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Synergistic Effects of Agronet Covers and Companion Cropping on Reducing Whitefly Infestation and Improving Yield of Open Field-Grown Tomatoes

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Abstract: Tomatoes (*Lycopersicon esculentum* Mill) are one of the biggest vegetable crops in the world, supplying a wide range of vitamins, minerals and fibre in human diets. In the tropics, tomatoes are predominantly grown under sub-optimal conditions by subsistence farmers, with exposure to biotic and abiotic stresses in the open field. Whitefly (*Bemisia tabaci* Gennadius) is one of the major pests of the tomato, potentially causing up to 100% yield loss. To control whitefly, most growers indiscriminately use synthetic insecticides which negatively impact the environment, humans, and other natural pest management systems, while also increasing cost of production. This study sought to investigate the effectiveness of agronet covers and companion planting with aromatic basil (*Ocimum basilicum* L.) as an alternative management strategy for whitefly in tomatoes and to evaluate the use of these treatments ontomato growth and yield. Two trials were conducted at the Horticulture Research and Training Field, Egerton University, Njoro, Kenya. Treatments comprised a combination of two factors, (1) growing environment (agronet and no agronet) and (2) companion planting with a row of basil surrounding tomato plants, a row of basil in between adjacent rows of tomato, no companion planting. Agronet covers and companion cropping with a row of basil planted between adjacent tomato rows significantly lowered *B. tabaci* infestation in tomatoes by 68.7%. Better tomato yields were also recorded in treatments where the two treatments were used in combination. Higher yield (13.75 t/ha) was obtained from tomatoes grown under agronet cover with a basil row planted in between adjacent rows of the tomato crop compared to 5.9 t/ha in the control. Non-marketable yield was also lowered to5.9 t/ha compared to 9.8 t/ha in the control following the use of the two treatments in combination. The results of this study demonstrate the potential viability of using companion cropping and agronet covers in integrated management of *B. tabaci* and improvement of tomato yield.

Keywords: *Bemisia tabaci*; *Lycopersicon esculentum*; agronet covers; row covers; floating covers; basil; companion cropping

1. Introduction

Among economically important vegetables, the tomato (*Lycopersicon esculentum* Mill.) is one of the most widely cultivated. It is consumed widely throughout the world and has been demonstrated to possess health benefits due to its rich content of phytonutrients [1,2] and great importance in metabolic activities of the human body [3]. In developing countries, fresh tomatoes have for a long time been produced for both domestic and export markets, with an increasing demand for processing [4]. In Kenya, thetomato is one of the most important vegetable crops with records indicating that it contributed approximately Ksh.12.8 billion in sales among the mainstream local market vegetables in the year 2012 [5].

Despite the important role of tomatoes in the economy and diets of many Kenyans, the cropis still grown in the country by small holder farmers under open field conditions subject to many challenges that are abiotic and biotic in nature [6,7]. Among the biotic challenges, whiteflies of the group *Bemisia tabaci* (Gennadius) [8] have been noted as a major problem in the area. Members of the *B. tabaci* group are highly prolific, polyphagous and invasive crop pest found all over the world, and cause significant yield decline [9]. For tomato, *B. tabaci* has been associated with both direct and indirect damage caused by feeding directly on the tomato plants, sucking sap from the phloem resulting in leaf and fruit spotting, weakening of plants and irregular fruit ripening [10]. In addition, *B. tabaci* has also been associated with transmission of many viral diseases which negatively impact crop yield [11].

Agronet covers, which refers to woven or knitted plastic fibres connected together to form a porous geometric structure that allow fluids (gases and liquids) to go through [12], has proved successful in protecting different crops from extreme weather and insect pests [13–16]. The use of these agronet covers has also served as a means of reducing or even preventing often indiscriminate insecticide applications by small scale growers and at the same time improve yield and quality of crops [17]. Considering how modifications in the light wavelength may reduce *B. tabaci* and related diseases [18], UV-blocking nets have also been used effectively to control whitefly [19] through interfering with the necessary radiation stimulus that play important role in their ecological behavior. The use of insecticide treated net covers has also proved effective against a wide range of pests such as the invasive tomato leafminer *Tuta absoluta* [20]. Agronet covers also protect agricultural crops from excessive solar radiation and other environmental hazards thus enhancing plant microclimate for better crop performance [14]. Pek and Heyles [21] recorded better regulation of air temperature, reduced crop stresses and better crop performance with the use of netting technology compared to open field production of vegetable.

Companion planting, which refers to the practice of establishing two or more plant species in close proximity for cultural benefits, has been documented to have multiple advantages such as suppression of insect pests, weeds [22] and as an approach in organic farming. A number of plants have been planted together with vegetables in a garden setting to serve as companion crops. For instance, intercropping mustard (*Brassica juncea*) as a companion crop for collards (*Brassica oleraceae* var. acephala) has successfully been used to repel whitefly [23] while tomato has successfully been used as a repellent for the diamondback moth (*Plutella xylostella*) on cabbage (*Brassica oleraceae* var. capitata) [24].

