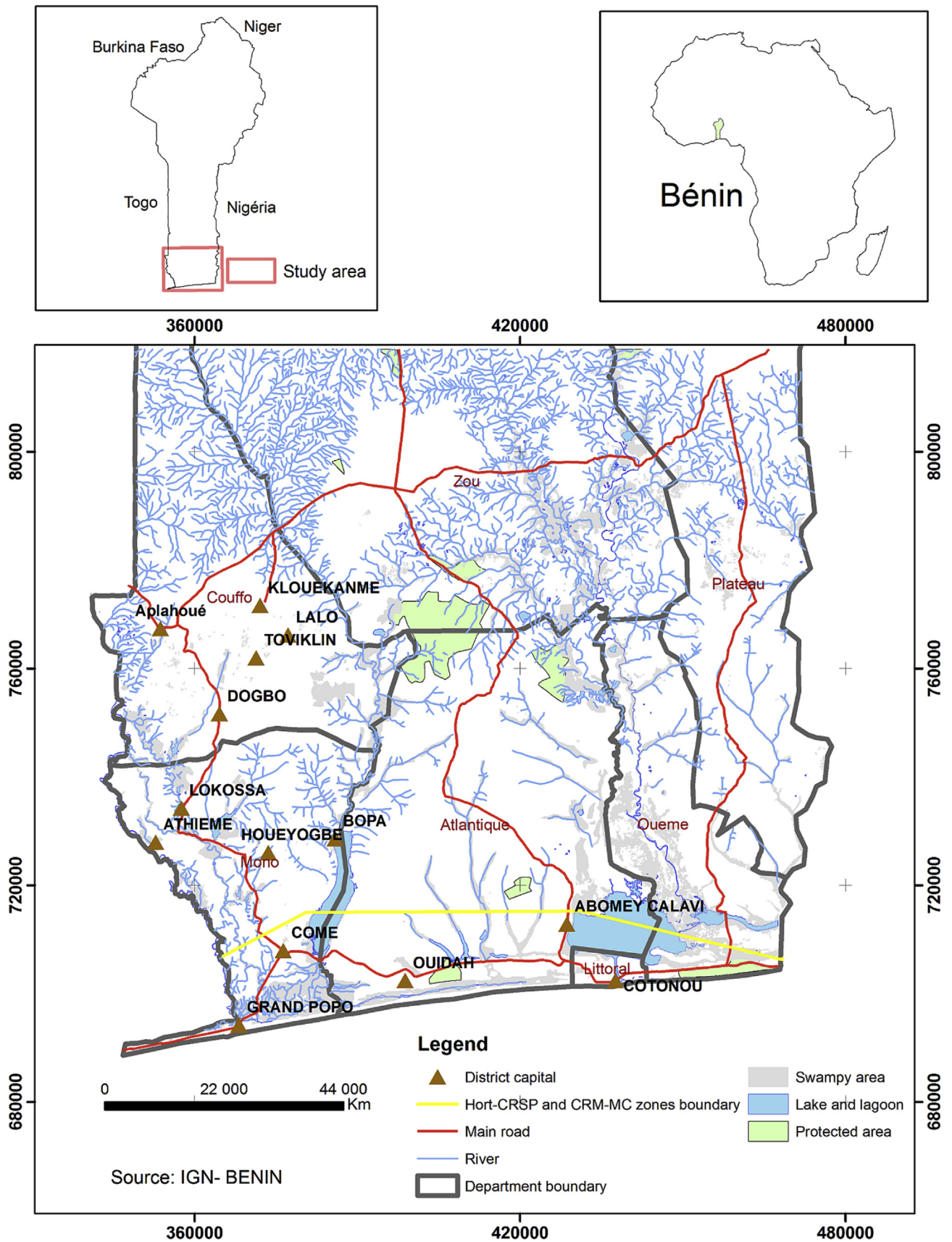


Fig. 1. Research area in southern Benin.

need some knowledge of and exposure to it (e.g. Dimara and Skora, 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).

