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Is vegetable cultivation under low tunnels a profitable alternative to pesticide use? The case of cabbage cultivation in northern Tanzania

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ABSTRACT

The health benefits of fruit and vegetable consumption can be jeopardized by pesticide residues, especially in developing countries, due to their misuse. While vegetable growing under cover is growing in popularity worldwide as an effective technique for improving yields while reducing pesticide use, these protected cultivation techniques often remain underutilized by smallholder farmers. A cost-benefit analysis was conducted with fifty smallholder farmers in northern Tanzania over two seasons to compare the profitability of growing cabbage in open plots and under inexpensive low tunnels. Although all farmers significantly improved their yields under nets over the two seasons (9.85, as opposed to 6.80 kg m^{-2} and 10.09, as opposed to 8.63 kg m^{-2}, in each season respectively) and reduced their pesticide use (by 3.5 and 2.8 times), the large variations in market prices observed between seasons called into question the profitability of this cultivation technique. With the conducive market conditions of the second season, it would have taken 5.3 crops cycle on average, i.e. less than 2 years, to recoup the investment costs of low tunnels, whereas with the poor market conditions observed in the first season, the investment in tunnels compounded the negative economic results obtained from growing cabbages in an open field. Consequently, our results showed that using low tunnels could be a suitable alternative for reducing pesticide use, but this technique was not economically viable with the existing marketing systems used by the farmers. For this technique to be adopted, further work is needed to identify changes in vegetable marketing systems that would promote the use of cultivation techniques that reduce pesticide use.

1. Introduction

Increasing attention is being paid to fruits and vegetables as essential components of healthy diets and food security. Despite efforts to promote fruit and vegetable consumption, most people fail to consume the minimum intake of 400 g per day recommended by the World Health Organization (WHO), especially in developing countries (Schreinemachers et al., 2018). Besides quantity, the quality of vegetables sold on local markets in developing countries has often been questioned by numerous reports revealing higher pesticide residues than accepted standards (Bempah et al., 2016; Diop et al., 2016; Lehmann et al., 2017; Mutengwe et al., 2016). Despite increasing public awareness of their potential effects on human health and the environment, pesticides remain the main method of controlling pests and diseases in vegetable crops in sub-Saharan Africa (De Bon et al., 2014).

Alternatives to pesticide use need to be introduced to reduce farmers' heavy reliance on chemical pesticides, but also to reduce insecticide resistance in major vegetable crop pests (Gnankiné et al., 2013; Houndété et al., 2010) and the potential spread of new invasive species (Brévault et al., 2014; Goergen et al., 2011). The benefits of growing vegetables under nets in tropical regions have been highlighted for several decades, despite some reported limitations, such as increasing temperatures and the rapid multiplication of small insect pests such as aphids, whiteflies, and spider mites inside protected structures. Although protected cultivation techniques are increasingly being adopted by large- and medium-scale farmers of high-value crops in Africa, notably in flower and export tomato crops, such practices remain unexploited by smallholders (Nordey et al., 2017). A study conducted with a small number of farmers in Benin reported that using low net tunnels significantly increased the profitability of cabbage cultivation

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because of improved yields combined with reduced pesticide use (Vidogbéna et al., 2015). Similar results were also obtained in an earlier experiment in Arusha in northern Tanzania, but some concerns were raised about the profitability of growing cabbages under nets. Yield improvements with low tunnels encouraged surrounding smallholders to test this cultivation method and to assess its profitability over two seasons. The results of the cost-benefit analysis of cabbage cultivation in open fields and under tunnels conducted by fifty farmers in the Arusha region are presented and discussed in this study.

2. Material and methods

2.1. Experimental sites

The experiment was conducted over two seasons, i.e. from August to December 2018 and from March to June 2019, with 50 farmers in the Arusha region. Each farmer simultaneously grew sixty cabbages under two sets of conditions, an open plot and in a adjacent plot covered with a low net tunnel (Supplementary Fig. S1). The experiment was considered a complete block design with the cultivation method (i.e. in an open plot and under a tunnel) as a factor and each farmer as a block. An initial survey was conducted to select farmers interested in taking part in these research activities. Selection criteria included at least 3 years' experience in cabbage production, willingness to share results and exchange respective experiences during workshops, and gender balance. Farmers were grouped in three different locations, 1) Shiboro-Kimnyaki, 2) Sangananu – Embaseni and 3) Leguruki (Fig. 1). Thirty-six percent of the farmers were females, and the farmers were from 21 to 74 years old, with an average age of 43.

