1    **Is vegetable cultivation under low tunnels a profitable alternative to pesticide use? The case of cabbage**

2    **cultivation in northern Tanzania**

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12

13    Abstract

14    The health benefits of fruit and vegetable consumption can be jeopardized by pesticide residues, especially

15    in developing countries, due to their misuse. While vegetable growing under cover is growing in popularity

16    worldwide as an effective technique for improving yields while reducing pesticide use, these protected

17    cultivation techniques often remain underutilized by smallholder farmers. A cost-benefit analysis was

18    conducted with fifty smallholder farmers in northern Tanzania over two seasons to compare the

19    profitability of growing cabbage in open plots and under inexpensive low tunnels. Although all farmers

20    significantly improved their yields under nets over the two seasons (9.85, as opposed to 6.80 kg.m$^{-2}$ and

21    10.09, as opposed to 8.63 kg.m$^{-2}$, in each season respectively) and reduced their pesticide use (by 3.5 and

22    2.8 times), the large variations in market prices observed between seasons called into question the

23    profitability of this cultivation technique. With the conducive market conditions of the second season, it

24    would have taken 5.3 crops cycle on average, i.e. less than 2 years, to recoup the investment costs of low

25    tunnels, whereas with the poor market conditions observed in the first season, the investment in tunnels

26    compounded the negative economic results obtained from growing cabbages in an open field.

27    Consequently, our results showed that using low tunnels could be a suitable alternative for reducing

28    pesticide use, but this technique was not economically viable with the existing marketing systems used by

29    the farmers. For this technique to be adopted, further work is needed to identify changes in vegetable

30    marketing systems that would promote the use of cultivation techniques that reduce pesticide use.

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32    **Keywords:** Africa; Economics; Profitability; Protected cultivation; Small-scale farmer

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## 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, 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 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.

## Material and methods

### 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 Figure 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 (Figure 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.

### 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 m² low tunnel (1.5 m high, 2 m wide, and 10 m long) made of white netting (0.7 x 0.9 mesh size, AtoZ). The farmers constructed low tunnels with locally available wood and bamboo poles (Supplementary Figure 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 x 10 m open plot and under a small 2 x 10 m tunnel. Cabbage seedlings were transplanted every 40 cm in three lines per plot. The farmers were advised to apply 10 g

85    per plant of NPK 17-17-17 and 10 g of urea in the 2nd and 5th weeks after transplanting. Lambda-

86    cyhalothrin (Karate 5EC, Syngenta, applied at 400 mL/Ha) was used to control sucking insects (whiteflies

87    and aphids) and Lepidoptera, consistent with locally used pesticide.  Mefenoxam and mancozeb (Ridomil

88    Gold, Syngenta, applied at 2.5kg/Ha) were used to control fungal diseases, i.e. black rot, based on scouting

89    of individual plots once symptoms appear on cabbages. Pesticides were applied with a backpack sprayer.

90

91    Data collected

92    Air temperature and moisture, global radiation, and rainfall were measured each minute and averaged

93    every 30 minutes with a fully equipped weather station (Vantage PRO2, Davis Instruments, California, USA)

94    installed at The World Vegetable Center for Eastern and Southern Africa, Duluti, Arusha (Latitude

95    −3.373, Longitude 36.80, decimal degrees) (Figure 1). The data collected over the two seasons are provided

96    in Table 1. The quantity of inputs (seeds, organic and synthetic fertilizers, and pesticides), the equipment

97    used (hoe, seedling trays, drip irrigation system, and tunnels), the labor required, and the selling price of

98    cabbages produced in open plots and under tunnels were assessed for each farmer throughout the two

99    seasons of cabbage production. Data were collected by the farmers and with the support of agronomists

100   (extension officers) by phone and during follow-up visits (Supplementary Figure S1). Agronomists helped

101   farmers to harvest, to sort marketable and non-marketable cabbages, and to weigh the cabbages.

102   Furthermore, a workshop was held with all the farmers involved in the experiment at the end of each

103   season to exchange experiences, provide feedback, and receive supplemental training. In addition, an

104   individual survey was conducted during the last workshop to gather the views of the farmers on the

105   different techniques and inputs used, i.e. seeds, drip irrigation systems and low tunnels, and to determine

106   how much they would pay for the low tunnel without knowing the actual cost.