We applied the Moivre-Laplace theorem as suggested by Advantages surveys (Advantages, 2004) 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  $\mu_{\alpha}$  is the 'p-value' of the standard normal distribution ( $\mu_{\alpha} = 1.96$ ),  $F_n$  is the proportion of vegetable growers who took part in the demonstration trials.  $\delta$  is the half-amplitude of the confidence interval, equal to 0.05 for the selected confidence level. The integration of these data in Eq. (1) gives a required sample size of 220 (93 users and 127 observers).

### 2.3. Data collection and questionnaire

Six local people, all knowledgeable in agronomy, were trained to collect the data. The whole study consisted of a pilot survey and two phases of the main survey with vegetable producing farmers. In the pilot survey, which took place over ten days in August 2011, we used semi-structured interviews and collected information about choices of crops, yield, types and severity of pests, and pest control strategies, including costs and quantities. We also asked for perceptions about handling pesticides, their overuse and associated health risks. This information was used to create attributes and labels and allowed us to design a first draft of the CE. The first phase of the main survey with the whole sample (220 farmers) was conducted between October and November 2011. During this phase, 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, experience in vegetables cropping, and relevant information about farmers' vegetable production systems (yield, variable and fixed costs, revenues, quantity sold at markets, labor distribution etc.). The data on vegetable production were used to assess the benefits and costs of alternative pest control strategies. The second survey phase, in which the CE was presented to the 220 farmers, was conducted between January and March 2012.

In addition to the interviews with farmers, we visited two health care centers in each research zone to obtain information about

**Table 1**  
Distribution of the sample frame, grouped into users and observers, across the two research zones.

Research area	Stakeholders implementing trials	Users	Observers	Total sample frame
Zone 1	National Agricultural Research Institute of Benin (INRAB) & NGO APRETECTRA	16	60	76
Zone 2	Conseil Régional des Maraîchers du Mono-Couffo (CRM-MC)	77	385	462
Total		93	445	538

Note: **Users** were those farmers who participated in the trial phase of the EFNs and were given some nets to actually use in their own vegetable fields. **Observers** were those farmers who participated in the trial phase of the EFNs but who did not use the nets at home.

APRETECTRA = Association for the renewing of traditional technologies.

health issues that arising from prevailing high rates of pesticide use. This was necessary because no official data are yet available from health care spending in the research area and in Benin in general (Ahouangninou et al., 2012). In informal interviews with practitioners we asked about the frequencies of health issues that could be attributed to pesticide overuse (e.g. skin diseases, cardiopulmonary disorders, digestive, neurological and hematological symptoms) and the cost of treatment.

### 2.4. The choice experiment








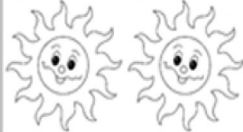
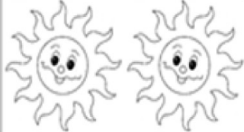



In a CE, respondents are presented with a hypothetical setting and asked to choose their preferred option among several options presented in a series of different choice tasks. These choice tasks, known as choice sets, contain a finite number of options which describe the environmental policy outcome in question (Adamowicz, 2004). The options vary in their level of attributes of importance and to estimate welfare changes each option is required to include a cost attribute (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/benefit of a product, such as the EFN, as the sum of the values of its characteristics. The values are inferred from farmers' WTP which is derived from the choices farmers make and statistically analysed using random utility models (see Analysis section).

We used choice sets consisting of three options (see Fig. 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 all farmers in the research area and that was characterized by high levels of expenditure on 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 12 m<sup>2</sup>. This size corresponded to the plot size on which the EFNs were trialed and also to the vegetable 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 (Fig. 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.

