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Cost:Benefit analysis of insect net use in cabbage in real farming conditions among smallholder farmers in Benin

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ABSTRACT

Insect net use provides a physical exclusion of pests as well as a microclimate change, thus increasing soil humidity, vegetable quality and yields in tropical conditions. This paper presents the findings of a cost:benefit analysis of this technology in real farming conditions compared to current insecticide practices. The surveys were conducted in Benin for cabbage production (*Brassica oleracea* L.) during two production cycles. There were almost no significant differences in costs between unnetted and netted cabbage for the two production cycles. The only factors that varied were farm gate prices, the number of cabbages marketed and their size. Improved yields contributed significantly to the higher cost:benefit ratio for netting protection. Insecticide costs significantly declined by 68%–95% when shifting from unnetted protection to netted protection and total operational and labor costs declined by 3%–40%. Insect net use generated threefold higher margins and an average 1:2.66 cost:benefit ratio compared to 1:1.58 for current practices. Overall, the netting technology displayed less variation for costs, yield, and cabbage quality than insecticides. The next step is to scale up the supply of marketed insect nets.

1. Introduction

Africa has the lowest rate of pesticide use in the world but vegetable production seems to be an exception (Williamson et al., 2008). Agricultural intensification in sub-Saharan Africa is hampered by the widespread year round presence of pests. Insects are among the leading causes of harvest losses for vegetable crops (de Bon et al., 2014). For example, the major pest of cabbages such as the diamondback moth *Plutella xylostella* (Linnaeus) and the cabbage webworm *Hellula undalis* (Fabricius) are responsible for the highest yield losses in Benin (Martin et al. 2006). To ensure their production and income, farmers in Benin carry out chemical treatments more frequently with increasingly higher doses (Ahouangninou et al., 2011). They also often use unlicensed and non-recommended products with the risk of contaminating crops and the environment with poisonous residues (Ahouangninou et al., 2012; de Bon et al., 2010, 2014).

Pesticide overuse has severe environmental and health impacts. Notwithstanding soil and water contamination, chemical insecticides have been applied to such a high extent in peri-urban areas that major insect pests have developed resistance (Sarfraz et al., 2005; Carletto et al., 2010; Houndété et al., 2010). Farmers' only solution is to increase the chemical doses and spraying frequency. Insecticide overuse is facilitated by their wide availability in official or informal markets and by the lack of control or chemical residue analyses in many Sub-African countries (Ahouangninou et al., 2013). By this vicious circle, harvest losses increase, fruits and vegetables are increasingly contaminated by chemical residues, soils and groundwater are polluted, fauna destroyed and human health affected. *P. xylostella*, is an important pest of brassicaceous crops worldwide. It has developed resistance to almost every synthetic insecticide applied in the field and consequently is often hard

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to control in crucifer-growing areas (Sarfraz et al., 2005). Studies in Côte d'Ivoire, Burkina Faso and Benin showed that intensive pesticide use in the cotton cultivation *Gossypium hirsutum* L. increases the resistance of the malaria vector *Anopheles gambiae* Gilles (Yadouleton et al., 2011). This resistance thus hampers the fight against malaria, with long-lasting insecticide treated bed nets recommended by the World Health Organization.

Health impacts of pesticides are increasingly documented. Prolonged exposure to pesticides has been associated with short-term (nausea, irritation, and allergy) and long-term diseases (non-Hodgkin's lymphoma, leukemia, cardiopulmonary disorders, neurological and hematological symptoms and skin diseases) (Audibert, 2010; INSERM, 2013). From a social perspective, ill health and high healthcare costs overwhelmingly represent the greatest reason for households slipping into poverty in communities in Kenya, Uganda, India and Peru (Krishna, 2007). The health impacts of agrochemical inputs have not yet been reported as a factor contributing to the pauperization of farmers in the economic development literature, but they probably contribute to the vulnerability of farmers, along with malaria and HIV.

The World Bank supports pest control strategies that promote the use of biological or eco-friendly control methods. The European Union is conducting a program to set standards and 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 Pesticide Initiative Programme). This is a significant challenge in Africa for present export markets as well as for domestic markets in the future. We need to anticipate future requirements in biological or eco-friendly control methods in West African domestic markets.

Integrated pest management (IPM) promotes more environmentally friendly methods for pest control, with pesticide applications as a last resort. This approach results in reduced pesticide use, increased productivity and profitability, and fewer deaths from poisoning. IPM is viewed as one of the most effective alternatives to the application of single synthetic pesticides and plant extract sprays (Pretty et al., 2011; Amoabeng et al., 2014).

IPM based on passive physical methods to protect crops is reported to be a more preventive and sustainable pest management tool (Way and van Emden, 2000). Among the various alternatives available to farmers wishing to adopt an ecological intensification approach, insect nets ensure physical exclusion of pests as well as a microclimate change, thus increasing soil humidity, vegetable quality and yields in tropical conditions (Martin et al., 2006).