107

108   Economic analysis

109   A cost-benefit analysis was conducted for each farmer, each season, and for each cultivation method

110   tested (open field and low tunnel). Economic indicators were expressed as US$/m² consistent with the

111    surface area that could be potentially cultivated under low tunnels. The profits were computed by

112    subtracting the sum of the variable and fixed costs from the total revenue. Variable costs were those

113    directly associated with cabbage production, including labor and inputs (seeds, fertilizers and pesticides).

114    The costs of irrigation were only related to those for labor and equipment, since all the farmers in the

115    study had free access to surface water. The cost of labor was estimated using the average of the

116    opportunity cost of labor reported by the local village authorities surveyed, i.e. 3.0 US$ per day. Only the

117    depreciation of the equipment was considered in the calculation of the fixed costs, since all the farmers

118    owned their land or had free access, and they did not take out a loan to buy the equipment.

119    Depreciation of the items of equipment was calculated according to their respective lifespans and the

120    potential number of crop cycles per year, i.e. three cycles for cabbage. The lifespan of the seedling trays,

121    watering can, sprayer, hand hoe, drip irrigation, nets, bamboo poles and ropes were estimated to be 2,

122    10, 10, 10, 3, 4, 2, and 1 year, respectively. Based on farmer experience, it was estimated that three crop

123    cycles per year were possible in the region where the experiments were conducted.

124    The costs of equipment and inputs were estimated from local suppliers. The total revenue was computed

125    from the selling prices for marketable and non-marketable cabbages. The gross margin was calculated by

126    subtracting the variable costs from the total revenue. The gross margin minus the fixed costs related to

127    equipment other than the low tunnels was used to calculate the number of crop cycles required to start

128    generating positive profits, hereafter referred to as break-even, and higher profits from growing cabbages

129    under tunnels than from growing them in open fields, hereafter referred to as added-value.

130    Statistical analysis

131    Skillings–Mack tests were used to compare agronomic aspects, namely yields, the weight of cabbages, and

132    the number of pesticide applications, along with economic parameters, such as the variable and fixed

133    costs, gross margin, and profits, which were indicators between cultivation methods since the data did not

134    follow a normal distribution. Each farmer was considered a replicate in the analyses. All computations and

135    statistical analyses were carried out using R software (R Development Core Team, 2012) with the

136    PMCMRplus package (Pohlert and Pohlert, 2018).

137

139    *Agronomic performance*

140    The second season was wetter than the first season, but the temperature, air moisture, and solar radiation

141    were relatively similar (Table 1). All farmers obtained higher marketable yields under low tunnels than in

142    the open plots for both seasons (Table 2). Improved yields under nets (expressed in kg per m²) were related

143    to the higher number and weight of cabbages harvested (Table 2). Yields greatly varied between the

144    farmers, regardless of the production methods. The marketable yields varied from 1.09 to 12.6 kg.m$^{-2}$ in

145    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

146    open plots and from 7.5 to 12.1 kg.m$^{-2}$ under small tunnels in the second season (Table 2). The discrepancy

147    in yields between farmers was attributed to variations in pest pressure and crop management, such as

148    watering, weeding, fertilization and pest and disease management. The main insects observed over the

149    two seasons were aphids, the diamondback moth (*Plutella xylostella*) and various larvae of Lepidopteran

150    insects such as *Hellula undalis*, *Helicoverpae armigera*, and *Spodoptera litura* were also occasionally

151    observed. Pesticide use was significantly lower under low tunnels than in open plots for the two seasons,

152    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

153    two, respectively (Table 3). The farmers generally had a good opinion of the technology tested (Table 4).

154    All of them were willing to continue using it (data not shown), but about a third (34%) complained about

155    the durability of the materials used for tunnel construction, including the nets, bamboo poles, and the zip

156    system. More than 37% of the farmers were interested in increasing the height of the tunnels, in order to

157    facilitate work under the tunnels. Interestingly, when farmers were asked at the end of the experiment

158    how much they would pay for the tunnel without knowing the actual costs (52 US$) they were willing to

159    purchase it for a higher price (97 US$ on average).

160

161

162 *Economic performance*

163 Only half of the marketable cabbages produced in open fields and under tunnels were sold in the first

164 season (54% and 52%, respectively), because of reduced demand due to a market glut, in contrast to the

165 second season where almost all marketable cabbages were sold (98.2 and 99.9%, respectively) (Table 2).