Experience from many parts of the world has shown the benefits of cultivating aromatic plants in companion with other crops due to the variety of volatile organic compounds contained in such plants. These organic volatile compounds are well known for their insecticidal, antifeedant, repellent, attractant and oviposition deterrent effects on insect pests [25,26]. For instance, aromatic basil (*Ocimum basilicum*) was found to offer repellent action against mosquitoes [27] and flea beetles on Pechay (*Brassica perkinensis*) [28]. Apart from the direct effects on insect pests, companion planting has also been found to increase the abundance of beneficial insects [29] which lead to reduced need for pesticide use. Limited studies, however, exist on the effects of combined use of agronet covers and companion cropping on insect pest population and crop performance. This study sought to evaluate the effects of combined use of agronet covers and companion cropping on *B. tabaci* infestation and yield of tomatoes in an open field production system.

2. Materials and Methods

2.1. Experimental Site Description

Two trials (November 2013 to April 2014 and May 2014 to October 2014) were conducted at the Horticulture Research and Teaching Field, Egerton University, Njoro-Kenya. The field lies at an altitude of approximately 2238 m above sea level, latitude 0°23′ S and longitudes 35°35′ E in the Lower Highland III Agro Ecological Zone (LH3). Average maximum and minimum temperatures range from 19 °C to 22 °C and 5 °C to 8 °C, respectively, with a mean annual rainfall of about 1000 mm. The soil is predominantly well drained sandy-Vintric mollic andosols [30].

2.2. Planting Material

Tomato seedlings cultivar "Rio Grande" started from seeds purchased from Simlaw Seeds Company Ltd., Nairobi, Kenya, Nakuru-Kenya were used. "Rio Grande" is a tomato cultivar with a high yield potential and is thus preferred by many farmers. In addition, it has good disease tolerance especially against fusarium wilt (*Fusarium oxysporum*). Basil (*Ocimum basilicum*) variety "Bonanza" seeds were obtained from Amiran Kenya Ltd., Nairobi, Kenya. Basil is a perennial herb usually grown as an annual in tropical climates. The choice of basil as a companion crop was made due to the characteristic strong smell of the essential oils that it contains and its ability to withstand relatively cool conditions like those that prevail in the study site.

2.3. Experimental Design and Treatment Application

The experimental design used was a Randomized Complete Block Design (RCBD) with six treatments and five replications. Treatments comprised a combination of two factors: (1) growing environment (agronet and no agronet) and (2) companion planting with basil consisting of three cropping systems (tomato plants surrounded by a of row basil, basil row planted between consecutive tomato rows, and no companion planting). The resulting six treatments were: (i) tomato under agronet cover with a row of basil surrounding outside of the agronet cover; (ii) tomato under agronet cover with a row of basil in between adjacent rows of tomato; (iii) tomato under agronet cover without basil; (iv) tomato without agronet cover but with a row basil surrounding the crop; (v) tomato without agronet cover but with a row of basil in between adjacent rows of tomato crop; and (vi) tomato planted with no agronet cover or basil (control). Equal numbers of basil plants were used per companion planting treatment, regardless of their configuration. Basil was spaced 30 cm apart. The polyethylene knitted agronet covering material used was of (0.4 mm) average pore diameter, provided by A to Z Textile Mills, Arusha, Tanzania. Each experimental unit measured 3 m by 5 m with four (4) rows of tomato spaced 80 cm between rows and 50 cm within a row. Each block measured 3 m × 32.5 m separated from an adjacent block by 1 m buffer while plots within individual blocks were separated by 0.5 m. Four posts 1.5 m long were used to support the agronet cover in net-covered plots where one post was placed at each corner and sisal twine and binding wire wereused to join the posts and to support the crop.

2.4. Crop Establishment and Maintenance

Land was manually prepared using hoes and garden rakes to a medium tilth. Transplanting holes were then manually dug using hoes and diammonium phosphate (DAP-18% N, 46% P_2O_5) fertilizer applied at a rate of 240 kg·ha^{-1} (approximately 10 g per hole) [31] and thoroughly mixed with the soil prior to transplanting. Tomato seedlings were transplanted in four rows in each experimental unit at spacing of 80 cm × 50 cm giving a total of 40 plants per experimental unit. Basil was drilled as per the treatments at the start of tomato seeds in the nursery to give it time to establish before the transplanting of tomato seedlings. Thinning of the basil seedlings was later done when the plants were about 8 cm tall to a spacing of 30 cm between plants. Thereafter, all other agronomic and maintenance practices ranging from gapping, watering, weeding and top-dressing were uniformly done on all experimental units following the technical recommendations for the respective crops [3]. Fungicide sprays were applied on a need be basis for the prevention and control of tomato fungal diseases.