Insect nets are made of synthetic or natural fiber and the netting mesh can be varied to suit the crop or the size of the target pests. The design and use of insect nets depends on the target problem they are meant to mitigate (Briassoulis et al., 2007; Martin et al., 2010, 2013). These nets are regarded as eco-friendly because they reduce pesticide use and can be recycled. The main function of insect nets is to exclude pests from the crops, but they also provide other benefits. Insect nets buffer the impact of heavy rainfall and the negative impact of several common pests such as birds and snails. Insect nets can be combined with organic fertilizers, organic mulch and drip irrigation. The suppression or reduction of chemical pesticide use reduces soil pollution. In temperate areas or in tropical highlands they stabilize the air temperature and improve soil moisture, thereby improving crop quality and yield (Muleke et al., 2013).

Insect nets were successfully tested in experimental stations and in the field with smallholder farmers in Benin, Kenya and France. Insect nets reduced insecticide sprays by 70–100% in Benin and Kenya for cabbage and tomato crops (Martin et al., 2006; Licciardi et al., 2008; Saidi et al., 2013; Muleke et al., 2013; Gogo et al., 2014; Simon et al., 2014).

This technology can (or should) be adapted to local constraints. For example, in humid climates, the netting can be occasionally removed to reduce overheating. The height of netting pegs can be adjusted depending on crop requirements. Nets of various mesh sizes are available depending on the target pests. Insect nets in orchards can also be made from hail nets. In applying this technology, the social and economic setting in which farmers conduct their activities also have to be taken into account.

Despite some limitations, cost:benefit analyses are a necessary and a preliminary step for assessing the cost-effectiveness before adoption and diffusion assessments. This paper quantifies the costs and benefits of insect nets compared to synthetic insecticide treatments in real farming conditions, i.e. considering current farmers' practices. The investigations were conducted in 4 districts of Benin.

2. Material and methods

This study is part of a larger multidisciplinary project aimed at assessing the impact of insect nets among farmers. The economic investigations involved 214 farmers, including 90 farmers who were testing insect nets. A sample of 19 farmers were randomly selected from these 90 farmers for the cost:benefit analysis. However, only 7 of these 19 farmers managed to provide us with complete data during the investigations. The 7 farmers included 2 women (farmers 2 and 6).

Even though the vegetable farmers in our sample may have been aware of official insecticide recommendations, we assessed real farming practices where recommended insecticides, doses and frequencies do not always apply. Income is farmers' first concern, so they often neglect sanitary issues. Poor insecticide practices are due to many different factors: poor access to credit for farmers, informal and uncontrolled insecticide supplies, lack of law enforcement, poor quality insecticides that may be unsuited to the targeted pests, etc. Higher insecticide doses and application frequencies could be explained by uncoordinated pest prevention among farmers, illegal use of subsidized cotton insecticides for food crop production, pest resistance and the year round presence of pests. The cost:benefit analysis estimated yields, best practice recommendations, practice diversity among farmers, total farm size, the percentage of the farm area devoted to protected and unprotected cabbage, the input type and quantity (labor, fertilizers, pesticides, fuel, motor oil) used and the depreciation components. The timing of each farming operation was recorded. The study concerning the diverse range of practices used by farmers were based on the detailed observations of the 7 farmers simultaneously operating on protected and unprotected cabbage fields.

Data were collected during two production cycles the short rainy season (October–December 2012) and the long dry season (January–March 2013) in 7 farms in the coastal region and hinterlands of Benin. Each period targeted specific holidays during which demand was high for cabbages. The long dry season targets the Easter holidays. The short rainy season targets the Christmas holidays.

The research areas were located in the coastal region and hinterlands of Benin: to the west in the districts of Grand Popo (1 farmer), Comé (2 farmers) and Ouidah (2 farmers); and to the east in the district of Sèmé-Kpodji (2 farmers). Agriculture and peri-urban agriculture in this area is characterized by intensive practices and improved access to urban markets due to the presence of the country capital (Cotonou).

2.1. Traditional farming system for cabbage production in Benin

The traditional farming system for cabbage production in Benin consists of 4 m × 2 m nurseries, with each one including traditional 8 m × 1.5 m crop areas referred to as *planks* among farmers. A total of 28 *planks* makes a *kantin*, which is around 400 m^2, including the alleys between *planks*. A *kantin* is the traditional land size unit for farmers in southern Benin.

As the investigations in real farming conditions revealed that nurseries and *planks* differed in size, all of results were converted to nurseries of 8 m^2 and *planks* of 12 m^2. The overall results were then converted to a *kantin* and a 28 *plank* area including alleys between *planks*, and then to a hectare. Fuel and lubricant consumption also differed depending on the motor-pump characteristics. We considered a potential of 75 cabbage heads per *plank* over two cycles, i.e. 150 cabbages over 2 cycles.