### 2.5. Analysis

The random utility theory (McFadden, 1974) is the econometric foundation of statistical models of choice. According to the random

Pest control option A	Pest control option B	Current practise
Labour requirement: 1 person 	Labour requirement: more than 1 person 	Labour requirement: 1 person 
Persistence: 2 months 	Persistence: 1 month 	Persistence: 15 days 
Time to be effective: within 4 hours 	Time to be effective: after 12 hours 	Time to be effective: after 12 hours 
Target insects: all damaging 	Target insects: all 	Target insects: all 
Costs: 2800	Costs: 1000	Costs: 2800

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

Fig. 2. Example of an unlabeled 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 practice, characterized by the use of large quantities of insecticides. The other two options (A and B) imply alternative pest control strategies, i.e. changes from the current practice.

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 utility/benefit.

A growing body of literature exists on improving the 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 start with the presentation of results from a mixed logit (MXL) model, for many years the most commonly applied model in choice data analysis. The advantages of an MXL model over the basic multinomial logit (MNL) model include relaxation of the assumption about the distribution of error terms,<sup>2</sup> 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, for instance, because of different choice task processing strategies or understanding of the choice tasks. Separating scale and taste heterogeneity, which are inseparable in an MXL model, is important to avoid making false recommendations. Thus, alternative models such as the scaled multinomial logit (S-MNL) model (Brefle and Morey, 2000), the generalized multinomial logit model (G-MNL) model (Fiebig et al., 2010; Greene and Hensher, 2010) and the willingness-to-pay in space (WTP-S) 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 as opposed to preference space models have increasingly

<sup>2</sup> This assumption is known as the independence from irrelevant alternatives (IIA) condition. It means that the probability of a particular alternative in a choice set being selected is independent of the other alternatives (Hensher et al., 2005).

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

Attribute	Description	Levels <sup>a</sup>
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 (SQ) More than 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 (SQ) 1 month 2 months
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 h, 5–12 h and more than 12 h.	Within 4 h 5–12 h After 12 h (SQ)
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 depend on the types of insect for which the chosen pest control is effective.	Few damaging insects All damaging insects All insects (damaging and harmless) (SQ)
Costs of applying technology (in FCFA) <sup>b</sup>	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, 1600 and 2800 (€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 2800) as this is equivalent to the cost of insecticides required for a standard plot of vegetables (12m <sup>2</sup> ).	2800 (SQ) 1600 1000

<sup>a</sup> SQ indicates the level used for the status-quo option.

<sup>b</sup> €1 = FCFA 656.

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 WTP-S models 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 tested for farmers' heterogeneous preferences by including interaction effects between the SQ option and socio-demographic characteristics variables in all three 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).

The utility coefficients from the WTP-S model can immediately be interpreted as the welfare estimates while those from the MXL and G-MNL models have to be approximated by simulations (Hensher et al., 2005). For this, numerous draws were taken from the distribution of the coefficients and the non-cost and cost attributes, 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. For the subsequent benefit-cost analysis the WTP estimates for the relevant attributes were aggregated to obtain the total benefits of different pest control strategies with the associated characteristics and under different scenarios.

### 3. Results

#### 3.1. 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 (40–60 years), and many never attended a formal school (38%) or only completed primary school (21%) while 41% at least completed Year 10.

In Benin, the mean income is CFA 120,500 (€184) per adult equivalent (INSAE, 2011). Given the average household size of seven, this is about FCFA 840,000 per household. Almost half of the respondents (45%) had an annual household income of less than FCFA 800,000 (~€1200), 40% had an annual income between FCFA 800,000 and 3 million and 15% had an annual income of more than FCFA 3 million (~€4600). 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.

#### 3.2. Results of the choice experiment

##### 3.2.1. Finding the base models and comparison of model results

Only the attribute 'effect within 5–12 hours' was insignificant and was dropped from the saturated model. 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

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-S models are more practical as they offer a more immediate interpretation of the

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

Characteristics	N	Percentage
<i>Gender</i>		
Male	204	95
Female	10	5
<i>Age</i>		
20–39 (young)	82	38
40–60 (middle-aged)	108	51
>60 (older)	24	11
<i>Education (in number of years in schooling)</i>		
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
<i>Total income per year (in FCFA<sup>a</sup>)</i>		
≤800,000	97	45
800,001–3,000,000	86	40
>3,000,000	31	15
<i>Number of important activities for cash flow</i>		
1	118	55
2	93	44
3	3	1
<i>Experience in vegetable growing (in years)</i>		
1–10	138	64
11–30	71	43
>30	5	2

<sup>a</sup> €1 = FCFA 656.