2.5. Data Collection

Bemisia tabaci infestation: Two weeks after transplanting, yellow sticky traps (Horivers) from Koppert Biological Systems (K) Ltd., Nairobi, Kenya, were mounted at the centre of each plot to monitor *B. tabaci* adults on each treatment. Once a week, the number of adult *B. tabaci* stuck on the sticky traps were counted and the numbers recorded as number per plot (No./plot). Horivers traps were cleaned each time counting was done to avoid double counting. Non-destructive sampling of immobile larger nymphs of *B. tabaci* (4th nymph stage) was also done on a weekly basis on two leaves randomly selected but not cut away from plant at the 6th to 8th node from the growing point in every experimental plot as described by [32]. This was done from the underside of leaves using a hand lens ($\times$10, 12–105 W; Shanghai, China) beginning two weeks after transplanting until the last harvesting. The number obtained was recorded as number of *B. tabaci* nymphs per leaf per plant (No./leaf).

Yield: Tomato fruits from each treatment were harvested at the breaker stage. At each harvest, fruits from each treatment were separately counted and later weighed using a weighing balance (K23-2002 W; Shanghai, China) to determine fruit numbers per plant (No./plant) and weight in kilograms per plant (kg/plant) for each respective treatment. Thereafter, non-marketable fruits were sorted out, counted and weighed and data obtained recorded. Non-marketable fruit in this context were tomato fruits with insect damage, sun scotch or rotten and thus considered not sellable. Marketable fruits were also counted and weighed. The weights of individual harvests for each treatment were later summed up after the last harvest to obtain total yields in terms of fruit number (No./ha), weight for marketable fruits (t/ha) and non-marketable fruit yield (No./ha) for each treatment.

2.6. Data Analysis

The data collected was subjected to analysis of variance (ANOVA) at $p \leq 0.05$ and treatment means that showed significant difference at the F test separated using Tukey's honestly significant difference (Tukey's HSD) test at $p \leq 0.05$. SAS statistical package [33] was used in data analysis.

The basic model fitted for the experiment was:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \tau_k + \alpha\tau_{ik} + \varepsilon_{ij} \tag{1}$$

$$i = 1, 2; j = 1, 2, 3, 4, 5; k = 1, 2, 3, 4, 5, 6$$

where Y_{ij}—tomato response, μ—overall mean, α_i—effect of the ith season, β_j—effect of the jth blocking, τ_k—effect of the kth treatment, $\alpha\tau_{ki}$—interaction effect of the ith season and kth treatment, ε_{ij}—random error component which is assumed to be normally and independently distributed about zero mean with a common variance σ2.

3. Results

Bemisia tabaci infestation: Combined use of agronet covers and companion planting significantly reduced *B. tabaci* infestation on tomato plants (Figure 1) as well as number of adults captured by sticky traps in most sampling dates. In both seasons, *B. tabaci* infestation on tomato plants grown under agronet cover in companion with a row of basil planted in between adjacent rows of tomato registered the lowest *B. tabaci* although in most sampling dates the difference was not statistically significant from the treatment where basil surrounded the tomato crop from outside of the net cover. Also, a significant reduction in *B. tabaci* infestation was observed under the treatment where tomato was grown under agronet cover alone as a pure stand compared to the control treatments. Similarly, *B. tabaci* infestation on tomato plants was also lower on tomato plants grown in the open without agronet cover but in companion with basil, compared to the infestation registered for the control treatment in most sampling dates. The control treatment registered the highest *B. tabaci* infestation on tomato crops compared to the other treatments during the entire data collection period.