2.2. Costs

During the trials, farmers were provided with free nets, steel arcs, seeds, and organic fertilizers. Insect nets were delivered free of charge in 50 × 3 m rolls. A roll normally costs FCFA 60,000 (USD 125.40), i.e. USD 0.60 per m^2. A roll can cover a surface equivalent to 7 standard traditional *planks* of 12 m^2. Insect nets from manufacturers in France benefit from a 7 year warranty in Europe and 5 years elsewhere. Warranties are not yet available in Africa, but they could be considered to be of at least 3 years. Insect nets destined for Africa are currently supplied by an international manufacturer based in Tanzania. The manufacturer specializes in mosquito bed nets but has now diversified into netting technology for crop protection. The 12 m × 6 mm steel arcs supporting the nets were also distributed for free but they normally cost FCFA 1500 (USD 3.1).

Collected data were related to inputs, labor, income, yields, and investments. Monitored farms belonged to farmers who continued to use the insect nets free of charge after the trials. Insect nets current use in real farming conditions is understood as a use by the farmers on the basis of their knowledge and perception without any extension worker influence.

Operational costs concerning nurseries and *planks* included seeds, mineral fertilizers (urea and/or NPK), organic fertilizers (chicken manure), insecticides, nematicides, fungicides, fuel, and lubricants.

Labor costs were set at the labor opportunity cost in Benin, i.e. FCFA 31,625 per month (about USD 66). The workforce is mostly family labor, involving men, women, and sometimes children. Labor costs were estimated for clearing and plowing, *plank* construction, dibbling, sowing, mulching, hoeing, weeding, hilling, spraying, fertilizing, applying organic fertilizers, plant health treatments, and net handling. Wages for hired labor are often calculated based on the *kantin* or *plank* unit area.

Market prices were recorded for all commodities at the time of the surveys. Prices differed according to the product considered, market channels and time. Farm gate prices were recorded for large, medium and small cabbages during the 2 production cycles. Unit prices for mineral fertilizer bags were lower from official supply agencies than from local traders, but farmers often opted for the second option due to credit constraints. Unit prices for organic fertilizers (chicken manure) were 50% cheaper the year before the surveys. Low pesticide residue levels for cabbages is not yet promoted in terms of price premiums on the markets in Benin despite the expressed willingness among consumers to pay for it (Coulibaly et al., 2011).

Investment depreciation costs were based on 2 production cycles per year and a 1 year product life for flexible garden hoses, 2 years for spraying equipment, 3 years for insect nets and motor pumps, 5 years for pipes, and a 10 years for steel arcs and wells.

2.3. Economic analysis

A literature review revealed the low reliability of recall data (Jagger et al., 2012; de Nicola and Giné, 2014), especially regarding income related information between husband and wife are secretive within a household (Lemay-Boucher and Dagnelie, 2012). Besides discretion issues, other realities that need to be considered are the fact that sub-Saharan small-scale farmers do not record their expenditures and incomes (agricultural and market outputs) and agricultural products are generally self-consumed and sold. Moreover, agricultural data in developing countries are not very reliable for cost:benefit assessments. On the basis of these considerations, this study involved follow-up visits and permanent contacts of survey agents with the farmers instead of cross-sectional surveys based on recall data. The case study was carried out with farmers who used the insect nets free of charge and accepted daily contact with the survey agents. The investigation progress was regularly monitored by the researcher during the two main cabbage production cycles.

Yields concerned the number of cabbage units and their respective sizes, ranging from small, medium to large. These different sizes correspond to different weights and farm gate prices. The nursery:*plank* ratio was recorded (i.e., the number of planks of cabbages planted out with the supply of one nursery). Yields were recorded for each *plank*. Income from cabbage sales was calculated by multiplying the number of cabbages per *plank* in each size category by the corresponding average farm gate price. Total income per *plank* was obtained by adding the income derived from each cabbage size category. Total income per *plank* was computed in order to have a *kantin* estimation for comparative purposes. Operational costs were computed for nurseries and *planks*. Income was computed only according to the *plank* outputs. The net margin was obtained on the basis of the gross margin minus the depreciation of the irrigation equipment, nets, and steels arcs. The cost:-benefit ratio was computed for unnetted and netted production on the basis of the net income divided by the total costs. We considered the USD/FCFA 0.00209 exchange rate. Means of yields, production costs, pest management costs, incomes and net-benefit were compared among the 7 farmers (degrees of freedom = 6) using the parametric paired sample t-test of SPSS 16.0. Generated means and standard deviation within a season were used to calculate the coefficient of variation. The significance of difference is revealed by p values.

3. Results

Cabbage farm gate prices were higher during the Christmas and New Year season (Table 1). During the production period, the retail unit price (expressed in USD kg^{-1}) varied and showed an advantage (or premium) for large cabbages. In all cases, vegetable production markets in Benin are seldom oversupplied considering the food deficit situation of the country.