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 h) over effect within 5–12 h and effect after 12 h, 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.

### 3.2.2. Factors explaining variations in the likelihood of choosing the current farmer's practice (the SQ)

Overall, in 59% of the choices, respondents chose the SQ over one of the other two options that would involve the use of EFNs. The remaining 41% chose either option A (17%) or option B (24%). Only 17 respondents (8%) entirely rejected the two alternative control options A and B and opted for the SQ in all six presented choice sets.

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 observers in the trial groups (Table 4). The sign of the coefficient

of the interaction 'User × SQ' was negative and significant, meaning that being a user as compared to an observer decreased the probability of choosing the SQ option. The sign of the coefficient of the interaction 'Department Atlantique × 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.

### 3.2.3. Welfare estimates

We did not simulate the welfare estimates from the G-MNL model because the model results were very similar to those of the MXL model. The welfare estimates from the MXL and the WTP-S model did not differ greatly (Table 5). When averaged over both models, farmers were willing to pay about FCFA 15,000 (€2.30) for a pest control strategy that requires only one person to implement, FCFA 2200 (€3.40) for a two month persistence of the measure, and FCFA 2000 (€3.00) for fast effectiveness of the measure. Farmers would pay the most for the preferred insects that the control strategy can target. Compared to targeting all insects (damaging ones and harmless ones) farmers would be willing to pay about FCFA 2500 (€3.80) to target only a few damaging insects and about FCFA 3650 (€5.60) to target all damaging insects.

### 3.3. Benefit-cost analysis

We calculated the benefits and costs for the production of cabbage over four years on a plot of 12 m<sup>2</sup> 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 EFNs of different qualities (in terms of mesh 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 m<sup>2</sup> are about FCFA 6500 per cycle, i.e. FCFA 52,000 in total.

The costs of using EFNs comprised the purchase price of the nets and their maintenance costs which included the materials for holding up the nets (planks and iron arch) and of low doses of pesticides that are sprayed around the planks and under the nets against weeds, as the nets only protect against insects. Farmers quantified the maintenance costs of the EFNs to be FCFA 2050 per cycle, i.e. FCFA 16,400 over four years (Table 6). The current purchase price of a high quality net (0.4 mm mesh size) is FCFA 9220, including the shipping costs from Tanzania, where nets are produced, to Cotonou, custom tax and further transportation costs from Cotonou to the communities.<sup>3</sup> We assumed the costs of purchasing a low quality net (0.9 mm mesh 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 6400 in total).

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

<sup>3</sup> The price of EFNs is very similar to that of mosquito nets sold in Benin but the mesh and material are different (mosquito nets: mesh size = 1.5 mm, material = woven polyester; EFNs: mesh size = 0.4 or 0.9 mm; material = knitted polyethylene).

**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 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 h	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 × SQ	-0.303**	0.146	-0.303**	0.150	-0.300**	0.147
Department Atlantique × SQ	3.651***	0.254	3.666***	0.254	3.687***	0.247
<i>Standard deviations of random parameters</i>						
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 h (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 <sup>2</sup>		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.

to the same annual yield (field experiments to determine yield are currently progressing but EFNs have not yet been used over a full four year period). According to farmers, the annual yield from two production cycles amounts to FCFA 22,600, i.e. FCFA 90,400 in total, under the current practice (the SQ).

The health care benefits for the scenarios using EFNs were estimates based on the pilot study with farmers and personal communications with health care center practitioners but they maintain rough estimates. At a minimum farmers would save FCFA 400 per year (purchase of medicines and transport cost to health care center) during which they used EFNs instead of high doses of insecticides.