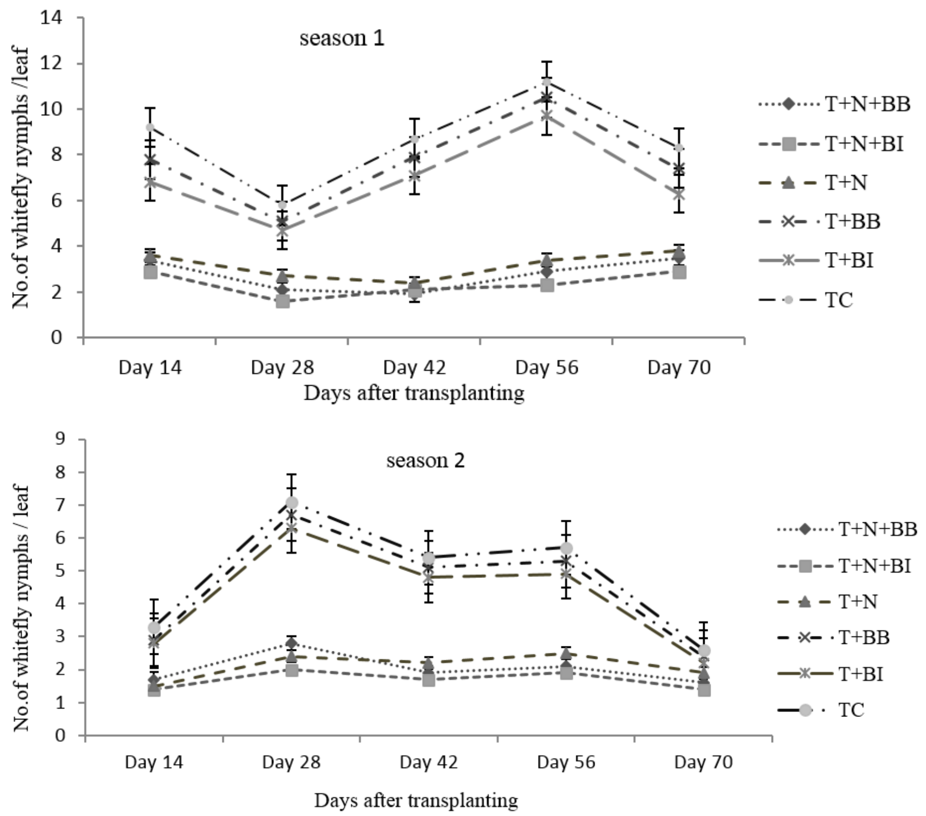

Figure 1. Effects of Agronet Cover and Companion Planting with Basil on Number of *B. tabaci* Nymphs on Tomato Plants (No./leaf)during Tomato Production in Season 1 (December 2013–April 2014) and Season 2 (May 2014–September 2014). Key: T + N + BB is tomato under agronet with abasil border surrounding outside of the net cover; T + N + BI is tomato under agronet with a basil row between adjacent rows of tomato; T + N is tomato under agronet without basil; T + BB is tomato without agronet cover with a basil row surrounding the outside of the agronet cover; T + BI is tomato without agronet cover with a basil row in between adjacent rows of tomato; and TC is tomato without agronet cover or basil (control).

The use of agronet cover was associated with less infestation of tomato plants by *B. tabaci*. Throughout the data collection period, *B. tabaci* infestation on agronet-covered treatments was significantly lower than in uncovered treatments in both seasons (Figure 2a). Companion planting with basil also reduced *B. tabaci* infestation compared to treatments where basil was not used throughout the data collection period in both seasons except at 14 DAT in season 2 where the difference between the two cropping regimes was not statistically significant (Figure 2b). Similarly, planting a row of basil in between adjacent rows of tomato plants resulted in a significantly higher reduction in *B. tabaci* infestation compared to planting a row of basil surrounding the tomato crop from outside in all sampling dates of both seasons except at 14 DAT in season 2 (Figure 2c).