There were no farm gate price premiums for pesticide-free cabbages in Benin in 2012 and 2013. Farm gate prices were similar between netted and unnetted cropping systems for the same cabbage size (Table 2). The difference in income could be explained by the higher quantities of large cabbages and lower harvest losses obtained with cabbages grown under insect nets.

On average, the number of marketable cabbages increased by 65% for netted *planks*. The number of large marketed cabbages was 93% higher for netted *planks* than unnetted *planks*. Insect nets doubled the yield of large cabbages and also doubled the total number of cabbages. Since there were no farm gate price premiums for pesticide-free cabbages in Benin at the time of the surveys, farmers' income was directly derived from the high yields obtained

Table 1
Cabbage farm gate prices in 2012 and 2013 (USD).

Size of cabbage	Average weight (kg)	Short rainy season: (October–December 2012): Christmas and New year targeted	Long dry season (January–March 2013): Easter targeted	One-year average per head
Large	1.5–2	0.84–1.26 (0.48–0.72)	0.73–0.84 (0.42–0.48)	0.79–1.05 (0.45–0.6)
Medium	0.75–1.5	0.63–0.84 (0.56–0.75)	0.31–0.63 (0.28–0.56)	0.47–0.79 (0.42–0.66)
Small	<0.75	0.42–0.52 (0.56–0.70)	0.16–0.26 (0.21–0.35)	0.29–0.39 (0.39–0.53)

Numbers out of brackets are the price per cabbage head. Numbers in brackets are the average prices per kilogram.
Source: field surveys (October–December 2012 and January–March 2013)

through the use of nets. Total average income was 69% higher for netted *planks*.

3.1. Average cost:benefit analyses for cabbage production in Benin

Yields obtained at the research stations were estimated at 26 t ha^{-1} and 60 t ha^{-1}, respectively, for unprotected and protected cabbage production. Considering a potential of 75 cabbage heads per *plank* over two cycles, i.e., 150 cabbages over two cycles, the cabbage head loss rate was 14% for netted *planks* and 48% for unnetted *planks*.

Insect net protection led to a net average cost:benefit ratio of 1:2.66 and 1:1.58 for unnetted protection (Fig. 1). The data are from Table 3. The differences between the two systems concerned yields at nursery and *plank* levels. Only labor costs for net handling and other labor tasks are displayed on the figure as they were carried out at no cost. Although farmers were provided with nets and steel arcs free of charge, their depreciation costs were considered in the net margin computation. The USD 30 net margin per plank would still cover the costs of the nets (about USD 7 for a 12 m^2 *plank*) and the steel arcs (USD 3.1) in the first cycle of production.

Table 3 displays the cost:benefit ratio computed on the basis of data from the 7 farmers surveyed. Market prices were derived from Table 2. The average income was computed for the Easter and Christmas periods for netted and unnetted *planks*. Total costs included nursery and plank maintenance expenses and were transformed into a USD/ha ratio. There were no differences in costs for the two seasons (production cycles), so the costs displayed in the table are similar. However, the farm gate prices, number of cabbages marketed and their sizes varied during the two seasons. Most of the labor was devoted to soil and crop preparation in both systems. Labor devoted to insecticide treatments and/or net handling represented a small share of it. The improved yields contributed significantly to the higher cost:benefit ratio for netted protection. Improved yields involved higher quantities of cabbages but also larger size cabbages which could be marketed at a higher farm gate price.

As all nurseries used insect nets for protection, only insecticide costs accounted for the differences in nursery operational costs (about 2% of total costs per nursery) and only insect net handling accounted for nursery labor cost differences (about 5% of total nursery labor costs and less than 1% of the total costs). Seed purchases accounted for 90% of the costs related to operational costs for nurseries and irrigation labor costs accounted for about half of the nursery labor costs.

3.2. Accounting for farm diversity for cabbage production in Benin

Yields obtained by the 7 surveyed farmers in real farming conditions revealed a diversity of situations. Under real farming conditions, the situation differed within the same farming system and between farming systems. Similar practices were noted as farmers used the same products and amounts of fertilizer with or without insect nets, the same quantities of fuel because the motor pumps supplied the whole farming system, as well as the same amount of labor. However, farmers sprayed agrochemical inputs more

Table 2
Average yield of cabbages in real farming conditions (per *plank* for the 7 farmers) October–December in 2012 and December–March 2013.

