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Enhancing Cabbage (*Brassica oleraceae Var capitata*) Yields and Quality Through Microclimate Modification and Physiological Improvement Using Agronet Covers

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Abstract

Adverse environmental conditions have contributed to perpetual poor cabbage (*Brassica oleraceae var. capitata*) yields in sub-Saharan Africa. Elsewhere, net covers have been reported to provide a low-cost technology with the potential of modifying the microclimate around a crop for better performance. Two experiments were therefore conducted over a span of two seasons to determine the effects of agronet covers on microclimate modification and subsequent cabbage yield and quality. The treatments comprised cabbage plants grown under either fine mesh (0.4 mm pore diameter) or large mesh (0.9 mm pore diameter) agronet covers maintained permanently closed, or opened thrice weekly from 9 am to 3 pm and a control treatment where cabbage was grown in the open field. Net covering generally modified the microclimate by raising temperatures, relative humidity and volumetric water content but lowering photosynthetic active radiation and diurnal temperature range compared to control. The use of agronet covers resulted in better cabbage performance. The large mesh (0.9 mm) enhanced leaf stomatal conductance and chlorophyll content, and improved fresh and dry weight as well as head quality. Results of this study present the use of agronet covers as a potentially effective technology for use by small-scale farmers in protected cabbage culture in sub-Saharan Africa.

Keywords: eco-friendly nets, crop environment, low cost production, cabbage performance, protected cropping

1. Introduction

Cabbage (*Brassica oleraceae var. capitata*) is an important vegetable mainly grown by resource restrained smallholder farmers for food. It is estimated that nearly half a million families in the countrysides of Africa derive substantial on-farm earning through the cultivation of cabbage (FAO, 2009). In Kenya for example, farming and marketing of cabbage provides a secure source of continuous income and enables small farms to remain financially viable, especially in the rapid growing peri-urban farming sector (Wambani et al., 2007). Despite the important role of cabbage, average yields per unit area of the crop is estimated at 15 tons ha^{-1} in Kenya (HCDA Report, 2008) and 30 tons ha^{-1} in sub-Saharan Africa (Allemann & Young, 2008), figures that fall far below the worldwide average production of 50 tons ha^{-1}.

Adverse ecological conditions including constant fluctuations in temperature, relative humidity, soil moisture and light factors have been cited among the major constraints to optimal cabbage production in many parts of Africa (Levasseur et al., 2006). Cabbage is a cool season crop with moderately low optimum temperatures of 15 to 20 °C and high water requirement for optimum performance. Cabbage growth, heading and consequently yields are greatly reduced under higher temperatures. Low moisture due to factors such as low and erratic relative humidity and poor soil moisture retention also adversely affect yields and quality of the crop. In most sub-Saharan countries, however, cabbage is still mostly grown in open fields. This exposes it to supra-optimal

solar radiation of the tropics, low moisture conditions and thermal fluctuations, which result in poor performance of the crop.

Netting technology has been used to protect crops from excessive solar radiation and other environmental hazards in the developed countries, with better microclimate conditions for crop growth recorded under the net covers compared to open field environment (Majumdar, 2010). Net covers have also been documented to have a potential for providing an amicable solution to sustainable and affordable cabbage transplant and/or crop production in sub-Saharan Africa (Muleke et al., 2013). This study aimed at establishing the effects of using agronet covers on the immediate microclimate of a cabbage crop and how this affects the physiological performance and yield of the crop.

2. Method

2.1 Site Description

The study was a two-season experiment (May-Aug., 2011 and Oct., 2011-Jan., 2012) conducted at the Horticulture Research and Teaching Field, Egerton University, Kenya. The area lies at altitude 2238 m, latitude 0º23'S and longitude 35º35'E. The average maximum and minimum temperatures range between 19 to 22 ºC and 5 to 8 ºC, respectively. The area receives an annual rainfall of 900 to 1200 mm (Egerton Metrological Station, 2009).

2.2 Experimental Design and Treatments

The study used a randomized complete block design (RCBD) with five replications and five treatments. The treatments comprised of growing cabbage in the open as the control treatment or under (i) 0.4 mm mesh size net maintained permanently covered (ii) 0.9 mm mesh size net maintained permanently covered (iii) 0.4 mm mesh size net opened thrice weekly from 9 am to 3 pm or (iv) 0.9 mm mesh size net opened thrice weekly from 9 am to 3 pm. In net-covered plots, wooden plunks were used to make arches to support the nets. The arches were 2 m wide and 0.3 m high, after being secured 0.2 m into the ground. Four such arches were used per plot mounted at 1.5 m apart along the 6 m length of the plot. Each of the 5 blocks measured 2 m by 38.5 m separated by a 1 m buffer. Individual plots within a block measured 2 m by 6 m separated by 0.5 m paths. The agronets were manufactured by A to Z Textile Mills, Arusha, Tanzania. They were white in colour and made from high-density polyethylene, which makes them durable with a potential life span of up to 4 years.