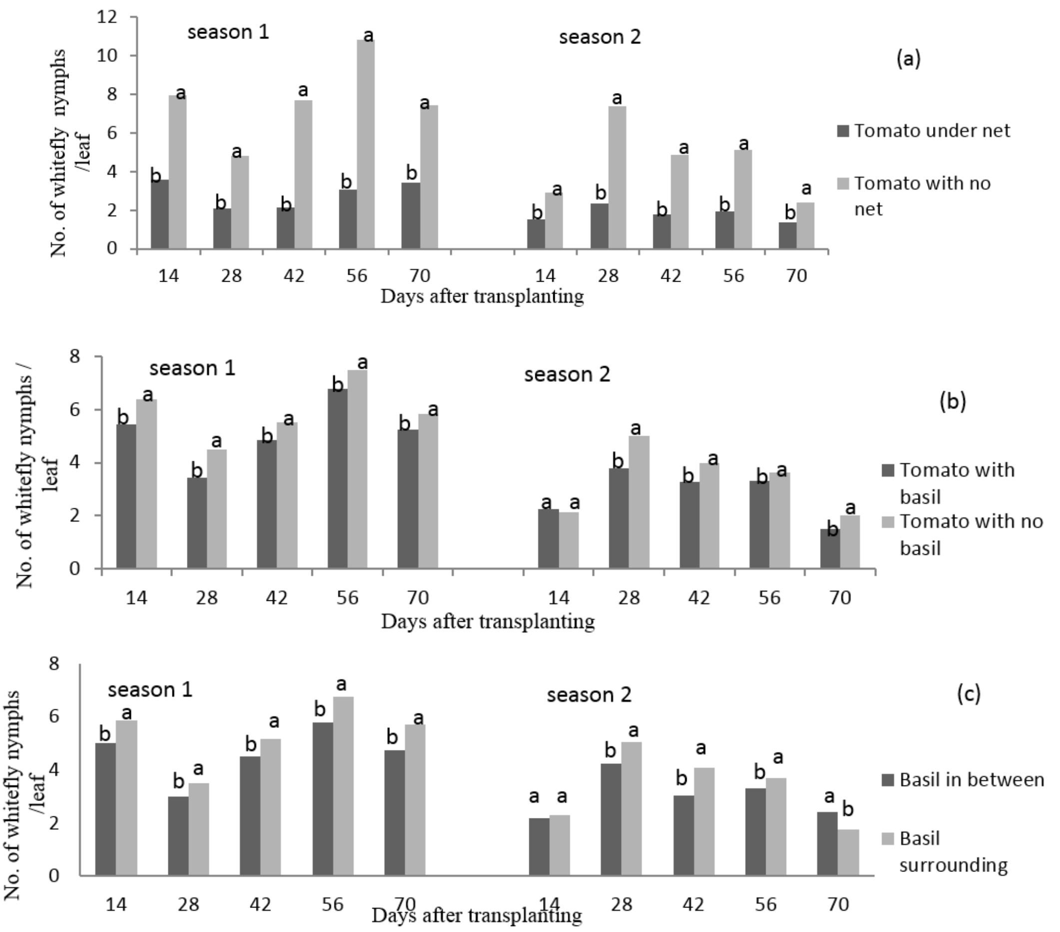

Figure 2. Effects of agronet cover, (**a**) companion planting, and (**b**) planting design (**c**) on No. of *B. tabaci* nymphs/leaf on tomato plants during tomato production in season 1 (December 2013–April 2014) and season 2 (May 2014–September 2014)). Means followed by the same letter within an evaluation date are not significantly different according to Tukey's Honestly Significant Difference (THSD) test at ($p \leq 0.05$).

Number of *B. tabaci* adults collected on yellow sticky traps (Figure 3) were lower under combined use of agronet cover and companion planting as observed in the various data sampling dates (Figure 3). In both seasons, planting a row of basil in between adjacent rows of tomato under agronet cover registered a significant reduction in *B. tabaci* adults collected on sticky traps compared to the control treatment in all sampling dates. Amongst the other agronet covered treatments, planting a row of basil surrounding the tomato crop from outside of the net cover as well as having tomato planted alone as a pure stand under agronet cover also recorded lower *B. tabaci* numbers on sticky traps compared to the control treatment in all data sampling dates. A reduction in *B. tabaci* numbers on sticky traps was also recorded for open treatments without agronet cover but with a row of basil in between adjacent rows of tomato, followed by the treatment where basil surrounded the tomato crop from outside compared to the control treatment which recorded the highest number of *B. tabaci* on sticky traps throughout the data sampling period of both seasons.

The use of agronet cover resulted in higher reduction in *B. tabaci* adults collected on sticky traps compared to when the plants were grown without net cover in all the sampling dates (Figure 4a). Growing tomato in companion with basil on the other hand also resulted to a reduction in *B. tabaci* adults on sticky traps than when tomato was grown without basil in most sampling dates (Figure 4b).

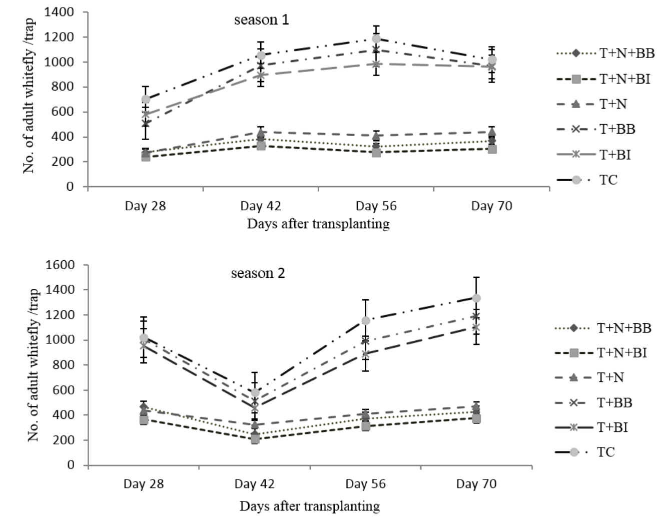

Figure 3. Effects of agronet cover and companion planting with basil on number of adult *B. tabaci* on sticky traps (No./trap) during tomato production in season 1 (December 2013–April 2014) and season 2 (May 2014–September 2014).

