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Evaluation of Agronet Covers to Reduce Pesticide Application for Yield Improvement and Profitability for Small Scale Cabbage (*Brassica oleraceae* var. *capitata*) Growers

Saidi Mwanarusi[1*] and Muleke Everlyne M'mbone[1]

[1]Department of Crops, Horticulture and Soils, Egerton University, P.O.Box 536 - 20115, Egerton, Kenya.

Authors' contributions

This work was carried out in collaboration between both authors. Author SM designed the study and wrote the protocol. Author MEM carried out the field experiment and wrote the first draft of the manuscript. Authors SM and MEM managed the analyses of the study. Author MEM managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Poor returns from open field cabbage (*Brassica oleraceae* var. *capitata*) production in sub-Saharan Africa are attributed to compromised yield due to high pest infestation. With chemical control measures becoming increasingly uneconomical and hazardous, relatively cheaper and eco-friendly alternative technologies are imperative. Two trials were conducted at the Horticulture Research and Teaching Field, Egerton University, Kenya to assess the yield and economic benefits of using agronet covers against major insect pests of cabbage. A randomized complete block design with six treatments replicated five times, was used. The treatments comprised of 0.4 mm and 0.9 mm pore diameter agronet covers maintained either by (i) opening thrice a week between 9.00 am and 5.00 pm or (ii) permanently covered except during routine crop maintenance, unprotected cabbage sprayed with insecticide and unprotected cabbage without any insecticide application (control).

**Corresponding author: E-mail: msaidi@egerton.ac.ke;*

Agronet maintained permanently covered significantly reduced populations of cabbage aphids, diamondback moth, cabbage looper, mites, and leaf miners at P=0.05. Agronet covers reduced insecticide sprays per crop cycle from 11 to 1 and improved marketable cabbage head numbers by between 15.0-43.5% compared to the control and 2.1-27.3% compared to spraying with insecticides. Marketable head weight was higher by between 28.7-130.1% under agronets compared to the control and by 9.3-95.4% compared to spraying with insecticides. The highest cabbage marketable yields and net income on sales were obtained under the 0.9 mm pore diameter agronet maintained permanently covered which gave the highest cost benefit ratio of 1:17.1 in season one and 1:26.2 in season two. These results present permanent use of 0.9 mm pore diameter agronets as a viable technology in reducing insect pest infestation and cost of cabbage production. This is achieved through reduced pesticide use with a potential of contributing towards environmentally safe and profitable cabbage production by small-scale growers in sub-Saharan Africa.

Keywords: Pest exclusion; microclimate modification; yield; cost benefit ratio; cabbage.

1. INTRODUCTION

Cabbage (*Brassica oleraceae* var. *capitata*) is an important vegetable in sub-Saharan Africa. In Kenya for example, the value of cabbage is about US $. 49.3 million per year, from a total area of 15,318 ha [1], with the bulk of the producers being resource poor smallholder farmers who grow it for food as well as a source of income. In most sub-Saharan countries, cabbage is grown in open fields where it is subject to rampant attack by insect pests, which are favoured by the tropical conditions prevalent in these areas. During its growing period of about 16 weeks, cabbage is exposed to a number of insect pests belonging to different orders, including Lepidoptera, Homoptera, Diptera and Coleoptera [2]. Losses ascribed to these pests have been documented to amount to between 10% and 30%, reaching over 80% in severe infestations [3]. To minimize output losses, farmers widely use synthetic pesticides with many of them solely dependent on these pesticides [4].

Broad-spectrum insecticides like, methomyl and permethrin sprays have been used by many farmers in cabbage growing season after season. However, extensive application does not suppress cabbage pests, but to the contrary, the pests quickly develop resistances leading to a build-up of the pests with repeated use of the pesticides [5,6]. Tests conducted in Kenya for example showed organophosphates, carbamates and pyrethroids to have lost effectiveness against diamondback moth and aphids in most brassicas [7,8]. Although this poses a challenge to many farmers, chemical overuse marked by high quantity and spray frequencies, as well as application of pesticide cocktails is expected to continue if alternative control methods are not sort [4]. Besides increasing the cost of production, these practices come with other potential implications including a further reduction in the already small populations of natural enemies, a decline in land and water quality through accumulation of pesticide residues and human and animal health problems [9,10].