2.3 Plant Material, Planting and Crop Maintenance

Healthy Gloria F1 hybrid cabbage seedlings produced under agronets were transplanted at a spacing of 40 cm by 40 cm giving a total of 75 plants per plot. Triple superphosphate (46% P_2O_5) fertilizer was used at planting at the rate of 225 kg ha^{-1}. Following transplanting, all the plots received a blanket spray of Bestox (50 g l^{-1} alpha-cypermethrin) at the rate of 15 ml per 20 litres of water, against any pests accrued during the transplanting process. This was done just before mounting of agronets on the net covered plots. A calcium ammonium nitrate (26% N) top dress was applied in two equal splits: at three and six weeks after transplanting to all plots at the total rate of 215 kg ha^{-1}. Thereafter, cabbage crop management practices like watering and weeding were carried out uniformly on need basis on all plots throughout the study.

2.4 Data Collection

2.4.1 Microclimate Data

WatchDog Plant Growth Station data loggers model 2475 (Spectrum Technologies, Inc. 3600 Thayer Court, Aurora, IL 60504 USA) were used to collect data on air temperature, relative humidity, volumetric soil water content, quantum light (PAR) and diurnal temperature range. The data loggers were each screwed on a wooden post, 10 cm high at the centre of each treatment. The loggers were programmed to record data hourly, which were then averaged daily. Accumulated data were downloaded on a weekly basis for safety.

2.4.2 Leaf Chlorophyll Content and Stomatal Conductance

Leaf chlorophyll content estimates in chlorophyll concentration index (CCI) units were collected using chlorophyll meter (CCM-200 Plus, Opti-Sciences Inc. 8 Winn Avenue Hudson NH 03051 USA). The leaf chlorophyll content estimates were taken from a recently fully expanded leaf of 20 tagged cabbage plants in the inner rows of each treatment. Estimation of chlorophyll was done after every two weeks starting the fifth week after transplanting (WAT). Stomatal conductance was also taken from the same leaf on which chlorophyll content was estimated. This was achieved using a steady state leaf porometer (SC-1, Decagon Devices, Inc. Hopkins Court Pullman, USA). The readings were also taken after every two weeks from 5 WAT and recorded in $\mu mol\ m^{-1}s^{-2}$.

2.4.3 Yield and Plant Dry Weight

Upon crop maturity, 20 cabbage plants were selected at random and uprooted from each plot as a representative sample of the crop in the different treatments. The harvested cabbage was used for determination of the total plant fresh weight and fresh head weight. Before weighing, the stems and roots were washed using clean water to remove any adhered soil particles and then wiped dry using a clean cotton cloth. Using a mechanical weighing pan scale (10 kg per 40 g, 18636, Shenzhen west-Boao Science and technology Co. Ltd), the weight of the whole plant was taken and thereafter that of the fresh head alone with both measurements done in kilograms per plot (kg $plot^{-1}$) and later converted into metric tonnes per hectare (MT ha^{-1}). Thereafter, a random sample of 5 heads was picked from the 20 heads initially harvested from each plot and separately chopped into smaller pieces, thoroughly mixed and put in separate containers. A sample of 100 g was then drawn from each container, put in paper bags and oven dried at 75 ºC to a constant weight. The dry weight for each 100 g fresh head weight sample was then determined and used to compute total head biomass using the formula:

$$\textit{Total head weight/plant} = \textit{Total fresh weight/ head} * \textit{Dry weight/100 g fresh weight} \quad (1)$$