166 All the farmers sold their cabbages at the farm gate, to retailers or to neighbors. Large variations in the

167 selling price of cabbages were observed between seasons and producers (Table 2). The average price of

168 cabbages grown in open fields and under tunnels increased 3.4- and 3-fold, respectively, between the first

169 and the second season (Table 2). Cabbages grown under tunnels were sold for 50% and 87% more, on

170 average, in the first and the second season, respectively, than those grown in open fields. The variable

171 costs were significantly higher under nets than in open fields because of the labor required to construct

172 the tunnels. Growing cabbages under nets reduced the cost of pesticide treatments by 0.03 and 0.02

173 US$.m² in the first and the second season, respectively, in comparison to open field cultivation (Table 2).

174 This reduction was negligible compared to the depreciation cost of tunnels per crop cycle, i.e. 0.24 US$.m$^{-}$

175 $^{2}$. Total production costs were significantly higher under nets than in open fields for both seasons. Labor

176 costs amounted to 86% and 70% of the total cost, on average, for the first season in open fields and under

177 tunnels, respectively, as opposed to 77% and 65% in the second season. The higher labor costs in the first

178 season were related to the high frequency of irrigation.

179 Due to poor sales, most farmers incurred negative profits in the first season. No significant difference in

180 profits was recorded between cultivation methods in the first season. However, contrasting results were

181 obtained in the second season, as more favorable market conditions enabled the generation of positive

182 profits. The profits for cabbages grown under tunnels were significantly higher than those generated for

183 cabbages grown in open fields (0.28 as opposed to 0.17 US$.m$^{-2}$).

184 Computations were carried out to compare the total profits generated by growing cabbages in an open

185 field and under a tunnel over the estimated lifespan of the tunnels (four years, equivalent to 12 crop cycles)

186 considering data collected in the first and second seasons. As previously indicated, the simulation-based

187 performance of the first season indicated that farmers would produce cabbages at a loss (Figure 2A). It is

188  worth noting that the economic losses estimated were significantly higher under nets than in open plots

189  because of investment costs. These simulations revealed that only 2% of farmers would manage to break

190  even by investing in low tunnels within the lifespan of four years. Computations based on data collected

191  in the second season suggested that the total profits generated under tunnels over their lifespan were

192  60% higher than those generated in open fields (3.35, as opposed to 2.08 US$/m²) (Figure 2B). These

193  estimations indicated that 98% of farmers would manage to recoup the cost of investing in tunnels after

194  5.3 crop cycles, on average, which is less than two years, and would start generating higher profits than in

195  open fields after 7.5 crop cycles (2.5 years).


196  Discussion

197  Although several earlier publications highlighted the merits of growing vegetables under low tunnels in

198  sub-Saharan Africa, this is the first study attempting to assess the economic performance of this cultivation

199  method with a large number of farmers (Martin et al., 2006; Muleke et al., 2014; Simon et al., 2014). Our

200  results were consistent with previous studies and confirmed the merits of using nets to improve yields,

201  whilst reducing pesticide use. Although all farmers experienced improved yields under tunnels, our results

202  underline some concerns about the profitability of growing cabbages under nets because of the large

203  variations in the economic results between seasons. This seasonal variation was related to changes in

204  market prices and the number of unsold cabbages, rather than to a difference in yields. The positive

205  economic results of using nets in the second season contradicted the negative profits generated in the

206  first season, which were compounded by the investment costs for tunnels. The need to offset investment

207  within the shortest period is associated with the limited lifespan of the materials used for tunnels, which

208  obliges farmers to maximize the number of crop cycles per year. Moreover, the use of low tunnels is

209  restricted to low-height crops, such as carrots, onions, and French beans, and this cultivation method

210  would not necessarily improve the yields of these crops significantly, as nets do not keep out all insect

211  pests especially the smallest ones, such as aphids, mites, whiteflies, and thrips. In addition, as for cabbages,

212  the potential increase in yields of these crops under low tunnels and the reduction in pesticide use in

213  comparison to open fields need to offset investment costs.

214    The constraints related to cultivation under tunnels leave less room to adapt the choice of crops and

215    production schedules to the seasonal variations of the market than in the case of open field production.

216    The contrasting conclusions of the cost-benefits analysis conducted in Benin with a smaller number of

217    farmers (7 producers) are explained by the lower seasonal variations in the economic results of cabbage

218    cultivation under nets (Vidogbéna et al., 2015). In contrast to our study, changes in economic results

219    between seasons were mainly related to lower yields during the warmer seasons.