With chemical control measures becoming increasingly ineffective, uneconomical and hazardous, alternative physical control measures are gaining attention [11,12]. Growing crops under net covers has been used for many years in the temperate world to provide physical exclusion of insect pests thereby reducing the incidences of direct crop damage and insect-transmitted viral diseases [13], besides modifying the microclimate to favour plant growth and yields [14]. Information on cost effective environmental friendly cabbage production technologies with the potential of enhancing cabbage production through physical exclusion of insect pests is, however, lacking in many sub-Saharan countries. This study aimed at establishing whether growing cabbage under agronet covers would reduce pest infestation on the crop and consequently the need for insecticide sprays while increasing both yield and profitability of the crop.

2. MATERIALS AND METHODS

2.1 Experimental Site Description

Two trials (May–August, 2011 and October, 2011–January, 2012) were conducted at the Horticulture Research and Teaching Field of Egerton University, Njoro, Kenya. The field is

located at 0º23'S and longitude 35º35'E in the Lower Highland III Agro Ecological Zone (LH3) at an altitude of about 2238 m above sea level. The average maximum and minimum temperatures range from 19 to 22ºC and 5 to 8ºC, respectively, with a mean total annual rainfall of 1200 to 1400 mm. Soils are predominantly andosols with a pH of 6.0 to 6.5 [15].

2.2 Experimental Design and Treatments

A randomized complete block design with five replications and six treatments was used. Treatments comprised of growing cabbage under (i) 0.4 mm pore diameter agronet cover maintained permanently covered except during routine crop maintenance, (ii) 0.9 mm pore diameter agronet cover maintained permanently covered except during routine crop maintenance, (iii) 0.4 mm pore diameter agronet cover opened thrice a week from 9 am to 3 pm (iv) 0.9 mm pore diameter agronet cover opened thrice a week from 9 am to 3 pm (v) uncovered plot sprayed with Innova Alpha-Cypermethrin 100 Duo insecticide (Syngenta Crop Protection Pty Limited) weekly and (vi) uncovered plot with no insecticide sprayed throughout the growing season as a control. Each block therefore comprised of six experimental units each measuring 2 m by 6 m giving a total of 30 experimental units. Individual blocks measured 2 m by 38.5 m separated by a 1 m buffer. For agronet covered plots, poles 0.5 m long and about 5 cm thick were mounted before planting to provide support for the net covers. The poles were driven 20 cm deep into the ground at each corner and at the centre of the plot to provide the needed support for the nets. Binding wire was then fixed at the top of the posts along the perimeter and the centre of the plots using u-nails to allow for good draping of the agronets. Agronets measuring 3 m wide by 7 m long were then mounted on each plot ensuring that the nets provided a complete cover of the plots (Fig. 1).

2.3 Land Preparation, Planting and Crop Maintenance

The field was manually tilled using hand hoes to approximately 20 cm depth and prepared to a fine tilth using rakes. Healthy Gloria F1 hybrid cabbage seedlings produced under agronets were then transplanted at a spacing of 40 cm by 40 cm giving a total of 75 plants per plot. Triple superphosphate (45% P_20_5) fertilizer was used at planting at the rate of 225 kg/ha [16]. Agronets were then mounted on each of the net protected plots immediately after transplanting. A two

Fig. 1. Layout of the experiment showing agronet covers on the cabbage crop

split Calcium Ammonium Nitrate (26%N) top dress was also done to all plots, the first one at three weeks after transplanting and the second one, three weeks later to a total rate of 300 kg/ha as recommended by [16]. Control plots had no chemical spray applied throughout the crop cycle while chemical sprayed plots were sprayed with Innova Alpha-Cypermethrin 100 Duo (Active ingredient - 100 g/l Alpha-cypermethrin) at the rate of 20 ml/20 L of water with a total of 10 sprays in season one and 11 sprays made in season two. Permanently covered Agronet treatments on the other hand received one insecticide spray at ten weeks after transplanting during each crop cycle, when it was noted that the population of most pests on the cabbage plants was on the rise. In season one, a total of four sprays were done on plots with agronet covers opened three times a week at seven, eight, nine and ten weeks after transplanting. In season two, these plots received a total of five sprays at six, seven, eight, nine and ten weeks after transplanting. Other crop maintenance practices were carried out uniformly on all plots based on standard good agricultural practices recommended for cabbage [16].