2.4.4 Quality Parameters

Head firmness, total soluble solids and percent moisture content were the quality parameters considered in this study. Cabbage head firmness was determined using the 5 randomly sampled cabbage heads used to determine head dry weight before they were chopped. The head firmness was measured using a hand held penetrometer (model FT327, QA Supplies, LLC. U.S.A), probe no. 16, by exerting pressure on the head. The reading in force (kg) at which the cabbage head was punctured indicated the head firmness. From the remainder of the chopped up cabbage used to determine dry weight, a handful was taken from every treatment for Total soluble solids (TSS) determination. Fluid was squeezed from the tissues by hand and the TSS of the extracted liquid determined using a hand held refractometer (model RHB-32atc, Fuzhou Hedao Trade Co. Ltd. China) and recorded as % brix TSS. Percent moisture content was determined from the sample of 100 g that was oven dried at 75 ºC to a constant weight during dry matter determination using the formula:

$$\textit{Percent moisture} = [(100\text{ g Fresh weight} - \text{Dry weight})/100] * 100 \quad (2)$$

2.5 Data Analysis

Data collected was subjected to Analysis of Variance (ANOVA) using PROC GLM code of SAS (version 9, 2005). Means were separated using the Tukey's Honestly Significant Difference Test at $P \leq 0.05$. Since season by treatment interaction was not significant, data for the two seasons were pooled and analysed together using the RCBD model:

$$Y_{ijk} = \mu + \rho_i + \beta_k + \varepsilon_{ijl.} \quad (3)$$

where, $\boldsymbol{Y_{ijk}}$ is the cabbage response, $\boldsymbol{\mu}$ is the grand mean, $\boldsymbol{\rho_i}$ is the ith blocking effect (i = 1, 2,3,4,5), $\boldsymbol{\beta_k}$ is the kth treatment effect (k = 1, 2,3,4,5), and $\boldsymbol{\varepsilon_{ijk}}$ is the random error component which are normally and independently distributed about zero means with a common variance σ^2.

3. Results

3.1 Crop Environment

3.1.1 Air Temperature

The use of agronet covers modified the cabbage crop environment with higher temperatures recorded under agronets plots compared to uncovered treatments throughout the study (Figure 1A). Averaged over the two seasons, mean temperatures were 23.4 ºC under 0.4 mm agronet used permanently, 21.1 ºC under 0.4 mm agronet opened thrice weekly, 19.1 ºC under 0.9 mm agronet used permanently; 18.7 ºC under 0.9 mm agronet opened thrice a week and 17.9 ºC under the control. This corresponded to 5.5 ºC, 3.2 ºC, 1.2 ºC and 0.6 ºC increase in temperatures following the use of 0.4 mm agronet permanently, 0.4 mm agronet opened thrice a week, 0.9 mm agronet permanently and 0.9 mm agronet opened thrice a week, respectively compared to the control treatment.

3.1.2 Relative Humidity

Relative humidity (RH) within the immediate crop environment also displayed a trend similar to that of temperature. It was highest under 0.4 mm netting used permanently and lowest under the control treatment throughout the study (Figure 1B). The mean relative humidity for the two seasons was 84.4% under the 0.4 mm netting used permanently and 82.2% under the same mesh size netting opened thrice a week against 73.6% relative humidity recorded for the control treatment. This depicted a 10.8% and 8.6% increase in relative

humidity when the 0.4 mm agronet was used permanently or opened thrice a week, respectively. Relative humidity under the 0.9 mm agronets was on the other hand, 80.3% and 77.8% when used permanently and when opened thrice a week, respectively corresponding to 6.1% and 4.2% increase, respectively.