Targeted events	Cabbage size	Average quantity (cabbage heads marketed)	Unit farm gate price (USD)	Income (USD)	Average quantity (cabbage heads marketed)	Unit farm gate price (USD)	Income (USD)
		Netted *planks*			Unnetted *planks*		
Easter	Large	53.6	0.8	42.1	25.0	0.8	19.6
	Medium	5.3	0.5	2.5	8.3	0.5	3.9
	Small	4.0	0.2	0.8	0.4	0.2	0.1
	Total average (a)	62.9		43.4	33.7		23.6
	Mean diff.	29.1**					
	SD	20.5					
	CV	32.6%					
Christmas and New year	Large	39.4	1.0	41.3	22.5	1.0	23.6
	Medium	3.4	0.7	2.5	7.3	0.7	5.4
	Small	23	0.5	10.8	14.3	0.5	6.7
	Total average (b)	65.8		54.6	44.1		35.7
	Mean diff.	21.7***					
	SD	7.7					
	CV	11.7%					
Mean	Large	46.5	0.9	41.7	24	0.9	21.6
	Medium	4.5	0.6	2.5	8	0.6	4.6
	Small	13.5	0.3	5.8	7.5	0.3	3.4
	(a) + (b)	128.7		98.0	77.8		59.3
	Mean diff.	50.9**					
	SD	20.7					
	CV	16%					

**$P < 0.01$. ***$P < 0.001$. SD = Standard deviation. CV = Coefficient of variation.
Source: field surveys (June–August 2013).

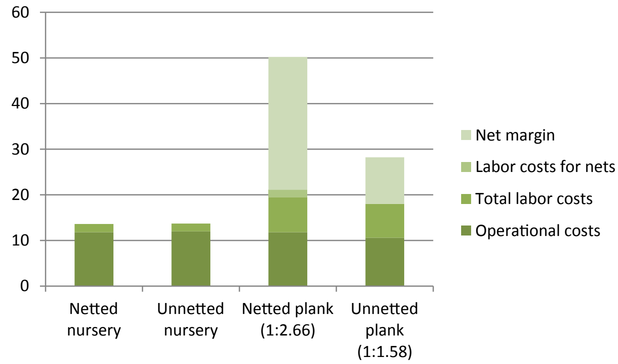

Fig. 1. Average net cost:benefit over two cycles for netted and unnetted cabbage production in Benin (USD). Source: field surveys.

frequently than recommended, which impacted the depreciation calculation. Farmers also used different agrochemical products in nurseries and open fields. The number of daily insect net handling operations varied between farmers, which was also the case regarding the number of agrochemical treatments, and the input supply conditions in terms of price differentials.

All of the results were standardized for an 8 m^2 nursery × 12 m^2 *plank* ratio for comparison purposes (Table 4). Diversity was assessed in terms of the total farm size devoted to cabbage production and the full farm nursery:*plank* ratio. The total farm size devoted to vegetable production ranged from 50 to 450 *planks*, i.e. from 0.06 to half a hectare, and nursery *plank* sizes ranged from 3 to 15 m^2. The nursery:plank ratios ranged from 1:19 to 1:100. Variations in the ratios did not depend on the geographical location but instead probably on the farmers' knowledge and farming practices.

The systematic use of insect nets to protect nurseries and *planks* could be explained by the fact that they were supplied to the farmers free of charge, so that they did not take this cost into account in their assessment.

There were no significant differences for labor costs because the use of nets did not bring any change in labor for insect control and the decreased cost of insecticide sprays was slightly exceeded by the net handling cost (Table 5). Variable costs (operational and labor costs) ranged from −3% to −29%. The difference between nursery netted *planks* and nursery unnetted *planks* could be explained by insect net and arch usage cost, probably because of the relatively short plant production time (almost 25% of cabbage head production). Insecticides were still required with the use of nets as they did not provide a physical barrier against small insect pests such as aphids. However this insecticide requirement remained significantly lower than the amount of insecticides used under usual farmer practices ($P < 0.01$). This explained differences concerning *planks* for insecticide costs, which ranged from 68% to 95% when comparing unnetted and netted protection. Conversely, labor costs related to insect net handling ranged from 20% to 30% of total operational and labor costs for each *plank*. Moreover, the coefficients of variation for operational and insecticide costs were lower for netted *planks*. This finding could have been due to extension workers' efforts to harmonize practices related to net use. Netted protection enabled not only a reduction but also less variation in costs for insecticides and handling than unnetted protection.

The differences in total costs between netted and unnetted protection were of a different nature. First, similar or minor farming practices caused small differences in total costs at the plank level and in such cases the differences ranged from 3% to 9% only. Second, when differences are caused by variability in pesticide applications and costs at the plank level, differences in total costs ranged from 22% to 26%. Third, extreme pesticide costs to avoid total crop losses may have resulted in a very high cost per *plank*. In such cases, there was a 29% total variable cost difference.

The cost:benefit ratio for the Easter and Christmas periods were averaged at a *plank* level (Table 6). The total costs per *kantin* were similar during the two seasons because of similar farming practices. The difference in total cost between unnetted and netted protection was not significant ($P < 0.01$). However, costs for netted protection for the seven farmers were closer to the average cost compared to costs for exclusive pesticide protection. The difference in average total income between unnetted and netted protection was

Table 3
Average net cost:benefit of two successive cycles for netted and unnetted cabbage production in Benin in USD.