2.4 Data Collection

Data collection commenced four weeks after transplanting and was continued until harvest. Data was collected from twenty plants randomly selected from the inner rows of individual plots leaving plants in the outer rows as guard rows. Data were collected on:

2.4.1 Pest counts

Once every week, the number of arthropod pests including cabbage aphids (*Brevicoryne brassicae*) at the nymph stage, diamond backmoth (*Plutella xylostella*) at larval stage, cabbage looper (*Trichoplusia ni*) at larval stage, mites (*Tetranchynus sp*) at adult stage and leaf miners (*Lyriomyza brassicae*) at larval stage on all leaves of the 20 randomly selected and tagged plants were physically counted and recorded. Counting of pests was done early in the morning when most pests are inactive. For very small pests like aphids and mites, hand lens (G-888-075; Shanghai Precision and Scientific Instrument Co., Shangai, China) was used to magnify the pests for ease of counting.

2.4.2 Marketable yields

Upon maturity, cabbage heads from the inner rows of individual experimental units were harvested for determination of head numbers and fresh head weight. The number of heads was determined by physical counting while head weight was determined using a mechanical weighing pan scale (10 kg/40 g, 18636 Shenzhen west-Boao Science and technology Co. Ltd. 3/F, 3 Building, Jiuxiangling Industrial Park, Xili Town, Nanshan District, Shenzhen, Guangdong, China). Fresh head weight was measured in kilograms per plot (kg/plot) and later converted into metric tonnes per hectare (ton/ha) while head number was expressed as number per plot (no/plot) and later into number per hectare (no./ha). Out of the cabbage heads harvested from each plot, marketable heads were separated from unmarketable heads by taking them to a roadside market and allowing customers to choose for themselves. Cabbage heads that did not attract a buyer at all were considered as unmarketable. The average marketable head numbers for the individual treatments was then computed as the summation of the heads sold out for the different replications of a given treatment divided by the number of replications. Marketable head weight on the other hand, was determined by getting the difference between the total weights of the cabbage heads and the weight of the cabbage heads that did not attract any buyer. Thereafter, percent increase in marketable head numbers and percent increase in head weight due to a given treatment was obtained by getting the difference between the marketable yield (head number or weight) of the given treatment and that of the control treatment then dividing the difference by the marketable head number or weight of the control treatment multiplied by one hundred.

2.4.3 Cost: Benefit ratio

Cabbage protection against major pests using different mesh sizes and management regimes of agronets were compared with a commonly used insecticide (Innova Alpha-Cypermethrin 100 Duo) and an unsprayed control. The costs of crop protection were recorded during the two growing seasons; the long rain (season one) and short rain (season two) seasons. These comprised of the cost of purchasing the agronet covers, labour cost for mounting and opening of the agronet covers, cost of purchasing the insecticide and labour cost for applying the insecticide depending on the treatment. Throughout the study, labour cost was based on the existing wage for an unskilled labourer at the locality at the time of the study which was at Kshs. 180 per man day (US$ 2.12) for both

seasons. Gross income from yield was obtained by multiplying the marketable head weight per hectare by the selling price per kg of cabbage which was at Ksh. 10 per kilogram (US$ 0.118) in season one and Ksh.15 per kilogram (US$ 0.177) in season two. Net benefit per hectare for each treatment was derived by subtracting the total cost of plant protection from total income [17]. Benefit over unsprayed control for the insecticide and agronet covered treatments were obtained by subtracting the income of the control treatment from that of each of the other individual treatments [18]. Thereafter, the cost: benefit ratio of each treatment was derived by dividing the benefit over unsprayed control for each individual treatment by the total cost of plant protection for each treatment as described by [17].

2.5 Data Analysis

Data collected were subjected to Analysis of Variance (ANOVA) using PROC GLM code of SAS version 9 (2005). Treatments means were separated using Tukey's Honestly Significant Difference Test at *P* =.05. Original data for pest counts was subjected to square root transformation before analysis of variance was done but values presented are the original means.

3. RESULTS AND DISCUSSION

3.1 Cabbage Arthropod Pest Population

The main pests observed in this study were cabbage aphids (*Brevicoryne brassicae*), cabbage looper (*Trichoplusia ni*), diamondback moth (*Plutella xylostella*), mites (*Tetranchynus sp*) and leaf miners (*Lyriomyza brassicae*).