2.2. Production methods

The experimental protocol was designed with farmer representatives, extension officers from five villages, and agronomists from the World Vegetable Center. One-day training sessions on good agricultural practices for cabbage cultivation and on the use of low tunnels were held in the villages. At the end of the training sessions, each farmer received mineral fertilizers (17-17-17 NPK and urea), a low-cost drip irrigation system, as well as a locally made and ready-to-use 20 m^2 low tunnel (1.5 m high, 2 m wide, and 10 m long) made of white netting (0.7 × 0.9 mesh size, AtoZ). The farmers constructed low tunnels with locally available wood and bamboo poles (Supplementary Fig. S1). One or two farmers per location with experience and skills in seedling production were in charge of producing four-week-old cabbage seedlings of a hybrid variety (Tsavorite, SeedCo, green cabbage) and distributing them to the other farmers.

Twenty kilograms of well decomposed manure was applied per plot during manual ploughing of raised beds. Each farmer grew 60 cabbages in a 2 × 10 m open plot and under a small 2 × 10 m tunnel. Cabbage seedlings were transplanted every 40 cm in three lines per plot. The farmers were advised to apply 10 g per plant of NPK 17-17-17 and 10 g of urea in the 2nd and 5th weeks after transplanting. Lambda-cyhalothrin (Karate 5 EC, Syngenta, applied at 400 mL/Ha) was used to control sucking insects (whiteflies and aphids) and Lepidoptera, consistent with locally used pesticide. Mefenoxam and mancozeb (Ridomil Gold, Syngenta, applied at 2.5 kg/Ha) were used to control fungal diseases, i.e. black rot, based on scouting of individual plots once symptoms appear on cabbages. Pesticides were applied with a backpack sprayer.

2.3. Data collected

Air temperature and moisture, global radiation, and rainfall were measured each minute and averaged every 30 min with a fully equipped weather station (Vantage PRO2, Davis Instruments, California, USA) installed at The World Vegetable Center for Eastern and Southern Africa, Duluti, Arusha (Latitude

−3.373, Longitude 36.80, decimal degrees) (Fig. 1). The data collected over the two seasons are provided in Table 1. The quantity of inputs (seeds, organic and synthetic fertilizers, and pesticides), the equipment used (hoe, seedling trays, drip irrigation system, and tunnels), the labor required, and the selling price of cabbages produced in

Fig. 1. Location of farmer groups involved in the experiment in the Arusha region. The numbers between commas indicate the number of farmers per location. Weather data were recorded at The World Vegetable Center campus (WVC ESA, (Latitude −3.373, Longitude 36.80, decimal degrees)).

Table 1
Environmental conditions during the experiments on cabbage in Tanzania (Arusha).

Season	Average temperature (°C)	Average relative humidity (%)	Total rainfall (mm)	Average solar radiation (MJ.m^{-2}.day^{-1})
S1 (August–December 2018)	20.3	73.9	112.6	12.0
S2 (March–July 2019)	20.4	81.2	308.4	11.4

open plots and under tunnels were assessed for each farmer throughout the two seasons of cabbage production. Data were collected by the farmers and with the support of agronomists (extension officers) by phone and during follow-up visits (Supplementary Fig. S1). Agronomists helped farmers to harvest, to sort marketable and non-marketable cabbages, and to weigh the cabbages. Furthermore, a workshop was held with all the farmers involved in the experiment at the end of each season to exchange experiences, provide feedback, and receive supplemental training. In addition, an individual survey was conducted during the last workshop to gather the views of the farmers on the different techniques and inputs used, i.e. seeds, drip irrigation systems and low tunnels, and to determine how much they would pay for the low tunnel without knowing the actual cost.

2.4. Economic analysis

A cost-benefit analysis was conducted for each farmer, each season, and for each cultivation method tested (open field and low tunnel). Economic indicators were expressed as US$/m^2 consistent with the surface area that could be potentially cultivated under low tunnels. The profits were computed by subtracting the sum of the variable and fixed costs from the total revenue. Variable costs were those directly associated with cabbage production, including labor and inputs (seeds, fertilizers and pesticides). The costs of irrigation were only related to those for labor and equipment, since all the farmers in the study had free access to surface water. The cost of labor was estimated using the average of the opportunity cost of labor reported by the local village authorities surveyed, i.e. 3.0 US$ per day. Only the depreciation of the equipment was considered in the calculation of the fixed costs, since all the farmers owned their land or had free access, and they did not take out a loan to buy the equipment.