	Easter		New year and Christmas		Average	
	Unnetted protection	Netted protection	Unnetted protection	Netted protection	Unnetted protection	Netted protection
1 Nursery (8 m^2): (USD)						
Operational costs	12.0	11.8	12.0	11.8	12.0	11.8
Insecticides costs	0.2	0.0	0.2	0.0	0.2	0.0
Labor	1.7	1.8	1.7	1.8	1.7	1.8
Insecticide costs	0.1	0.0	0.1	0.0	0.1	0.0
1 *Plank* (12 m^2): (USD)						
Operational costs	10.6	11.8	10.6	11.8	10.6	11.8
Insecticide costs	3.8	0.5	3.8	0.5	3.8	0.5
Net costs	0	0	0	0	0	0
Labor	7.4	7.7	7.4	7.7	7.4	7.7
Insecticide costs	0.0	0.1	0.0	0.1	0.0	0.1
Net costs	0.0	1.6	0.0	1.6	0.0	1.6
1 Nursery depreciation	0.2	2.2	0.2	2.2	0.2	2.2
1 Plank depreciation	0.3	3.1	0.3	3.1	0.3	3.1
Results for 1 ha (=25 *kantins*) = >25 nurseries of 8 m^2 in size and 700 *planks* of 12 m^2 in size (28*25)						
Total income	16,545	31,791	24,964	38,223	20,756	35,009
Total variable costs	12,680	9022	12,680	9022	12,680	9022
Depreciation	406	4118	406	4118	406	4118
Gross margin	3864	22,769	13,531	31,068	8928	28,382
Net margin	3458	18,651	13,125	26,950	8522	24,264
Net cost:benefit ratio	1:1.26	1:2.42	1:2.00	1:3.05	1:1.58	1:2.66
Marginal costs		53		53		53
Marginal net margin		15,193		13,825		15,743
Marginal cost:benefit ratio		1:288		1:262		1:298

Source: field surveys (September–December 2012 and December–March 2013). USD 0.00209 = FCFA 1.

Table 4
Diversity of farm size and test characteristics.

Farmer	Survey site	Total farm size devoted to vegetable production (*planks*)	Nursery size before netting project (m^2)	Number of *planks* before netting project	*Plank* size before netting project (m^2;)	Nursery size with netting project (m^2)	Equivalent number of *planks* to plant under netting (nursery:*plank* ratio)
1	Comé	100	6	8	45	8	1:40
2	Comé	50	3	11	12	8	1:29
3	Ouidah	124	6	14	12	8	1:19
4	Ouidah	280	15	80	12	8	1:43
5	Comé	450	15	60	12	8	1:32
6	Sémé	120	3	9	12	8	1:24
7	Sémé	60*	6	75	12	8	1:100

Source: field surveys (September–December 2012 and December–March 2013). * The 7th farmers' land size is 60 planks where the survey was implemented. The surveys did not take account for his remaining farm since it's far from the survey site.

favorable for netted protection (P < 0.01). Moreover, incomes and net benefits for the seven farmers were less dispersed compared to the unnetted alternative, as shown by the coefficients of variation. The difference in average net-benefit between unnetted and netted protection was favorable for netted protection (P < 0.01). The diversity of situations was mainly explained by unnetted protection differences in yields and pesticide costs. Farmer 2 ended with a deficit under unnetted protection because of pest infestations despite insecticide applications. Under netted protection, there were fewer variations in pesticide costs and lower pesticide costs between farms. Since labor costs were stable and relatively low in the total costs, the cost:benefit ratios were more stable for netted protection. Concerning netted protection, the average cost:benefit ratios ranged from 1:1.93 to 1:2.87. Concerning unnetted protection, cost:benefit ratios ranged from 1: 0.99 to 1:2.77. The latter ratio was computed at an average farmer's level and revealed that single pesticide sprays could sometimes lead to high yields. This performance could be achieved when the pesticides are tailored for controlling the targeted insects. In conclusion, pesticide costs, the nursery:*plank* ratio, and nursery yield impacted the cost:benefit ratios. Insect net operational and labor costs were stable and relatively low in the total costs.

4. Discussion

Our results showed that insect nets generated better cost:benefit ratios than pesticide use. The cost:benefits were lower than those obtained with botanical insecticides in other studies (Amoabeng et al., 2014). Our method differed from other studies as we used field surveys to determine the diversity of situations among farmers. Studies in Benin revealed that vegetable consumers are aware of the heavy use of chemicals on vegetables and are willing to pay for quality (Assogba-Komlan et al., 2007; Coulibaly et al., 2011; Ahouangninou et al., 2012).