3.1.1 Cabbage aphids

The use of agronet covers influenced aphid population on the cabbage crop. In both seasons and during most sampling dates, aphid population was highest in the uncovered control and lowest under the 0.4 mm and 0.9 mm permanently covered agronet treatments (Fig. 2). Aphid population was also higher on insecticide sprayed cabbage than on cabbage grown under permanently covered 0.4 mm or 0.9 mm agronet treatments throughout the study. At commencement of data collection, aphids' counts were also lower under the 0.4 mm and 0.9 mm agronet opened thrice a week treatments compared to the unsprayed treatment in most sampling dates. However, as the season advanced, the aphid population for these treatments increased rapidly surpassing that of the unsprayed control treatment by 10 Weeks After Transplanting (WAT) in both seasons.

3.1.2 Cabbage looper

First infestation of the crop by cabbage looper occurred at different times in the two seasons. The first infestation was noted at 7 WAT in season one and at 4 WAT in season two, and thereafter persisted till harvest. Regardless of the time of infestation, protecting the crop with agronets significantly reduced cabbage looper population (Fig. 2). Throughout the study, the lowest cabbage looper population was recorded on cabbage plants grown under a permanent cover of either the 0.4 mm or 0.9 mm agronets. On the other hand, cabbage looper population tended to be highest under the 0.4 mm agronet treatment opened thrice a week in most sampling dates of both seasons. More cabbage loopers were also recorded on the insecticide sprayed cabbage than on cabbage grown under the 0.4 mm or 0.9 mm agronet maintained permanently covered throughout the study. Generally, at all sampling dates, cabbage looper population remained highest on the unsprayed cabbage plants.

3.1.3 Diamondback moth

The use of agronet covers over cabbage crop lowered population of diamondback moth (DBM) on the crop (Fig. 2). Throughout the study, diamondback moth population on cabbage plants was significantly reduced when cabbage plants were permanently covered with either the 0.4 mm or the 0.9 mm agronet. Between these two treatments, lower populations of diamondback moth were recorded under the 0.4 mm than 0.9 mm agronet, especially in season two. On the other hand, diamondback moth populations were higher in the unprotected unsprayed treatment and under the 0.4 mm and 0.9 mm agronets opened thrice a week treatments. This trend was persistent in most sampling dates of both seasons.

More diamondback moths were also recorded on the insecticide sprayed cabbage than on cabbage grown under the 0.4 mm or 0.9 mm agronet maintained permanently covered throughout the study. In all sampling dates, diamondback moth population for this treatment was however lower than that of unsprayed cabbage.