220    The seasonal variations in market prices observed in our study were not specific to cabbage and are

221    commonly observed for food products in Africa, especially for fruits and vegetables, because of their

222    restricted shelf-life (Gilbert et al., 2017). Poor access to markets and less market intelligence are generally

223    considered as key impediments in the wellbeing of smallholder farmers, as testified by development

224    projects advocating a market-oriented approach to increase smallholder incomes (Diao and Hazell, 2004).

225    As in previous studies on the vegetable marketing system in Tanzania (Lenné and Ward, 2010), our results

226    showed that farmers had restricted access to the market and failed to increase their negotiating power

227    with retailers by not selling their products collectively.

228    Our results showed that investment costs under variable market conditions and the fact that, under the

229    existing circumstances, crops grown under tunnels may command the same market price on the main

230    farmer markets as those produced conventionally, increased the economic risk of growing cabbages under

231    tunnels. The risk exposure and the capacity to bear the risk is one of the main factors determining the

232    adoption of agricultural innovation (Feder et al., 1985). Consequently, promoting innovations to reduce

233    pesticide use, such as low tunnels, should be accompanied by an action plan to secure product sales, such

234    as contractualisation, grouped sales, and identification of niche markets, among other things.

235    Interestingly, our results suggested that there is demand for quality products since, once enlightened,

236    retailers and consumers were willing to pay a premium for cabbages produced under nets. Further studies

237    would be required to identify whether the higher sale price for cabbages under nets was justified by the

238    heavier weight, or the reduction in pesticide use.

239   It is worth noting that the dissemination of tunnels might also be impeded by the technical limitations

240   raised by farmers. Removing nets during the daytime in a hot and humid climate to reduce the

241   temperature increase under tunnels was identified as a key obstacle to the adoption of the technique in a

242   previous study (Vidogbéna et al., 2016). Nevertheless, the increase in temperature under tunnels was not

243   detrimental to crops in the present study because of temperate climatic conditions. The farmers also

244   complained about the low height of the tunnels since  it is difficult to walk inside. In addition, increasing

245   the height of tunnels would enable other crops to be grown, such as tomato, cucumber, pepper, or

246   eggplant, but would also significantly increase the initial investment costs. Lastly, some precautions should

247   also be taken when promoting protected cultivation techniques, since they also tend to introduce a

248   considerable quantity of plastic that are burnt or buried most of the time for want of a recycling scheme.

249   One might wonder whether short-term benefits justify the long-term pollution issues generated by

250   introducing plastic into production systems (Nordey et al., 2017; Steinmetz et al., 2016).

251   Conclusions

252   Our results confirmed that low tunnels increase vegetable yields while reducing pesticide use.

253   Nevertheless, the seasonal variation in the economic benefits of this technique related to fluctuating

254   market prices, calls for caution. The need to offset investment costs within the shortest period, the

255   restricted lifespan of the materials used for tunnels, as well as the suitability of this technique being

256   restricted to a small number of crops, reduce the ability of farmers to adapt to market changes. Any

257   promotion of this cultivation method should therefore be accompanied by an action plan to secure

258   markets for the products and ensure all-year-round production to maximize the benefits of low tunnels.

264    government, Australian Centre for International Agricultural Research (ACIAR), Germany, Thailand, the

265    Philippines, Korea, and Japan.

266

267    Tables and Figures

268    **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 |

269

270    **Table 2**: Profitability analysis of the cabbage production systems. Means followed by different letters are

271    significantly different between treatments at P < 0.05 according to Skillings–Mack tests whereas "NS"