4.1. Limits of the study

This study had some limitations which are inherent to cost:benefit analysis in general and our goal to account for real farming conditions and diversity among farms. Externalities cannot be easily considered at the farm level with a monetary-based method. This is a major concern for agroecological innovations which rely heavily on ecosystem services. Cost:benefit analysis also poses a problem when there are small samples and when considering the generic range of results under real farming conditions. The large amount of data required, their reliability and exhaustiveness reduce the possibility of expanding the sample size and may result in a high proportion of excluded farms because of unreliable data. Commodity price variations significantly affect cost:benefit estimates. Cost:benefit analyses are dependent on the market prices for inputs and the income and the results are therefore subject to variation. Moreover, the results can differ according to the farm size, and access to capital assets, credit, mechanization, or labor. The small sample size in our study was probably too low to account for the overall diversity of farming practices in Benin. A balance between large samples, detailed information, and costs of research needs to be found. Cost:benefit ratios also cannot consider positive externalities on the environment and human health. However this approach can be combined with environmental assessment methods based on the same datasets adapted with minor modifications and complemented with commodity chain assessments. Life cycle assessments for vegetable cropping systems can be useful to complement cost:benefit analyses (Perrin et al., 2014).

Table 5
Estimated costs of managing cabbage pests with unnetted/netted protection for *planks* (USD).

	Total variable costs per *plank*			Insecticide costs per *plank*			Netted labor costs per *plank*
	Unnetted	netted	(% change)	Unnetted	netted	(% change)	
Farmer 1	21.3	15.8	−26%	4.8	0.4	−92%	1.6
Farmer 2	21.9	15.6	−29%	7.5	0.4	−95%	1.6
Farmer 3	13.5	13.1	−3%	1.9	0.6	−68%	1.6
Farmer 4	16.3	14.4	−12%	2.3	0.3	−87%	1.9
Farmer 5	15.2	13.9	−9%	1.8	0.4	−78%	1.6
Farmer 6	21.7	16.9	−22%	5.7	0.4	−93%	1.6
Farmer 7	16.1	14.9	−7%	2.4	0.7	−71%	1.6
Mean	*18.0*	*14.9*	*−17%*	3.7	*0.4*	−83%	*1.6*
Mean diff	*−3.1*			*−3.3***			
SD	*3.5*	*1.2*	*−10%*	2.2	*0.1*	*−11%*	*0.1*
CV	*19%*	*8%*		*59%*	*25%*		*6%*

**P < 0.01. SD = Standard deviation. SD = Standard deviation. CV = Coefficient of variation.
Source: field surveys (September–December 2012 and December–March 2013).

Table 6
Estimated average costs and benefits of managing cabbage pests with unnetted and netted protection (USD) for the two cycles.

Farmers	Total cost/*kantin*		Total income/*kantin*		Benefit/*kantin*		Cost:benefit ratio	
	Unnetted	Netted	Unnetted	Netted	Unnetted	Netted	Unnetted	Netted
Farmer 1	620.7	555.1	856.6	1069.2	235.9	514.1	1:1.38	1:1.93
Farmer 2	657.7	569.5	653.0	1376.5	−4.6	807.0	1:0.99	1:2.42
Farmer 3	409.2	487.6	798.0	1386.4	388.8	898.8	1:1.95	1:2.84
Farmer 4	473.8	507.0	792.8	1339.2	319.0	832.2	1:1.67	1:2.64
Farmer 5	441.7	494.2	1225.2	1384.8	783.5	890.7	1:2.77	1:2.80
Farmer 6	634.7	588.8	726.9	1477.7	92.2	889.0	1:1.14	1:2.51
Farmer 7	478.0	530.7	719.5	1523.9	241.4	993.2	1:1.50	1:2.87
Mean	*530.8*	*533.3*	*824.6*	*1365.4*	*293.7*	*832.1*	*1:1.63*	*1:2.57*
Mean diff.	*−2.571*		*−540.81***		*−538.43***		*1:−0.94***	
SD	*103.1*	*39.1*	*188.5*	*145.5*	*253.4*	*152.1*	*0.6*	*0.3*
CV	*19%*	*7%*	*23%*	*11%*	*86%*	*18%*	*37%*	*13%*

**P < 0.01. SD = Standard deviation. CV = Coefficient of variation.
Source: field surveys (September–December 2012 and December–March 2013).

4.2. Economic considerations

Concerning the diversity of situations in a sample of 7 farmers, the results showed that total costs for nurseries were relatively stable among farmers but that diversity prevailed for *planks*. Only nursery yields and the nursery:*plank* ratio showed diversity among the different farms. In these conditions, it appears that netted nurseries could be promoted for a first stage of insect net adoption. Insect net protection at this level provided regular cash flows over several cycles for each farm. Pesticide applications ranged from best practices to pesticide overuse and consequently caused high variations in cash flows. In our study, insect nets can reduce pesticide costs by 68%–95%. This result is in concordance with other studies (Licciardi et al., 2008; Simon et al., 2014; Saidi et al., 2013). We also confirmed that overuse of pesticides is not uncommon in vegetable cropping systems in sub-Saharan Africa (de Bon et al., 2014).