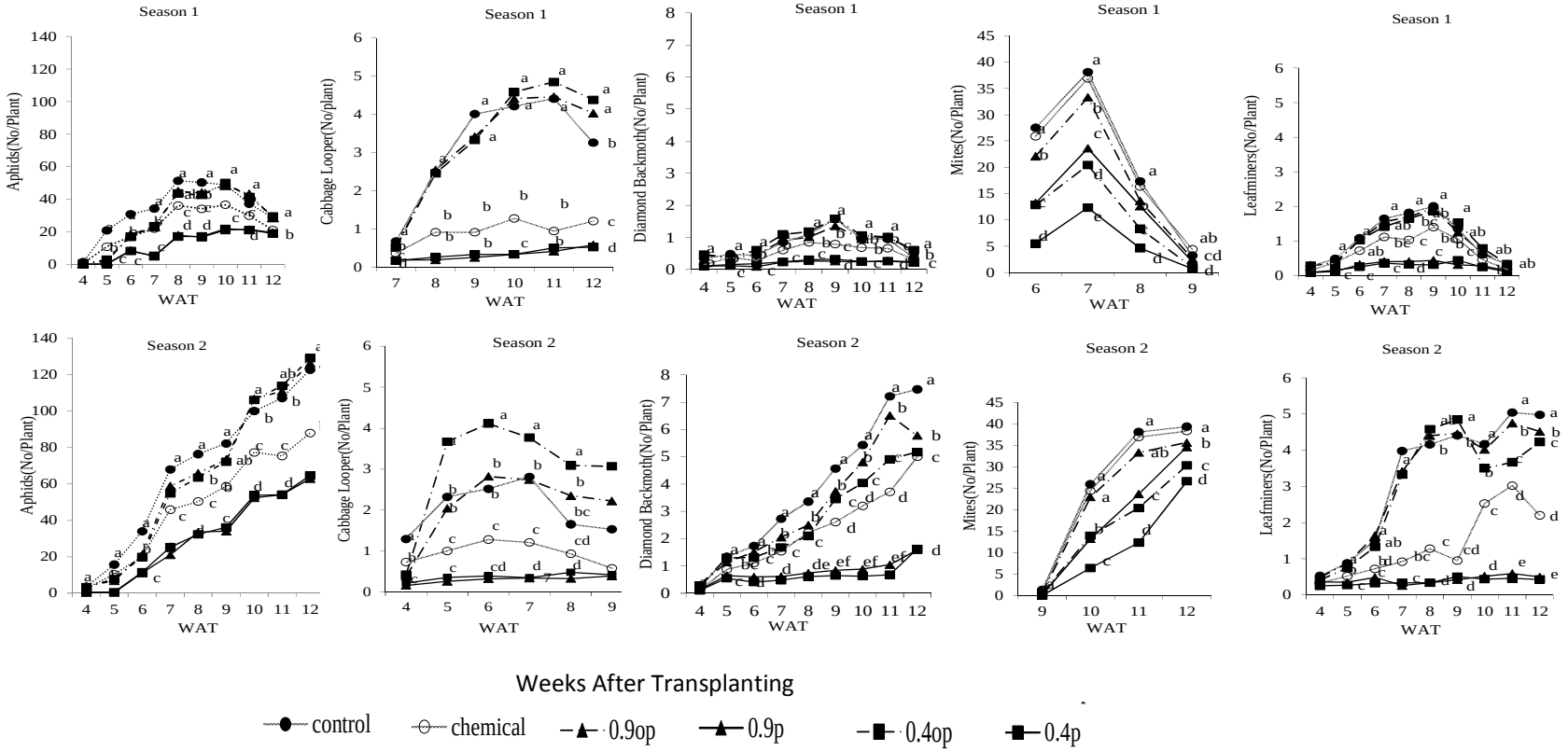

Fig. 2. Changes in insect pest population on cabbage plants as influenced by agronet covers during season 1 (May - August 2011) and season 2 (October 2011 - January 2012) field experiment. Control had no agronet cover; chemical had no agronet cover but the crop was sprayed with insecticide; Op is where the agronet was opened three times a week; P is where agronet was maintained permanently covered except during maintenance and data collection periods while 0.4 and 0.9 were the different agronet mesh sizes(mm) used. Insect pest data was subjected to square root transformation before ANOVA and mean separation but the means presented are original means

3.1.4 Mites

In season one, mites first appeared at 6 WAT and persisted for four weeks when the rains began, while in season two they appeared when the dry period commenced at 9 WAT and persisted to the end of the growing season. In both seasons, the use of agronet covers reduced mite population on cabbage crop when compared to producing the crop in an unprotected field (Fig. 2). Significantly lower mite numbers were observed on cabbage plants grown under the 0.4 mm agronet maintained permanently covered. The highest mite numbers were observed in the unsprayed control plots in most sampling dates. In both seasons, the insecticide spray treatment did not result in any significantly lower mite population than the unsprayed control treatment. Mite populations were generally higher on cabbage sprayed with insecticides than on plants grown under the 0. 0.9 mm net either maintained permanently covered or managed by opening it thrice a week. Mite populations also remained lower under the 0.4 mm agronet cover opened thrice a week than under the permanent cover of 0.9 mm agronet in most sampling dates.

3.1.5 Leaf miners

Cabbage plants grown under agronet covers registered lower cabbage leaf miner numbers compared to those grown in the open, in both seasons (Fig. 2). During all sampling dates, the lowest leaf miner population was recorded on cabbage plants grown under the 0.4 mm or 0.9 mm agronets maintained permanently covered. The highest leaf miner numbers were recorded under the unsprayed control treatment in most sampling dates. Leaf miner numbers for this treatment were, however, not any significantly different from those recorded under the 0.9 mm and 0.4 mm agronets opened thrice a week.