Depreciation of the items of equipment was calculated according to their respective lifespans and the potential number of crop cycles per year, i.e. three cycles for cabbage. The lifespan of the seedling trays, watering can, sprayer, hand hoe, drip irrigation, nets, bamboo poles and ropes were estimated to be 2, 10, 10, 10, 3, 4, 2, and 1 year, respectively. Based on farmer experience, it was estimated that three crop cycles per year were possible in the region where the experiments were conducted.

The costs of equipment and inputs were estimated from local suppliers. The total revenue was computed from the selling prices for marketable and non-marketable cabbages. The gross margin was calculated by subtracting the variable costs from the total revenue. The gross margin minus the fixed costs related to equipment other than the low tunnels was used to calculate the number of crop cycles required to start generating positive profits, hereafter referred to as break-even, and higher profits from growing cabbages under tunnels than from growing them in open fields, hereafter referred to as added-value.

2.5. Statistical analysis

Skillings–Mack tests were used to compare agronomic aspects, namely yields, the weight of cabbages, and the number of pesticide applications, along with economic parameters, such as the variable and fixed costs, gross margin, and profits, which were indicators between cultivation methods since the data did not follow a normal distribution. Each farmer was considered a replicate in the analyses. All computations and statistical analyses were carried out using R software (R Development Core Team, 2012) with the PMCMRplus package (Pohlert and Pohlert, 2018).

3. Results

3.1. Agronomic performance

The second season was wetter than the first season, but the temperature, air moisture, and solar radiation were relatively similar (Table 1). All farmers obtained higher marketable yields under low tunnels than in the open plots for both seasons (Table 2). Improved yields under nets (expressed in kg per m^2) were related to the higher number and weight of cabbages harvested (Table 2). Yields greatly varied between the farmers, regardless of the production methods. The marketable yields varied from 1.09 to 12.6 kg m^{-2} in open plots and from 6.3 to 15.3 kg m^{-2} under tunnels in the first season and from 3.8 to 11.3 kg. m^{-2} in open plots and from 7.5 to 12.1 kg m^{-2} under small tunnels in the second season (Table 2). The discrepancy in yields between farmers was attributed to variations in pest pressure and crop management, such as watering, weeding, fertilization and pest and disease management. The main insects observed over the two seasons were aphids, the diamondback moth (*Plutella xylostella*) and various larvae of Lepidopteran insects such as *Hellula undalis*, *Helicoverpae armigera*, and *Spodoptera litura*. Pesticide use was significantly lower under low tunnels than in open plots for the two seasons, i.e. 1.9 number of applications on average as opposed to 6.7, and 1.5 as opposed to 4.3 in season one and two, respectively (Table 3). The farmers generally had a good opinion of the technology tested (Table 4). All of them were willing to continue using it (data not shown), but about a third (34%) complained about the durability of the materials used for tunnel construction, including the nets, bamboo poles, and the zip system. More than 37% of the farmers were interested in increasing the height of the tunnels, in order to facilitate work under the tunnels. Interestingly, when farmers were asked at the end of the experiment how much they would pay for the tunnel without knowing the actual costs (52 US$) they were willing to purchase it for a higher price (97 US$ on average).

3.2. Economic performance

Only half of the marketable cabbages produced in open fields and under tunnels were sold in the first season (54% and 52%, respectively), because of reduced demand due to a market glut, in contrast to the second season where almost all marketable cabbages were sold (98.2 and 99.9%, respectively) (Table 2). All the farmers sold their cabbages at the farm gate, to retailers or to neighbors. Large variations in the selling price of cabbages were observed between seasons and producers (Table 2). The average price of cabbages grown in open fields and under tunnels increased 3.4- and 3-fold, respectively, between the first and the second season (Table 2). Cabbages grown under tunnels were sold for 50% and 87% more, on average, in the first and the second season, respectively, than those grown in open fields. The variable costs were significantly higher under nets than in open fields because of the labor required to construct the tunnels. Growing cabbages under nets reduced the cost of pesticide treatments by 0.03 and 0.02 US$.m^2 in the first and the second season, respectively, in comparison to open field cultivation (Table 2). This reduction was negligible compared to the depreciation cost of tunnels per crop cycle, i.e. 0.24 US$.m^{-2}. Total production costs were significantly higher under nets than in open fields for both seasons. Labor costs amounted to 86% and 70% of the total cost, on average, for the first season in open fields and under tunnels, respectively, as opposed to 77% and 65% in the second season. The higher labor costs in the first season were related to the high frequency of irrigation.