Agroecological innovations are often labor intensive, which impacts costs (Amoabeng et al., 2014). They may also be complex in the protocols required for handling materials. In our case, labor costs for insect nets were stable at nursery and *plank* levels. On the contrary, labor costs for pesticide use were correlated with the frequencies of pesticide use among unnetted *planks*. Therefore, from a strictly quantitative standpoint, labor costs with insect nets were relatively uniform in real farming conditions.

However, it should be noted that labor encompassed more aspects than just labor costs. Agroecological innovations require skills in terms of proper handling as well as timing constraints. Agroecological innovations for botanical insecticides or physical exclusion also differ significantly from the previous farming practices in terms of agronomic principles. These factors are hardly measurable but they play a significant role in time allocation and adoption processes.

Markets have a key role in a cost:benefit valuation. Commodity prices vary greatly and have a significant impact on cost:benefit analyses (Amoabeng et al., 2014). For example, quality could not be differentiated in the trials on stations and under real farming conditions. However, price variations should not be considered as a limitation but there are several considerations. There is not yet a tangible consumer market for pesticide-free products and it is not yet known how the added value should be shared between farmers and traders along the value chain. There are substantial market opportunities in Benin for city supplies and for regional exports in neighboring countries. There is a need to investigate the adaptability of agroecological innovations to segmented markets destined for commodity chains dedicated to general city supplies with lower pesticide use, organic food consumers with zero pesticide tolerance, and exports with international standards and specifications. Another topic which was beyond the scope of this study is the use of insecticides throughout the commodity chain, from the farm and to retail stores. Insecticide treatments may be applied all along the commodity chain. The constraints and needs of the overall commodity chain need to be taken into consideration.

4.3. Social considerations

Cost:benefit analyses are necessary but insufficient for adoption and diffusion support policies. Other factors which can hardly be monetized need to be considered (Rogers, 2003). Insect nets provide a clear comparative advantage compared to previous practices in terms of yields and income, and potential health and environmental issues. Agroecological innovations also need to be compatible with the values and social norms of end users. Insect nets imply a structural change in farming practices, which may not be easy to implement. For example, *planks* and *kantins* are structured in such a way that manual irrigation is optimized in terms of time allocation and painful labor. These aspects could be easily overcome but they need to be considered and treated accordingly with extension support, training, awareness campaigns and knowledge transfer. Agroecological innovations should not be too complex in terms of changing field management methods and underlying agronomic principles. Agroecological innovations need to be easily testable in their general physical pest exclusion principles. However, proper field management is required to ensure success. The results need to be easily observable in terms of yields and with a binary approach to efficiency (i.e. total exclusion of pests or total inclusion if pests are trapped under the nets). Externalities are harder to observe. Health impacts and environmental preservation are not easily measured at the farm level. Here also, extension, and general media communication are needed among the overall population, including farmers but also consumers and traders.

5. Conclusion

We compared protected and unprotected farming systems under real farming conditions and in on-station trials in order to estimate the diversity of situations in Benin and to obtain a benchmark for future studies in real farming conditions. Cost:benefit ratios were higher for netted protection than unnetted protection. However, our most important finding is that insect nets provided more stable costs and yields than unnetted protection, which generated stable cash flows in return. In a setting of high diversity among farming practices, yields and income, insect nets provide the opportunity to have a more stabilized financial vision of the future. During the tests, farmers were supplied with free insect nets and steel arcs. The next step is to scale up the supply of marketed insect nets. Supplies of insect nets could be part of a diversification strategy of manufacturers involved in making treated bed nets.

Agroecological innovations for pesticide reduction strategies require new forms of pest regulations. Cost:benefit analysis is one of the prerequisites before adoption and dissemination support policies. There is a need to consider the diversity of situations among real farming conditions in parallel with on station trials. Agroecological innovations need to be adaptable to the diversity of farming systems and practices, while providing stable and lower costs between farmers and within each farming system. Adaptability at this point is therefore more important than trying to measure the permanently moving and extremely diverse range of situations among farmers.

Future research is required to improve the generic range of insecticide prevention case studies. Investigations need to find a balance between the diversity of farming practices and the constraint of requiring large amounts of information to compute cost:benefit ratios. Moreover, innovations should be able to be tailored to various farming practices. Further research is also required for different segmented markets, each requiring different implementation and support policies, such as organic farming, export markets, or mass market consumption. In these different contexts, prices used for the cost:benefit ratios make more sense and enable selection of proper farming systems and farmer profiles. Cost:benefit analysis can be combined with environmental assessment methods and this can contribute to considering the positive externalities of agroecological innovations.

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