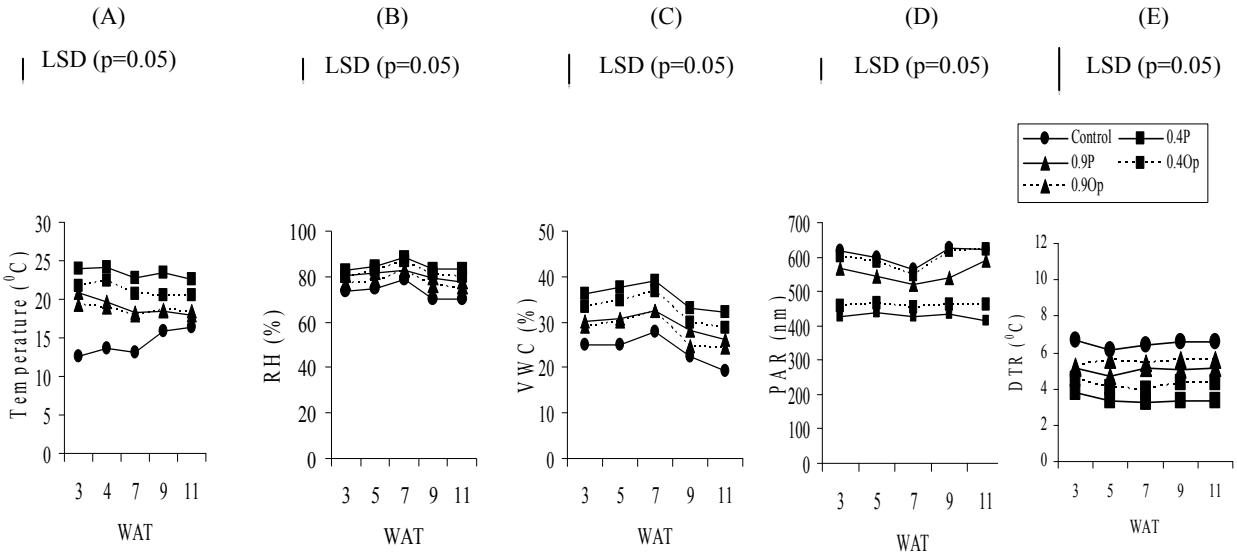

Figure 1. Air temperature (A), Relative humidity (B), Volumetric water content (C), Photosynthetic active radiation (D) and Diurnal temperature range (E) profiles as influenced by agronet covers during cabbage production

Season 1 (May-Aug, 2011) and season 2 (Oct-Jan, 2012). Control had no agronet cover, 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).

3.1.3 Volumetric Water Content

The use of agronet covers also improved the volumetric water content (VWC) of the immediate cabbage soil environment. Using the 0.4 mm agronet permanently resulted in the highest volumetric water content while the lowest volumetric water content was in soils of uncovered plots at all sampling dates (Figure 1C). The mean volumetric water content for the control treatment during the study period was 23.9% against 35.6% under the 0.4 mm agronet used permanently and 32.7% under the 0.4 mm agronet opened thrice a week. The 0.9 mm agronet net used permanently recorded a VWC of 29.6%, and 28.2% under the 0.9 mm agronet net opened thrice weekly accounting for an 11%, 8%, 5.7% and 4.3% increase in soil moisture content following the use of the respective agronet treatments.

3.2 Photosynthetic Active Radiation

The use of agronet covers lowered the Photosynthetic active radiation (PAR) received by the cabbage crop. Covered plots consistently recorded lower PAR than uncovered treatments throughout the study period (Figure 1D). Amongst the agronet-covered treatments, PAR was consistently lower under the 0.4 mm netting treatments compared to under the 0.9 mm netting. Averaged across the seasons, the mean PAR under the 0.4 mm net used permanently and opened thrice a week was 427.6 nm and 460.2 nm, respectively. Meanwhile, the 0.9 mm used permanently registered a PAR of 552.2 nm against 595.5 nm when opened thrice a week. The highest PAR was obtained under the no-net cover control, which registered a mean PAR of 605.4 nm.

3.3 Diurnal Temperature Range

Similar to PAR, Diurnal temperature range (DTR) within the vicinity of the crop was lowered with the use of agronet covers. Diurnal temperature range remained high under the uncovered control and lowest under the 0.4 mm agronet maintained permanently covered in all sampling dates (Figure 1E). Over the study period, the 0.4 mm mesh agronet registered a mean diurnal temperature range of 3.4 ºC and 4.2 ºC when maintained permanently covered or opened thrice a week, respectively. Mean diurnal temperature ranges were 5.0 ºC under the 0.9 mm mesh agronet when used permanently and 5.1 ºC when opened thrice a week. The control treatment

had a mean diurnal temperature of 6.4 ºC. This depicted a 3.0 ºC, 2.2 ºC, 1.4 ºC and 1.3 ºC decrease in diurnal temperature range with the use of the 0.4 mm mesh agronet maintained permanently covered or opened thrice a week and the 0.9 mm mesh agronet used permanently or opened thrice a week, respectively.