3.2 Marketable Yield

Cabbage marketable yield expressed as either head numbers or fresh weight per hectare was significantly influenced by growing the crop under agronet covers (Table 1). In both seasons, cabbage grown under the larger mesh of 0.9 mm pore diameter maintained permanently covered yielded the highest marketable heads that were firm with relatively low pest status and less soiled. Marketable weight for this treatment was, however, not significantly different from that of the 0.9 mm mesh managed by opening the net cover thrice a week in both seasons. Expressed as a percentage, use of 0.9 mm agronet cover maintained permanently covered resulted in a 41.4% and 22.6% increase in marketable head numbers compared to the control and insecticide sprayed treatment, respectively in season one and a 45.7% and 32.7% increase, respectively in season two. Marketable head weight for this treatment on the other hand increased by 114.5% and 90.0% compared to the control and insecticide sprayed treatment, respectively in season one and by 151.0% and 102.0%, respectively in season 2. Marketable yields were generally lower in the uncovered plots with the least marketable yields obtained under the control treatment in both seasons. Among the 0.4 mm agronet covers however, marketable yields tended to be higher when the cover was maintained by opening it thrice a week than when it was maintained permanently covered.

3.3 Cost Benefit Analysis

All 0.9 mm agronet covers were in both seasons economically superior compared to the other treatments in which cabbages were more heavily attacked by pests especially DBM and cabbage aphid. A cost: benefit ratio of 1:17.1 and 1:26.2 was obtained for the 0.9 mm agronet maintained as a permanent cover treatment in season one and two, respectively (Table 2). The 0.9 mm agronet cover treatment opened thrice a week followed, with a cost: benefit ratio of 1:11.9 and 1:16.9 in season one and two, respectively. The Alpha-cypermethrin sprayed treatment had a cost: benefit ratio of 1:11.1 in season one and 1:20.5 in season two. The lowest cost: benefit ratios of 1:1.4 in season 1 and 1:8.0 in season 2 were obtained from the 0.4 mm agronet maintained permanently covered and the 0.4 mm agronet opened thrice a week, respectively. The total revenue and cost: benefit ratio are directly dependent on the existing market price of the commodity, which is also influenced by the season. As shown in Table 1, all treatments had higher yield in the long rainy season but their cost: benefit ratio and total income (Table 2) were lower than those in the short rainy season. This is due to the fact that the price per kilogram of cabbage tends to be higher during the short than during the long rainy season. In this case, a kilogram of cabbage retailed at Kshs. 5.00 (US $ 0.06) higher during the short compared to the long rainy season [19].

Table 1. Effects of agronet covers on marketable yields of cabbage during season 1 (May-August, 2011) and season 2 (October 2011 - January, 2012) cabbage field production experiment

Treatment*	Cabbage heads (no./ha)	% increase from		Head weight (Mt/ha)	% increase from	
		Control	Chemical		Control	Chemical
Season one						
Control	40666.7fg	0.0	-13.3	89f	0.0	-11.4
Chemical	46916.7cdef	15.4	0.0	100.5e	12.9	0.0
0.9 mm opened	52500abc	29.1	11.9	171ab	92.1	70.1
0.9 mm permanent	57500a	41.4	22.6	190.9a	114.5	90.0
0.4 mm opened	45625cdef	12.2	-2.8	115.5d	29.8	14.9
0.4 mm permanent	48125cde	18.3	2.6	102.5e	15.2	2.0
Season two						
Control	38125g	0.0	-9.0	67.7g	0.0	-19.5
Chemical	41875efg	9.8	0.0	84.1f	24.2	0.0
0.9 mm opened	49375bcd	29.5	17.9	144.5c	113.4	71.8
0.9 mm permanent	55565ab	45.7	32.7	169.9b	151.0	102.0
0.4 mm opened	45000efg	18.0	7.5	106.3de	57.0	26.4
0.4 mm permanent	50000bcd	31.1	19.4	109.3de	61.4	30.0

**Control treatment had no agronet cover or chemical sprayed, chemical had no agronet over but was sprayed with insecticides, opened is where the agronet was opened three times a week, permanent is where agronet was maintained permanently covered except during maintenance and data collection periods while 0.4 and 0.9 mm were the different agronet mesh sizes used.*

***Values followed by the same letter within a column are not significantly different according to the Tukey's HSD test (p≤0.05)*