272    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/m²) | 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/m²) | 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$/cabbage) | Open field | 0 - 0.37 | 0.08 ± 0.09 (B) | 0 - 0.36 | 0.27 ± 0.06 (B) |
| | Tunnel | 0 - 0.55 | 0.13 ± 0.14 (A) | 0 - 0.68 | 0.39 ± 0.06 (A) |
| Variable costs (US$/m²) | 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) |

| Parameter | Production | First season | | Second season | |
|---|---|---|---|---|---|
| | | Range (min-max) | Mean ± standard deviation | Range (min-max) | Mean ± standard deviation |
| Including Pesticides (US$/m²) | *Open field* | 0.01 - 0.04 | 0.03 ± 0.008 (A) | 0.013 - 0.04 | 0.02 ± 0.006 (B) |
| | *Tunnel* | 0.0002 - 0.03 | 0.004 ± 0.007 (B) | 0.005 - 0.02 | 0.01 ± 0.003 (A) |
| Including Labor (US$/m²) | *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$/m²) | *Open field* | 0.09 - 0.09 | 0.09 ± 0 (B) | 0.09 - 0.09 | 0.09 ± 0 (B) |
| | *Tunnel* | 0.31 - 0.38 | 0.33 ± 0.01 (A) | 0.31 - 0.31 | 0.38 ± 0.01 (A) |
| Total costs (US$/m²) | *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$/m²) | *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) |

273

274 **Table 3**: Comparison of the number of pesticide applications between production methods. The data are

275 averages ± standard deviations. Different letters indicate that there are significant differences (P < 0.05)

276 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 |

277

278　　**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 |

279

280    **Figure 1:** Location of farmer groups involved in the experiment in the Arusha region. The numbers between

281    commas indicate the number of farmers per location. Weather data were recorded at The World

282    Vegetable Center campus (WVC ESA, (Latitude −3.373, Longitude 36.80, decimal degrees).).

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284

285   **Figure 2:** Simulation of cumulative profits for farmers growing cabbages in open fields and under tunnels

286   using the agronomic and economic performance recorded in the first (A) and the second season (B). The

287   average (continuous lines) ± standard deviation (gray region) of the profits for cabbage cultivation under

288   nets and in open fields are displayed in gray and black, respectively.



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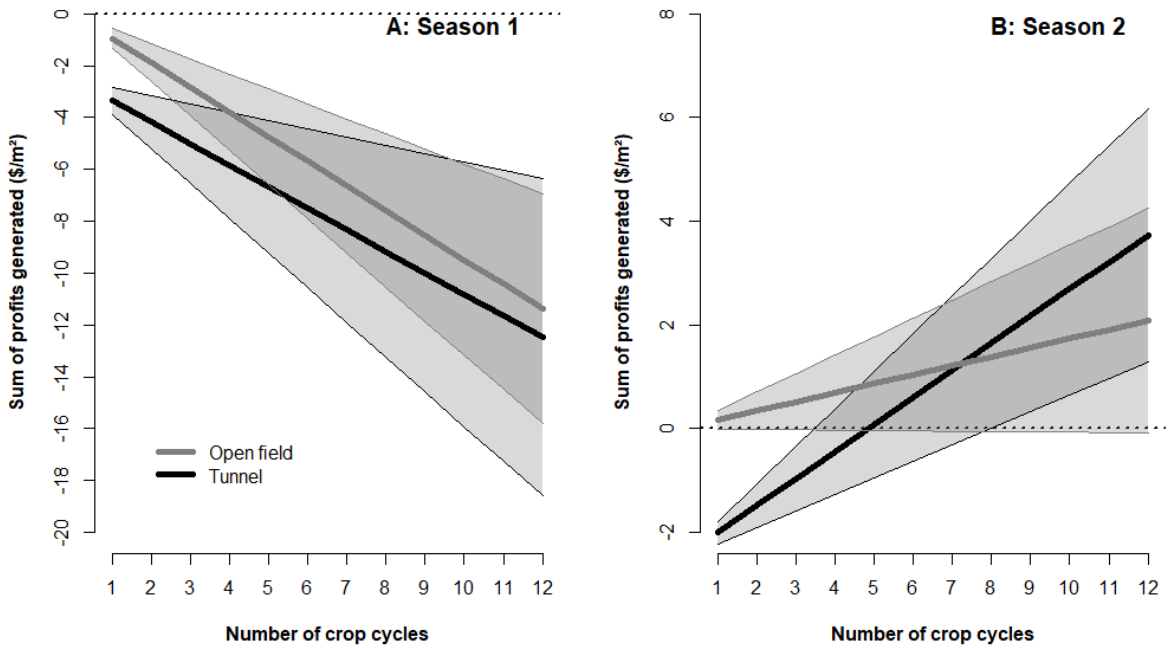
**Supplementary Figures**

**Figure S1**: Training farmers to use the drip irrigation system (A), follow-up visit of agronomists (B), crop

management in open field plots (C) and inside tunnels (D).

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