Table 2
Profitability analysis of the cabbage production systems. Means followed by different letters are significantly different between treatments at P < 0.05 according to Skillings–Mack tests whereas "NS" indicates no significant differences.

Parameter	Production	First season		Second season	
		Range (min-max)	Mean ± standard deviation	**Range (min-max)**	Mean ± standard deviation
Marketable yield (kg/m^2)	*Open field*	1.09–12.66	6.80 ± 2.37 (B)	3.82–11.26	8.63 ± 1.25 (B)
	Tunnel	6.36–15.31	9.85 ± 1.71 (A)	7.5–12.13	10.09 ± 0.81 (A)
Number of marketable cabbages (cabbages/m^2)	*Open field*	0.05–3	2.58 ± 0.62 (B)	1.8–3.0	2.81 ± 0.29 (B)
	Tunnel	2.65–3	2.98 ± 0.06 (A)	2.65–3.0	2.98 ± 0.06 (A)
Weight of marketable cabbages (kg)	*Open field*	1.02–4.22	2.58 ± 0.69 (B)	1.16–3.76	3.02 ± 0.38 (B)
	Tunnel	2.12–5.08	3.28 ± 0.59 (A)	2.55–4.04	3.38 ± 0.27 (A)
Marketable cabbages sold (%)	*Open field*	0–100	51.4 ± 50.1 (NS)	0–100	98 ± 14.1 (NS)
	Tunnel	0–100	52.0 ± 50.4 (NS)	98.3–100	99.9 ± 0.23 (NS)
Average price (US$/cabbage)	*Open field*	0–0.37	0.08 ± 0.09 (B)	0–0.36	0.27 ± 0.06 (B)
	Tunnel	0–0.55	0.13 ± 0.14 (A)	0–0.68	0.39 ± 0.06 (A)
Variable costs (US$/m^2)	*Open field*	0.73–1.70	1.09 ± 0.20 (B)	0.43–0.64	0.51 ± 0.04 (B)
	Tunnel	0.71–1.72	1.12 ± 0.20 (A)	0.47–0.95	0.56 ± 0.072 (A)
Including Pesticides (US$/m^2)	*Open field*	0.01–0.04	0.03 ± 0.008 (A)	0.013–0.04	0.02 ± 0.006 (B)
	Tunnel	0.0002–0.03	0.004 ± 0.007 (B)	0.005–0.02	0.01 ± 0.003 (A)
Including Labor (US$/m^2)	*Open field*	0.57–1.55	0.94 ± 0.19 (B)	0.30–0.51	0.37 ± 0.04 (B)
	Tunnel	0.59–1.61	1.00 ± 0.19 (A)	0.35–0.82	0.44 ± 0.07 (A)
Fixed costs (US$/m^2)	*Open field*	0.09–0.09	0.09 ± 0 (B)	0.09–0.09	0.09 ± 0 (B)
	Tunnel	0.31–0.38	0.33 ± 0.01 (A)	0.31–0.31	0.38 ± 0.01 (A)
Total costs (US$/m^2)	*Open field*	0.82–1.79	1.18 ± 0.20 (B)	0.52–0.74	0.60 ± 0.04 (B)
	Tunnel	1.04–2.08	1.45 ± 0.20 (A)	0.80–1.28	0.90 ± 0.07 (A)
Net profits (US$/m^2)	*Open field*	−1.79–0.09	−0.95 ± 0.37 (A)	−0.56–0.49	0.17 ± 0.18(B)
	Tunnel	−2.08–0.59	−1.07 ± 0.51 (B)	−0.12–1.19	0.28 ± 0.20 (A)

Table 3
Comparison of the number of pesticide applications between production methods. The data are averages ± standard deviations. Different letters indicate that there are significant differences (P < 0.05) between the treatments.

Season	Treatment	Number of pesticide applications	Number of fungicide applications
1	Tunnel	1.9 ± 1.2 b	0
	Open Field	6.7 ± 1.6 a	0
2	Tunnel	1.5 ± 0.6 b	2.9 ± 0.8
	Open Field	4.3 ± 1.1 a	3.0 ± 0.8

Table 4
Opinions of farmers on the techniques tested after two seasons.