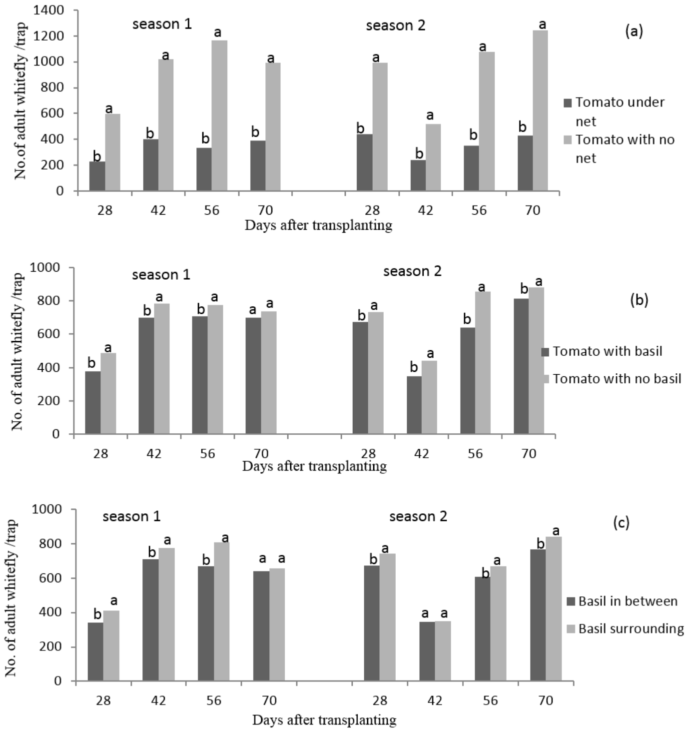

Figure 4. Effects of agronet cover (**a**); companion planting (**b**) and planting design (**c**) on number of adult *B. tabaci* on sticky traps (no./trap)during tomato production in season 1 (December 2013–April 2014) and season 2 (May 2014–September 2014). Means followed by the same letter within an evaluation date are not significantly different according to Tukey's Honestly Significant Difference (THSD) test at ($p \leq 0.05$). Key: T + N + BB is tomato under agronet with a basil border surrounding theoutside of the net cover; T + N + BI is tomato under agronet with a basil row in between adjacent rows of tomato; T + N is tomato under agronet without basil; T + BB is tomato without agronet cover with a basil row surrounding theoutside of the agronet cover; T + BI is tomato without agronet cover with a basil row in between adjacent rows of tomato; and TC is tomato without agronet cover or basil (control).

Considering the two basil companion planting designs, planting a row of basil in between adjacent rows of the tomato plants resulted in a reduction in *B. tabaci* adults collected on sticky traps compared to surrounding the tomato crop from outside with a row of basil in almost all sampling dates except at 70 and 42 DAT in seasons 1 and 2, respectively (Figure 4c).

Tomato fruit yields: Growing tomato under agronet cover and companion planting with basil significantly influenced harvestable tomato fruits per hectare (Table 1). Where agronet cover was used in combination with basil, theharvestable tomato fruit number was highest under agronet cover and companion planting with a row of basil planted in between adjacent rows of tomato crop compared to the control treatment which recorded lowest harvestable fruit numbers in both seasons. There was no statistical significant difference observed amongst the other agronet covered treatments compared to the control in all sampling dates of the respective seasons. Considering the open treatments, growing tomato without agronet cover but in companion with basil also recorded more tomato fruits compared to the control treatment. Tomato grown with a row of basil in between adjacent rows of tomato plants gave the best results among the open treatments although the difference was not statistically significant from the other open companion treatment in almost all sampling dates.

Table 1. Effects of agronet cover and companion planting basil on total marketable fruit number (No./ha), total fruit weight (t/ha), total non-marketable fruit (No./ha) and total non-marketable fruit weight during tomato production in season 1 (December 2013–April 2014) and season 2 (May 2014–September 2014).

Treatment	Season	Total Marketable Fruit Number (No./ha)	Total Marketable Fruit Weight (t/ha)	Total Non-Marketable Fruits (No./ha)	Total Non-Marketable Fruit Weight (t/ha)
T + N + BB	1	350,000ab **	12.41ab	48,875fg	6.98c
T + N + BI	1	385,000a	13.75a	43,625g	6.44cd
T + N	1	345,000ab	11.58ab	64,375cde	7.44c
T + BB	1	274,500bc	9.51bc	95,625abc	9.91ab
T + BI	1	299,500b	10.47bc	811,25bc	8.78b
TC	1	223,750cd	8.75cd	101,875ab	11.05a
T + N + BB	2	276,250bc	10.74b	56,875de	6.54cd
T + N + BI	2	300,000b	12.59ab	51,250ef	5.90d
T + N	2	243,125c	9.79bc	68,125cd	6.50cd
T + BB	2	180,750de	8.21cd	98,250ab	8.73b
T + BI	2	200,750cde	8.73cd	79,460bc	8.21bc
TC	2	160,165e	5.9d	118,125a	9.80ab

** Treatment means followed by the same letter within a column in an evaluation date are not significantly different according to Tukey's Honestly Significant Difference at ($p \leq 0.05$). Key: T + N + BB is tomato under agronet with basil border surrounding outside of the net cover; T + N + BI is tomato under agronet with a basil row in between adjacent rows of tomato; T + N is tomato under agronet without basil; T + BB is tomato without agronet cover with a basil row surrounding outside of the agronet cover; T + BI is tomato without agronet cover with a basil row in between adjacent rows of tomato; and TC is tomato without agronet cover or basil (control).