Table 2. Cost: Benefit analysis per hectare of cabbage during season 1 (May-August, 2011) and season 2 (October 2011 - January, 2012)

Treatment	Costs of pest control (US $)					Total revenue	Net benefit	Benefit over control	Cost: Benefit ratio
	Agronet	Labour opening	Insecticide	Labour spraying	Total cost				
Season one									
Insecticide	-	-	58.89	63.60	122.50	11837.46	11714.96	1232.04	1:10.1
0.4 mm agronet permanent	651.86	-	-	6.36	664.11	2073.03	11408.92	926.00	1:1.4
0.4 mm agronet opened	651.86	46.64	23.56	25.44	747.50	13604.24	12856.74	2373.82	1:3.2
0.9 mm agronet permanent	651.86	-	-	6.36	664.11	22485.28	21821.17	11338.24	1:17.1
0.9 mm agronet opened	651.86	46.64	23.56	25.44	747.50	20141.34	19393.84	8910.92	1:11.9
Control	-	-	-	-	-	10482.92	-	-	-
Season two									
Insecticide	-	-	64.75	69.96	134.75	14856.66	14723.91	2762.78	1:20.5
0.4 mm agronet permanent	651.86	-	5.89	6.36	664.11	19310.95	18646.84	6685.71	1:10.1
0.4 mm agronet opened	651.86	46.64	29.45	31.80	759.75	18780.92	18021.17	6060.04	1:8.0
0.9 mm agronet permanent	651.86	-	5.89	6.36	664.11	30017.67	29353.56	17392.43	1:26.2
0.9 mm agronet opened	651.86	46.64	29.45	31.80	759.75	25530.04	24770.28	1280.91	1:16.9
Control	-	-	-	-	-	11961.13	-	-	-

**Control treatment had no agronet cover or chemical sprayed, chemical had no agronet cover but was sprayed with pesticides, opened is where the agronet was opened three times a week, permanent is where agronet was maintained permanently covered except during maintenance and data collection periods while 0.4 and0.9 mm were the different agronet mesh sizes used*

3.4 Discussion

3.4.1 Effects of agronet covers on pest population on cabbage

Net covers in crop production have not only been used to offer a physical barrier to exclude pests, but also to attract various insects because of their bright colour, hence distracting their feeding and mating habit leading to lower pest population on the covered crop [20-22]. Results of our study corroborate these findings with significantly lower pest numbers observed on cabbage grown under agronet covers compared to the population recorded on open field grown cabbage. Besides the physical and visual barrier created by net covers, numerous studies have shown net covers to modify microclimate parameters including temperature, relative humidity and the general moisture content of the immediate environment of the crop [14,23,24]. Crop environment influences the population of certain pests like aphids, leaf miners and mites on growing plants. Cabbage aphids become numerous during prolonged warm and dry periods but are significantly reduced under high relative humidity conditions [25]. Mites also tend to be more problematic under hot dry conditions than under moist and humid conditions.The lower aphid and mite numbers recorded under agronet covers in the current study could also therefore be attributed to the high general moisture and relative humidity conditions under these treatments created by the existence of a netting cover hence reducing the need for insecticide sprays. In our study, managing net covers by opening them thrice a week resulted in a build-up of most pests under study as the season advanced. This could have been as a result of pests finding their way into the covers when opened coupled with the fact that plants grown under net covers tend to be more tender and succulent due to favourable growth conditions within the covers which could have favoured rapid feeding, multiplication and development of some of the pests, especially the cabbage looper.