Questions	
Mean opinion score on the use of seedling trays (1 bad - 5 good)	4.4
Mean opinion score on the use of a drip irrigation system (1 bad - 5 good)	4.6
Mean opinion score on the use of cabbage seeds (1 bad - 5 good)	4.5
Mean opinion score on the use of tunnels (1 bad - 5 good)	4.6
Average purchase price granted for tunnels (US$)	97
Percentage of farmers reporting issues with the sizing of tunnels (%)	37
Percentage of farmers reporting issues with the durability of tunnels (%)	34
Percentage of farmers reporting issues with the strenuous work under tunnels (%)	19
Percentage of farmers reporting issues with insects under tunnels (%)	16
Percentage of farmers reporting issues with fungi under tunnels (%)	10

Due to poor sales, most farmers incurred negative profits in the first season. No significant difference in profits was recorded between cultivation methods in the first season. However, contrasting results were obtained in the second season, as more favorable market conditions enabled the generation of positive profits. The profits for cabbages grown under tunnels were significantly higher than those generated for cabbages grown in open fields (0.28 as opposed to 0.17 US$.m^{-2}).

Computations were carried out to compare the total profits generated by growing cabbages in an open field and under a tunnel over the estimated lifespan of the tunnels (four years, equivalent to 12 crop cycles) considering data collected in the first and second seasons. As previously indicated, the simulation-based performance of the first season indicated that farmers would produce cabbages at a loss (Fig. 2A). It is worth noting that the economic losses estimated were significantly higher under nets than in open plots because of investment costs. These simulations revealed that only 2% of farmers would manage to break even by investing in low tunnels within the lifespan of four years. Computations based on data collected in the second season suggested that the total profits generated under tunnels over their lifespan were 60% higher than those generated in open fields (3.35, as opposed to 2.08 US$/m^2) (Fig. 2B). These estimations indicated that 98% of farmers would manage to recoup the cost of investing in tunnels after 5.3 crop cycles, on average, which is less than two years, and would start generating higher profits than in open fields after 7.5 crop cycles (2.5 years).

4. Discussion

Although several earlier publications highlighted the merits of growing vegetables under low tunnels in sub-Saharan Africa, this is the first study attempting to assess the economic performance of this cultivation method with a large number of farmers (Martin et al., 2006; Muleke et al., 2014; Simon et al., 2014). Our results were consistent with previous studies and confirmed the merits of using nets to improve yields, whilst reducing pesticide use. Although all farmers experienced improved yields under tunnels, our results underline some concerns about the profitability of growing cabbages under nets because of the large variations in the economic results between seasons. This seasonal variation was related to changes in market prices and the number of unsold cabbages, rather than to a difference in yields. The positive economic results of using nets in the second season contradicted the negative profits generated in the first season, which were compounded by the investment costs for tunnels. The need to offset investment within the shortest period is associated with the limited lifespan of the materials used for tunnels, which obliges farmers to maximize the number of crop cycles per year. Moreover, the use of low tunnels is restricted to low-height crops, such as carrots, onions, and French beans, and this cultivation method would not necessarily improve the yields of these crops significantly, as nets do not keep out all insect pests especially the smallest ones, such as aphids, mites, whiteflies, and thrips. In addition, as for cabbages, the potential increase in yields of these crops under low tunnels and the reduction in pesticide use in comparison to open fields need to offset investment costs.