Similar to harvestable fruit numbers, the use of agronet cover and companion planting with basil significantly increased tomato fruit weight per hectare (Table 1). In both seasons, growing tomato under agronet cover and companion planting with a row of basil in between adjacent rows of tomato produced heavier tomato fruits compared with the fruits obtained from the control treatment which yielded theleast weight. Results from the other agronet covered treatments produced no statistical significant differences amongst them in both seasons compared to the control treatment. Also, planting tomato in the open without agronet cover but in companion with basil yielded heavier fruits compared to the control treatment, although no statistical significant difference between the two basil planting designs was recorded.

Non-marketable fruits yield: Growing tomato under agronet cover and companion planting with basil also significantly decreased non-marketable fruit number during the entire growing period (Table 1). Compared to the control treatment that produced the highest number of non-marketable fruits throughout the two seasons, the use of agronet cover and companion planting with a row of basil in between adjacent rows of tomato on the other hand recorded the lowest number of non-marketable fruits, followed by the treatment where basil surrounded tomato crop from outside of the net cover as recorded in all the different sampling dates. Growing tomato under agronet cover alone without companion basil also recorded a reduction in non-marketable fruit numbers compared to the control treatment. Considering the open treatments, tomato planted without net cover but in companion with basil recorded significantly high number of non-marketable fruit compared to agronet covered treatments even though their numbers were lower than those recorded from the control treatment in all the sampling dates. As a result of reduction in non-marketable fruits number through the use of agronet cover and companion planting, higher marketable fruit numbers were obtained in agronet-covered treatments in both seasons. Non-marketable fruit weight was lowest in the treatments where the two technologies were used in combination compared to the control treatment which recorded the highest non-marketable fruit weight.

4. Discussion

Netting technology has been shown to act as a visual barrier to sucking pests, thereby delaying outbreaks on vegetables [13,34]. On the other hand, intercropping with aromatic plants not only provides alternate habitats but also provides alternate food or intermediate hosts for predators, thus increasing natural enemies' population in an intercropped system [35,36]. Based on the current study's results, combined use of agronet cover and companion planting helped to lower *B. tabaci* infestation of tomatoes. Used separately, there was less infestation of the tomato crop under agronet covers by 53%–60% compared with 15.2%–17.5% obtained under companion cropping with basil alone. The lowest *B. Tabaci* nymphs infestation on tomato plants was achieved through combining agronet cover and companion planting with a row of basil in between adjacent rows of tomato, with 62.2%–68.7% and a 66.8%–72.1% lower numbers of adult *B. tabaci* captured on sticky traps compared with the control treatment.

Nets have not only been reported to offer physical barriers that exclude migratory insect pests from accessing the target crops but also provide avisual barrier to insect pests due to the bright colour, thus interfering with their feeding and mating habits [37]. The current study's results could possibly offer support to the success of net covers as physical and visual barrier against migratory insect pests as reported by [38] whoshowed, while working with temporary tunnel screens in Benin, that the netting technology was an economically viable method amongst small-scale growers in protecting cabbage against diamondback moths [39], reporting a 38% to 72% reduction in insect incidence on cabbage grown under net tunnels in the Solomon Islands resulting to significantly higher economic returns.

Higher plants on the other hand have been documented to harbor numerous compounds that manifest as secondary plant compounds and are considered to be part of a chemically based defence system against phytophagous insects [40]. These compounds may act through exhibiting chemical repellency, attractancy, oviposition deterrence, insecticidal effects, masking effect from the mix and/or luring pests away from the main crop leading to decreased colonization by harmful pests [41,42]. Juxtaposition of such plants and arrays of color, different ripening times and unique aromas produced in varying degrees by these plant species or varieties have often been known to cause camouflage of odor and appearance, thus confusing plant pests in search of a suitable host. Such diverse effects of companion crops on insect pests could have worked in the current study either in a synergistic or additive manner to give rise to the low *B. tabaci* infestation on tomato plants for treatments where basil was used as a companion plant.

Basil is an essential oil-producing plant and it may have provided various functions including attracting insects, as well as utilizing chemical constituents in the oil as defense material [43]. Ordinarily, these constituent plant essential oils occur as liquid at room temperature and are easily transformed from a liquid to gaseous state at room or slightly higher temperature without undergoing decomposition. Methyl chavicol, a predominant essential oil in basil, comprising upto 75% of its composition and also known to be temperature sensitive and tovaporize easily at temperatures above 28 °C [44], has been found to attract various insect pests including whitefly, thus disrupting their feeding on target crops such as tomatoes [43]. Agronet covers have, on the other hand, been reported to increase air temperature by 15% to 20% compared with open field treatments [15,45] which could have promoted the transformation of methyl chavicol and other volatiles from liquid to gaseous state in the current study. Owing to the nature of covers in reducing air circulation [14] this therefore may have led to the concentration of these volatile compounds inside the agronet cover. Therefore, it is possible that agronet covers and companion cropping may have lowered *B. tabaci* infestation through either combined effects or one of the effects as mentioned.