3.4.2 Effect of agronet covers on cabbage marketable yield

Physical appearance of commodities is an important factor that determines how well vegetables sell at the market. Vegetables grown under net tunnels are less damaged by heavy rain and insect pests resulting in a reduced number of insecticide applications, better produce quality, and higher marketable yield [26]. Generally, size, shape, absence of blemish from disease and insect damage as well as weight and firmness form important cabbage marketability attributes. In this study, growing cabbage under agronet covers resulted in improved marketable attributes and hence yields, with the highest marketable yields obtained under the 0.9 mm agronet cover. Net Covers modify internal temperature, soil moisture and diurnal temperature range inside protected culture [27] which tends to favour physiological processes of plants leading to better growth and development, and subsequently higher yields. Cabbage grows and produces best within the temperature range of between 15 to 20ºC. Temperatures above 20ºC delay maturity, increase vegetative growth (number of leaves), and lead to formation of loose heads. Temperatures have generally been observed to remain at above 20ºC under the fine mesh (0.4 mm) agronet covers but below 20ºC and within the upper range of the optimum temperature for cabbage growing under the larger mesh cover (0.9 mm) agronet cover [24]. Such temperatures could therefore have favoured optimal growth and heading of cabbage, subsequently resulting in the higher yields and better quality heads recorded for the 0.9 mm agronet cover treatment. Besides microclimate modification that favours physiological processes, reduction of insect pest infestations under net covers also contributes positively to marketable yield. In this study, the use of agronet covers improved marketable cabbage head numbers by between 15.0-43.5% compared to the control and by 2.1-27.3% compared to spraying with insecticides while marketable head weight was higher by between 28.7-130.1% under agronets compared to the control and by 9.3-95.4% compared to spraying with insecticides. The general increase in marketable yield of produce under netting observed in the current study is consistent with findings in pepper where [28] reported increased yields of two *Capsicum annum* cultivars when grown under shade nets compared to the no-net control. Marketable cauliflower yields of 1.5 to 2.0 times greater were also obtained under net tunnels than in the open field [29]. Additionally, reports from [30] showed tripled amaranthus yields under net tunnels in Vietnam when compared to open field production.

3.4.3 Effect of agronet covers on the cost: Benefit ratio of cabbage production

Cost: benefit ratio economically indicates the relative performance of different ventures [31], where a cost: benefit ratio exceeding 1 implies a

higher economic viability against other treatments of cost: benefit ratio less than 1 [18]. In this study, all treatments showed a cost: benefit ratio of more than 1, with treatments with higher cost: benefit ratios considered the most technologically effective because they resulted in a significant return on investment in plant protection. From the results of this study, the 0.9 mmagronet maintained permanently covered treatment registered the highest cost: benefit ratios of 18.1 and 27.2 in season one and two, respectively. These ratios were higher than those recorded for the insecticide treatment by 63.1% in season one and 26.5% in season representing on average 44.8% more efficiency in crop protection for this treatment in a given year compared to the use of insecticides. Existence of a physical insect pest barrier and the possible enhanced microclimate under the larger 0.9 mm pore diameter mesh cover favoured increased yield production. Higher marketable yields, reduced pesticide application frequencies, labour and relatively lower pest damage recorded for the 0.9 mm agronet maintained permanently covered, could explain the higher net incomes and cost: benefit ratios arising from this treatment. Similar to these findings, growing heading cabbage under net tunnels in the Solomon Islands, reduced insect pest incidence by 38-72%, and resulted in significantly higher economic returns than open field production [32]. Since all the treatments gave cost: benefit ratios of more than 1, farmers could have the option of selecting to use insecticides or agronet covers in cabbage production. However, opting for insecticides would mean compromising on factors such as food safety and environmental health. In developed countries where human health issues are key, there are premium prices for food commodities that have reduced pesticide. In the current study, cabbage heads from insecticide sprayed and agronet covered plots were sold for the same price implying that if cabbage heads from plots protected with agronets were sold for premium price there would be corresponding increases in economic benefit.

Although all treatments gave higher yield in the long rainy season than during the short rainy season, higher cost: benefit ratios and total income were realized in the short rainy season compared to the long rainy season. This can be attributed to better prices for most vegetables during the short rainy seasons which tend to be unfavourable for vegetable production especially cool season vegetables like cabbage. In this case, a kilogram of cabbage retailed at Kshs. 15.00 (US$ 0.177) during the short rainy season compared to Ksh. 10.00 (US$ 0.118) during the long rainy season depicting a 50% difference in the price of a kilogram of the vegetable. Similar to our findings, [18] recorded higher cost: benefit ratios for cabbage grown under different botanicals as crop protection treatments during the minor rainy season compared to those of the major rainy season.

4. CONCLUSION

Results of this study present the use of agronet covers as a beneficial technology for cabbage protection against pests and other distractive environmental factors that can potentially reduce on cabbage production costs and increase returns on cabbage production compared to the convectional use of synthetic pesticides. A further evaluation over varying environmental conditions is imperative for better utilization of the technology in the production of cabbage and other related vegetable. The use of agronet covers has worked for low scale production only and more research is needed for large scale production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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