The management and environmental benefits are derived from aggregating the welfare estimates for relevant characteristics as derived from the CE results. To be conservative, we took the results of the WTP-S model as they were slightly lower for all attributes. As management benefits we defined all advantage of a chosen strategy that arise from the labor requirement, persistence and the time to be effective. For the current practice (SQ), the aggregated management benefits of using a high quality EFN over four years would only be the lower labor requirement (FCFA 1454 per cycle or FCFA 11,632 over four years. There are no advantages of the SQ over the alternative scenarios for either persistence or time to be effective.

**Table 5**  
Welfare estimates of characteristics of pest control over one cycle of vegetable production, derived from two models: mean and 95% confidence interval (CI) (in FCFA).

Attribute	MXL model		WTP-S model	
	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 h	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; MXL = Mixed logit; WTP-S = Willingness-to-pay in space.

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<sup>4</sup>).

An environmental beneficial pest control strategy is one that specifically targets only damaging insects (all or a few) and not the harmless ones. For the high quality EFNs (scenario 2) this would amount to FCFA 28,840 over four years (FCFA 3605 per production cycle; Table 5). For scenario 4, the use of low EFNs that targets only a few damaging insects would have an environmental benefit of FCFA 2449 per cycle (Table 5), and over four years of FCFA 19,592. Scenario 3, also using EFNs that target only a few damaging insects, would result in environmental benefits of FCFA 9796 (see footnote 5).

Applying a high quality EFN for cabbage production on 12 m<sup>2</sup> 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.

### 3.4. Sensitivity analyses

#### 3.4.1. Lifespan of eco-friendly nets

The lifespan of the EFNs 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

<sup>4</sup> The management benefits over four years for scenarios 2 and 4 were calculated (from Table 5) as follows: FCFA 2203 × 8 + FCFA 1970 × 8 = FCFA 33,384. For scenario 2, the management costs equal half of those of scenario 1 plus half of those of scenarios 2/4 (FCFA 5816 + FCFA 16,692 = FCFA 22,508).

<sup>5</sup> The environmental benefits over four years (two years use of nets) were calculated as follows: FCFA 2449 × 4 = FCFA 9796.

**Table 6**  
Benefits and costs of cultivating a cabbage plot (12 m<sup>2</sup>) 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	9220	6454	12,908
Net maintenance costs	0	16,400	8200	16,400
Costs of pesticide use	52,000	0	29,200	6400
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	9796	19,592
Health care savings	0	1600	800	1600
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%

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). 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).

At the current purchase price, EFNs have a net benefit over pesticides within a year (after two production cycles). However, there is always the risk that EFNs do not last that long. Given that for farmers with multiple plots of 12 m<sup>2</sup>, 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.

#### 3.4.2. Purchase price of eco-friendly nets

First estimates showed that the nets will cost about FCFA 9220 per 12 m<sup>2</sup> (€14) in the future. 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 (Fig. 3). 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 12 m<sup>2</sup> (€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 competitiveness at a purchase price of about six times the current costs (about FCFA 70,000 or €107 per 12 m<sup>2</sup>).

## 4. Discussion

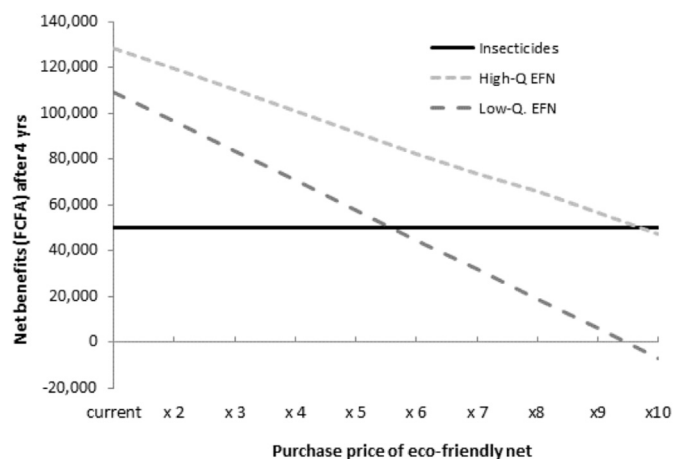
### 4.1. Farmers' attitudes towards eco-friendly nets