3.4 Leaf Stomatal Conductance and Chlorophyll Content

The stomatal conductance of cabbage leaves was enhanced by the use of agronet covers. Throughout the study, leaf stomatal conductance was consistently higher in cabbage plants grown under agronets and lowest under the uncovered plants (Figure 2). Cabbage plants under the permanent use of 0.9 mm netting registered significantly higher stomatal conductance followed by plants under the 0.9 mm net opened thrice a week. Plants under the 0.4 mm net used permanently and 0.4 mm net opened thrice a week, had slightly lower stomatal conductance with control plants exhibiting the lowest stomatal conductance at all sampling dates. Mean stomatal conductance for the study period were 395.8 µmol $m^{-1}sec^{-2}$, 354.1µmol m^{-1} sec^{-2}, 328.8 µmol $m^{-1}sec^{-2}$, 317.0 µmol $m^{-1}sec^{-2}$, and 277.4 µmol $m^{-1}sec^{-2}$ for the 0.9 mm netting used permanently, the 0.9 mm net netting opened thrice a week, the 0.4 mm net used permanently, the 0.4 mm net opened thrice a week and the control treatments, respectively. Similarly, cabbage leaf chlorophyll content was also enhanced by growing the crop under agronet covers (Figure 2). With progressive increase crop age, plants grown under 0.9 mm nets presented significantly ($p = 0.05$) higher chlorophyll content values than those under 0.4 mm net and the uncovered control. Averaged over the study period, the chlorophyll content of leaves of 0.9 mm net covered cabbage was 72.2 CCI when permanently used and 70.1 CCI when opened thrice a week. On the other hand, cabbage grown under the 0.4 mm net used permanently recorded chlorophyll contents of 56.3 CCI and 64.4 CCI when opened thrice a week. The uncovered plants had significantly lower mean chlorophyll content of 45.6 CCI.

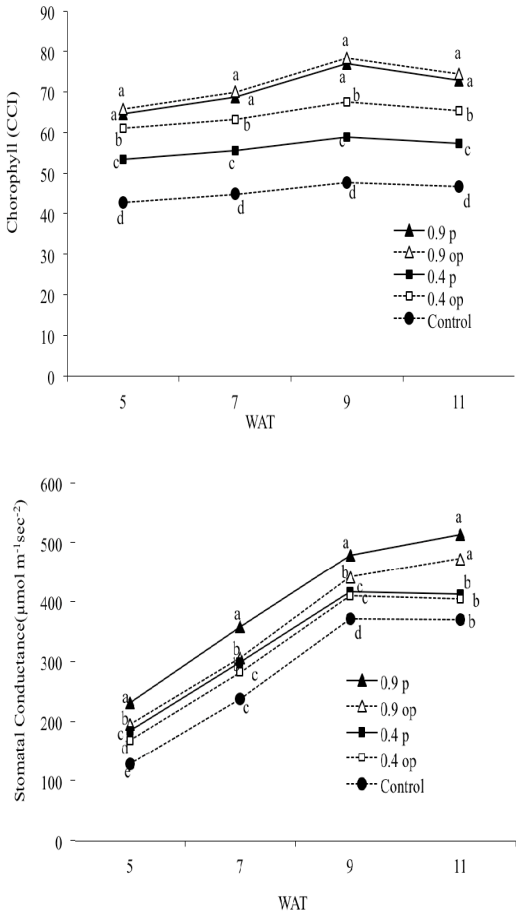

Figure 2. Leaf stomatal conductance and chlorophyll content profiles as influenced by agronets during cabbage experiment in season 1 (May - Aug, 2011) and season 2 (Oct 2011 - Jan, 2012)

Control had no agronet cover; op is where the agronet was opened three times a week, p is where the 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. Within each parameter and WAT data points with the same letter are not significantly different according to the Tukey's HSD test ($p \leq 0.05$)

3.5 Yields

Growing cabbage under agronet covers significantly increased head fresh weight (Table 1). The use of the larger mesh size of 0.9 mm pore diameter agronet cover maintained permanently resulted in the highest yields followed by the same mesh size maintained by opening thrice a week. The lowest yield was obtained from the control treatment. Among the agronet-covered treatments, the yields were lowest under the 0.4 mm agronet cover maintained permanently. An analysis of the unmarketable yields due to various defects, revealed a trend opposite to that of total yields (Table 1). The highest unmarketable cabbage yield was obtained in the control treatment while the lowest was under the 0.9 mm permanent cover. Cabbage grown under agronet covers also accumulated more dry matter than that grown in the open field (Table 1). Generally, the use of the larger mesh agronet of 0.9 mm pore diameter yielded cabbage with higher dry matter than the finer 0.4 mm pore diameter agronet while the least dry matter accumulation was in open field grown cabbage.