The use of agronet cover and companion planting with basil also improved total harvestable fruit numbers and weight with a significant reduction in non-marketable fruit yields being recorded too. From the current study, higher yields in terms of fruit number and weight was obtained with the use of agronet cover and companion planting with a 35%–51% increase in fruit number under agronet cover alone while combined use of agronet cover and companion planting with a row of basil in between adjacent rows of tomato recorded 72%–86.1% increase in tomato fruit number and 80%–83.5% increase in tomato fruit weight compared with the control. Results of the current study corroborate findings by [45,46] who reported increase in marketable yield by up to 70% in tomato and 58% in cabbage, respectively, and a reduction in non-marketable yield by up to 60% following the use of agronet covers compared to control treatments. Besides the shading effect offered by agronet covers and companion planting, net covers have been documented to modify air temperature and the diurnal temperature range hence providing ideal growth condition resulting to improved yield. Gogo et al. [15] reported an average increase in daily temperature of ~3.5 °C and a decrease in diurnal temperature range by ~3.4 °C indicating more stable temperature regimes under net covers compared to open field production. Such microclimate improvement under net covers has been reported to favour plant growth [14] and other physiological responses such as increased photosynthetic ability of tomato plants leading to more food being manufactured and translocated to active sinks, leading to better yield and crop quality [47]. Such a finding could be used in support of the high yield obtained under agronet covered treatments in the current study. Similar results were reported by [48] who reported higher marketable yield and quality fruits from protected culture treatments compared with the uncovered treatments.

Research results from similar trials have also shown that high light intensity can lead to disorders in the development and appearance of tomato fruit [49]; thus, shading tomato with net covers may have protected the fruits from such physiological disorders and physical damage, leading to fewer non-marketable fruits under the covers.

Other trials have also shown that many plants grow better when grown near others as companion crops and in turn exhibit efficient utilization of available resources to generate high and stable yields with lower input requirements [50]. Similar results were reported by [51] who recorded better yields of intercrops compared to the yield sum of the component species grown alone and attributed the good performance to better use of available growth resources such as nutrients, water, and light. Basil has on the other hand been reported to be a poor resource (water, nutrient, space and light) competitor when grown together with tomatoes in the open [52]. Given the fact that thetomato requires adequate soil moisture for its growth and development [53], intercropping basil with tomato may have enhanced theshading effect on the soil through the provision of living mulch [54] leading to a reduction in the rate of evapotranspiration resulting to improved soil moisture status [55] which in turn encouraged better growth and development, leading to thehigh yields of tomato recorded in the current study. Besides, like other crops grown under net covers, basil under net covers displayed better vegetative growth and flowered earlier and more profusely than that grown in the open. Better growth and more flowers on basil translates to a higher concentration of volatile compounds, leading to more insect pests and beneficial insect attraction [42] which in the current study could have led to a higher attraction of *B. tabaci* onto the basil, deterring them from feeding on tomato plants and hence, the reduction in non-marketable tomato fruits observed for the tomato-basil companion planting treatments. These phenomena, coupled with a better growing environment under agronet cover, may have led to higher fruit numbers, heavier fruits as well as reduced non-marketable fruit yield observed for the tomato–basil companion cropping treatment under agronet cover in this study.

5. Conclusions and Recommendations

Based on the results of this study, the use of agronet covers and companion planting of tomato with basil resulted in lower infestation by *B. tabaci* and improved yields of the tomato crop in open field production. Lower *B. tabaci* infestation and higher tomato fruit yield is obtained when the two technologies are used in combination, especially when a row of basil is planted in between adjacent rows of tomato under agronet covers. These results provide a basis for the use of agronet covers and companion planting with basil, either alone or in combination, to lower the amount of insect pest infestation on tomato, through utilizing the attractive nature of thebasil plant that makes it a better host for many insects including *B. tabaci* and thus improving yields for open field tomato production systems. Our results also present the technologies as a viable, environmentally friendly insect pest management strategy that, apart from being easy to use forsmall-to-medium scale farmers, can provide an option for reducing indiscriminate application of synthetic insecticides that increase cost of production and are harmful to humans and the environment. However, for broad application of the technologies, we recommend further tests with various companion crops and tomato varieties under agronet covers in different agro-ecological zones to broaden the knowledge base. Documentation of the effect of the use of these technologies on other insect pests and beneficial insects as well as the development and expression of vector-transmitted diseases may also be important.

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