Overall, a minority of farmers (8%) would not choose a control strategy other than the SQ (farmers' actual practices) which is promising for future acceptance of an alteration to farmers' current practice. Furthermore, the choices made by farmers as part of the CE 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 12–16 bouts of labor per month during a cycle for moving the nets are required, or, since two people are required, 24–32 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



**Fig. 3.** 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).

(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 to have effect 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 h 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 only a few 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 xylostella* and *Hellula undalis*) but fail to keep out numerous others like aphids and nematode vectors are beyond this control. To target these as well, the nets need 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 CE revealed differences in farmers' preferences for choosing one of the two alternative control strategies over the current practice (the SQ). While the research zone had no significant impact, 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 that farmers in these two districts are very close to the main markets in Cotonou which are also the biggest trading centers for pesticides, formally and informally (pesticides are often used as a payment vehicle). Farmers in these districts were in close contact with middlemen who sell pesticides and for whom the promotion of EFNs is against their interests. 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). 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). This is not surprising, assuming that the 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. Those users may also have been influenced by their positive experience of the EFNs in the short time the trials had been running before the CE was conducted and had better knowledge of the nets' potential costs and benefits than had those

farmers who only observed the trials without having taken the nets home to apply.

#### 4.2. Net benefits of different pest control strategies

The sensitivity analyses showed that pest control strategies around high quality EFNs yield the highest net benefit after four years (eight production cycles), which is more than double the net benefit of farmers' current practice (excessive use of pesticides). However, for undertaking the benefit-cost analysis we had to make the assumption that using the nets will deliver the same yield as farmers' current practice, which is unlikely. Intuitively one would think that farmers' current practice yields the highest possible outcome as farmers seek profit maximization. For the net benefits to be the same, yield under the high quality EFN could be 87% lower than under farmer's current practice. Using a low quality net with replacement after two years would require the 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.

#### 4.3. Health benefits

The potential health benefits from EFNs are to-date uncertain because of lack of data (Ahouangninou et al., 2012). Based on farmers' statements during the survey and information from health care centers we assumed 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 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 (~€15) (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). So, the health benefits from replacing most pesticides by EFNs is likely to result in much higher health benefits, particularly in the long-term, than we have assumed here.

#### 4.4. Study limitations

There are two main potential limitations to our study. Firstly, while we performed sensitivity analyses 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 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.

#### 4.5. Outlook

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; FAO, 2012; 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 other countries 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. Preliminary assessments of yield using EFNs suggest that yield over four years (for a plot of 12 m<sup>2</sup>) 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 depending of the climate conditions (Muleke et al., 2013, 2014). It could also be that the research project itself had an overall positive impact of farmer's understanding of vegetable production and proper use of pesticides through the participation in the EFNs on-farm trials. As this might explain some of the high yield under EFNs, this might in the future also reflect in higher yields under exclusive insecticide use.

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 raising 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.

## 5. Conclusions

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 which 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 and during this trial period the nets were provided to farmers for free. In the long-term the nets need to be sold to farmers. This study used a survey-based non-market valuation technique, a choice experiment, to assess farmers' preferences for pest control strategies with the aim of predicting the potential benefits of a wider distribution of eco-friendly nets. We conclude that eco-friendly nets are an economically viable alternative to farmer's current practice, the single insecticide spray, with a net benefit exceeding that of the current practice after only one year with two production cycles. 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 (€196 versus €76 for 12 m<sup>2</sup>). Shorter lifespan of the 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.

## Acknowledgments

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 (APPRETEC-TRA) in Benin for their support. We also wish to thank Stephen Garnett of Charles Darwin University for his editorial advice.

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