Table 1. Cabbage head fresh yield and selected quality attributes as influenced by agronet covers season 1 (May-Aug, 2011) and season 2 (Oct 2011 - Jan, 2012)

Treatment*	Fresh yield MT ha^{-1}	Unmarketable yield MT ha^{-1}	Water content (%)	TSS (%)	Firmness force (kg)
Control	101.40^{cd}**	33.77^{a}	85.45^{bc}	5.90^{a}	3.9^{c}
0.9 mm opened	176.86^{ab}	16.5^{c}	91.08^{abc}	4.53^{b}	4.85^{b}
0.9 mm permanent	183.06^{a}	6.21^{d}	91.92^{ab}	4.50^{b}	5.25^{a}
0.4 mm opened	119.25^{c}	20.36^{b}	92.0^{ab}	3.75^{c}	4.4^{bc}
0.4 mm permanent	105.68^{cd}	19.63^{b}	92.45^{a}	3.6^{c}	4.3^{bc}

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

**Values followed by the same letter within a parameter are not significantly different according to the Tukey's HSD test ($p \leq 0.05$).

3.6 Selected Cabbage Quality Attributes

Growing cabbage under the 0.9 mm or 0.4 mm netting resulted in more succulent cabbage as evidenced by the higher water content. Whether maintained as a permanent cover or opened thrice a week, cabbage water content remained significantly high in both nets and lowest in the control (Table 1). Although moisture content was higher for cabbage heads from the finer 0.4 mm agronet compared to that of cabbage grown under the larger 0.9 mm agronet, the differences were not significant at $p \leq 0.05$.

Contrary to moisture content, lower TSS was associated with the use of agronet covers in cabbage production (Table 1). Cabbage grown under the 0.4 mm agronet treatments recorded the lowest TSS followed by that from the 0.9 mm agronet covers with the highest TSS being obtained in control cabbage. The use of agronet covers however, yielded firmer cabbage heads than when the crop was grown in the open field (Table 1). The most firm cabbage heads were those grown under the 0.9 mm permanently covered agronet yield followed by those grown under the same mesh size agronet opened thrice a week. The least firm cabbage heads were obtained from the uncovered control. All 0.4 mm agronet covers yielded cabbage heads that were firmer than those under open field production but less firm than those under the 0.9 mm agronets covers.

4. Discussion

4.1 Effects of Agronet Cover on the Crop Environment

The agronet covers modified all microclimate variables under study. Air temperature, relative humidity and volumetric water content remained higher in agronet covered than in uncovered treatments throughout the study. On the other hand, photosynthetic active radiation and diurnal temperature range were reduced by the use of net covers. For all microclimate variables under study, the extent of modification was also influenced by the size of

the mesh used and whether the covers were maintained permanently covered or managed by opening them thrice a week. Microclimate modification was generally greater under the finer agronet mesh size of 0.4 mm than under the larger mesh size of 0.9 mm. A greater microclimate modification was also obtained by maintaining the agronets permanently covered than when they were opened thrice a week for ventilation. The existence of a screen has been shown to alter the exchange of radiation, momentum and mass between the crop and the atmosphere hence modifying the crop microclimate (Lloyd et al., 2005). Screens reduce the mixing of outside air with inside air thus reduce heat loss to the surrounding atmosphere, which leads to a temperature build up (Tanny et al., 2003). The finer mesh (0.4 mm) used in the current study possibly provided more resistance to air movement than the larger mesh (0.9 mm) leading to the higher temperatures recorded under the finer agronet than under the larger mesh size net. Findings of this study agree with those of Perez et al. (2006) on leather leaf fern, Tanny et al. (2003) on tomato and Stamps (1994) on cut foliage where netting screen increased temperature by 2.3 ºC to 5 ºC.

Relative humidity was also higher under agronets than in the uncovered plots in the current study. Relative humidity is often higher under netting than outside as a result of water vapour being transpired by the crop and reduced mixing of drier air outside with that of the netted area, even when temperatures under the netting are higher than the outside (Elad et al., 2007). Reduction in radiation resulting from netting also contributes to increased relative humidity with finer mesh providing a higher shade factor than larger mesh sizes (Stamps, 1994). Besides reducing radiation, nettings also reduce wind speeds, which in turn minimize mixing of inside air with outside dry air hence maintaining a higher relative humidity (Tanny et al., 2003). These arguments lend support to the observations made in the current study where a higher relative humidity was observed under agronet-covered plots than in the uncovered plots. Among the agronet covered plots, relative humidity was highest under the finer mesh (0.4 mm) than under the larger mesh (0.9 mm) possibly due to greater resistance to air movement and mixing offered by the finer mesh compared to the larger mesh agronet covers. These findings are in line with results by Cicero et al. (2012) who recorded a 2 to 6% increase in relative humidity with the use of different nets.