The constraints related to cultivation under tunnels leave less room

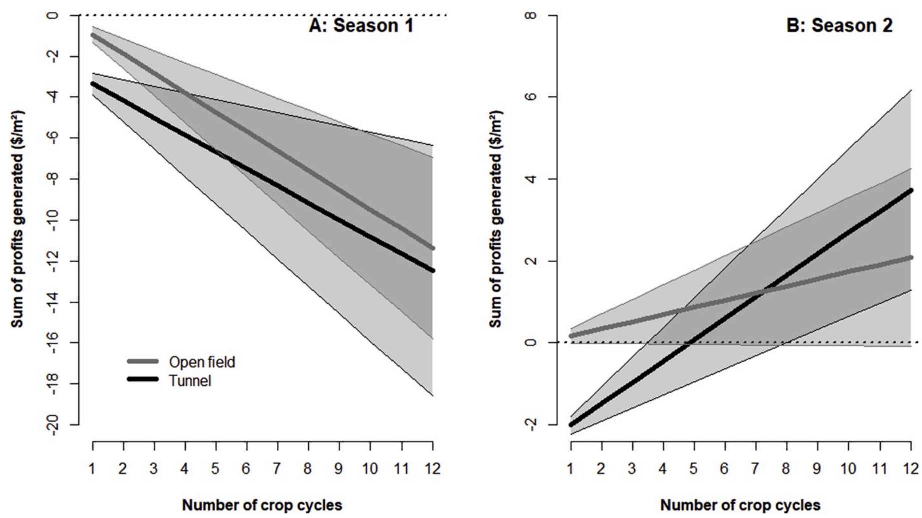

Fig. 2. Simulation of cumulative profits for farmers growing cabbages in open fields and under tunnels using the agronomic and economic performance recorded in the first (A) and the second season (B). The average (continuous lines) ± standard deviation (gray region) of the profits for cabbage cultivation under nets and in open fields are displayed in gray and black, respectively.

to adapt the choice of crops and production schedules to the seasonal variations of the market than in the case of open field production.

The contrasting conclusions of the cost-benefits analysis conducted in Benin with a smaller number of farmers (7 producers) are explained by the lower seasonal variations in the economic results of cabbage cultivation under nets (Vidogbéna et al., 2015). In contrast to our study, changes in economic results between seasons were mainly related to lower yields during the warmer seasons.

The seasonal variations in market prices observed in our study were not specific to cabbage and are commonly observed for food products in Africa, especially for fruits and vegetables, because of their restricted shelf-life (Gilbert et al., 2017). Poor access to markets and less market intelligence are generally considered as key impediments in the well-being of smallholder farmers, as testified by development projects advocating a market-oriented approach to increase smallholder incomes (Diao and Hazell, 2004). As in previous studies on the vegetable marketing system in Tanzania (Lenné and Ward, 2010), our results showed that farmers had restricted access to the market and failed to increase their negotiating power with retailers by not selling their products collectively.

Our results showed that investment costs under variable market conditions and the fact that, under the existing circumstances, crops grown under tunnels may command the same market price on the main farmer markets as those produced conventionally, increased the economic risk of growing cabbages under tunnels. The risk exposure and the capacity to bear the risk is one of the main factors determining the adoption of agricultural innovation (Feder et al., 1985). Consequently, promoting innovations to reduce pesticide use, such as low tunnels, should be accompanied by an action plan to secure product sales, such as contractualisation, grouped sales, and identification of niche markets, among other things. Interestingly, our results suggested that there is demand for quality products since, once enlightened, retailers and consumers were willing to pay a premium for cabbages produced under nets. Further studies would be required to identify whether the higher sale price for cabbages under nets was justified by the heavier weight, or the reduction in pesticide use.

It is worth noting that the dissemination of tunnels might also be impeded by the technical limitations raised by farmers. Removing nets during the daytime in a hot and humid climate to reduce the temperature increase under tunnels was identified as a key obstacle to the adoption of the technique in a previous study (Vidogbéna et al., 2016). Nevertheless, the increase in temperature under tunnels was not detrimental to crops in the present study because of temperate climatic conditions. The farmers also complained about the low height of the tunnels since it is difficult to walk inside. In addition, increasing the height of tunnels would enable other crops to be grown, such as tomato, cucumber, pepper, or eggplant, but would also significantly increase the initial investment costs. Lastly, some precautions should also be taken when promoting protected cultivation techniques, since they also tend to introduce a considerable quantity of plastic that are burnt or buried most of the time for want of a recycling scheme. One might wonder whether short-term benefits justify the long-term pollution issues generated by introducing plastic into production systems (Nordey et al., 2017; Steinmetz et al., 2016).

5. Conclusions

Our results confirmed that low tunnels increase vegetable yields while reducing pesticide use. Nevertheless, the seasonal variation in the economic benefits of this technique related to fluctuating market prices, calls for caution. The need to offset investment costs within the shortest period, the restricted lifespan of the materials used for tunnels, as well as the suitability of this technique being restricted to a small number of crops, reduce the ability of farmers to adapt to market changes. Any promotion of this cultivation method should therefore be accompanied by an action plan to secure markets for the products and ensure all-year-round production to maximize the benefits of low tunnels.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Thibault Nordey: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Justus Ochieng:** Conceptualization, Methodology, Writing - review & editing. **Zablon Ernest:** Investigation, Writing - review & editing. **Nickson Mlowe:** Investigation, Writing - review & editing. **Inviolate Mosha:** Investigation, Writing - review & editing. **Paula Fernandes:** Conceptualization, Methodology, Writing - review & editing.

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Appendix A. Supplementary data

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