In the current study, volumetric soil water content was higher under the agronet covers than the uncovered plots. The existence of shade netting may have reduced soil evaporation rate under netted areas due to restricted air movement, resulting in higher soil water retention. According to Akpo et al. (2005) one of the potential benefits of net covers above crops is creation of a shading effect. Such an effect, coupled with high atmospheric water content slows the rate of evaporation and retains higher water content in the soil. Another possible explanation to the higher soil moisture level under covers is the reduction of transpiration thereby minimised water uptake by plants leading to increased moisture retention in the soil (Iglesias & Alegre, 2006). This attribute of net covers presents a potential for lowering cabbage crop irrigation requirement. Similar to the findings of the current study, Akpo et al. (2005) observed increased volumetric water content in soils under shade than in the open.

Although the amount of light reaching the cabbage crop was in this study reduced under net covers with the highest reduction observed under the fine mesh (0.4 mm), light reaching the cabbage crop under all the covers still fell within the PAR region. Our observations indicate the possibility of finer mesh size nets filtering more light hence lowering the amount of PAR reaching the crop. In a study by Retamales et al. (2008), white nets reduced photosynthetic active radiation by 28% when used in high bush berry production. In apples, overall, incident solar radiation (as PAR) was reduced by 12% with the use of white (crystal, translucent) hail nets relative to the control outside (Solomakhin & Blanke, 2009). Similar to these findings, PAR reaching the cabbage crop in the current study was reduced by 1.6% to 29.4% with the use of net covers.

4.2 Effects of Agronet Covers on Cabbage Leaf Stomatal Conductance and Chlorophyll Content

Growing cabbage under net covers enhanced leaf stomatal conductance and chlorophyll content compared to growing the crop in the open field. These findings are consistent with those of Smith (2007) who reported increased stomatal conductance in blushed apple cultivars under netting. At all stages of the crop, agronet covered treatments in the current study registered higher relative humidity values than the uncovered plants. According to Bunce (1999), plants are generally known to react to low relative humidity by closing their stomata with a consequent reduction in CO_2 uptake and water loss. Stomatal response to atmospheric humidity is further intensified by the effect of high wind speed, which reduces the leaf water potential by depleting the moist boundary layer close to the leaf surface. The low stomatal conductance observed in cabbage plants produced in the open field in the current study could therefore have been a reaction of the plants to low relative humidity and higher wind levels. Microclimate data from the current study also revealed reduced soil moisture content levels in the open treatments compared to the agronet-covered treatments. Soil moisture reduction leads to a decline in gaseous exchange and leaf water potential (Gitlin et al., 2006; Otieno et al., 2002).

Although the use of agronet covers generally increased stomatal conductance in the current study, using the 0.9 mm agronet covers resulted in higher stomatal conductance than the 0.4 mm netting. Stomatal conductance is known to be affected by factors such as carbon dioxide (CO_2) concentration, light, humidity and temperature. The differences in stomatal conductance following the use of the different agronet mesh sizes and/or net management regimes could be attributed to the differences in these factors. Elevated levels of CO_2 could have resulted under net covers due to resistance to air movement, with the finer mesh imposing greater resistance. This coupled with low light and high relative humidity and temperature affect stomatal conductance. Similarly, a study by Bunce (1999) revealed that stomatal conductance decreases more rapidly in elevated levels of CO_2, low light, high relative humidity and high temperature.

Higher values of chlorophyll content estimates were also observed under agronet covers than under open field produced cabbage at all growth stages of the crop. As discussed earlier, agronet covered treatments had reduced levels of irradiance; with the decrease being higher under the finer mesh (0.4 mm) and the permanently covered treatments than under the larger mesh (0.9 mm) or where nets were opened thrice weekly. Leaves of shaded plants are thinner and contain larger pigment-rich chloroplasts. Low irradiance causes chloroplasts to be oriented along the upper and lower cell walls in order to maximize light absorption. However, when plants are grown under high irradiance, the chloroplasts orient themselves mainly along the vertical cell walls parallel to incident irradiance (Brugnoli & Bjorkman, 1992; Park et al., 1996). The higher chlorophyll estimates recorded for the agronet covered treatments in the current study could therefore have resulted from the alignment of the chloroplasts along the upper and lower cell walls as a coping mechanism for the plant following the reduced irradiance levels received under these treatments.

Cabbage covered with agronets also had high tissue water content compared to the control plants in this study. High leaf water content is vital in maintaining maximum amount of chlorophyll in the plant. Water is very important in the synthesis of chlorophyll. High and stable water supply increases the amount of chlorophyll while erratic and low water supply decreases chlorophyll content (Bohrani & Habili, 1992). In the current study, leaf chlorophyll content also tended to be lower under the finer mesh, which was characterized by high air temperature and soil moisture. Khayatnezhad et al. (2011) observed that very high soil water levels cause a decrease in the chlorophyll content of leaves. Gazula et al. (2005) also detected a decrease in chlorophyll content of lettuce at temperatures above 21 ºC while Lobos et al. (2009) reported increased leaf chlorophyll content in *Vaccinium corymbosum* as shading intensity under net treatment increased.

4.3 Effects of Agronets on Yields and Quality of Cabbage

Cabbage is a cool season crop and as such does not perform well under high temperatures. The optimum temperature range for cabbage production is 15 to 20 ºC. Temperatures above 20 ºC delay maturity, increase vegetative growth (number of leaves), and lead to formation of loose heads. In the current study, temperatures remained generally above 20 ºC under the fine mesh (0.4 mm) agronet covers. Under the larger mesh cover (0.9 mm), temperatures mostly remained at below 20 ºC but within the upper range of the optimum temperature for cabbage growing. These temperatures could therefore have favoured optimal growth and heading of cabbage, subsequently resulting in the higher yields and better quality heads. Although low temperatures were exhibited by the uncovered treatments, the absence of a netting cover meant that other environmental factors remained unstable resulting in low physiological performance of the crops as evidenced by the low leaf chlorophyll contents and stomatal conductance under these treatments. According to Taub (2010), stomatal conductance decreases in response to low moisture as a result of which the supply of CO_2 to chloroplasts reduces. Low physiological performance results in low photosynthetic turnover which in turn reduces growth and subsequently yield. In the current study, microclimate modification under nets resulted in high stomatal conductance and chlorophyll content which could consequently have led to high photosynthetic turnover resulting in the higher yields obtained especially under the 0.9 mm net.

High tissue water content was also noted for cabbage heads grown under agronet covers than for cabbage heads grown in the open field in the present study. This could have been as a result of high water uptake vis-à-vis reduced transpiration experienced by the net covered cabbage. While low TSS were recorded for cabbage heads grown under agronets compared to those of heads produced in the open field, the study also revealed that temperatures remained consistently lower in the unprotected treatment than in the net covered treatments. Generally low temperatures have been shown to reduce respiration rate and carbohydrate consumption, thus favouring accumulation of soluble solids and vice versa. According to Sivaci (2006), TSS content decreases with increase in temperature, which could explain the differences in TSS among the net covered and unprotected cabbage in the current study.

Findings from the current study reveal that growing cabbage under the larger 0.9 mm mesh size agronet results in firmer heads than growing cabbage under the 0.4 mm agronet cover. Although both treatments had higher levels of tissue water content which plays a major role in tissue turgidity, temperatures remained higher under the 0.4 mm agronet than the 0.9 mm agronet. High leaf water potential is a prerequisite for both leaf elongation and expansion and thus for head formation of cabbage. Leaf thickness has also been hypothesized to be closely related to water potential. According to Gardner and Ehling (1965), high temperature lowers the leaf water potential of cabbage thereby reducing leaf thickness, which in turn makes heading more difficult. This results in loose heads and subsequently lower cabbage yields and quality observed under high temperatures. The general increase in yield and quality of cabbage under netting observed in the current study is consistent with findings on pepper where Elad et al. (2007) reported increased yields of two *Capsicum annum* cultivars when grown under shade nets compared to the no-net control.

The results of this study demonstrate the potential of agronet covers especially those of larger mesh size as a viable strategy for modifying the crop environment and enhancing cabbage physiological performance, yields and quality. Based on the findings of this study, the 0.9 mm mesh size agronet maintained permanently covered is recommended for use in cabbage crop production in regions with climatic conditions similar to our site. Although opening of nets during the day has been recommended by some authors (Joubert & Poissonier, 1991), we recommend permanent use of covers under our research conditions since opening of nets would increase labour requirements with no additional benefit in yield and quality. While the findings of this study provide a good foundation for understanding the effects of agronet covers in cabbage production, further testing of these materials using a wider range of mesh sizes and colour, different cabbage varieties and in different cabbage growing agro ecological zones would be beneficial. An evaluation of the effect of different heights of the covers may also be of additional value to the technology. A full economic analysis factoring in the cost of purchase, installation and management of the agronets will also be useful. A comprehensive analysis on the effect of these nets on the sensory attributes, nutritive value and defects would also go along way in promoting the consumption of net grown cabbages.

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