INFLUENCE OF DIFFERENT COLOURED AGRONET COVERS ON WATER USE EFFICIENCY, INSECT PEST POPULATIONS, YIELD AND QUALITY OF FRENCH BEAN (*Phaseolus vulgaris* L.)

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EGERTON UNIVERSTY

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DECLARATION AND RECOMMENDATION

Declaration

This Thesis is my original work and has not been submitted before in any institution for any other award.

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Recommendation

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DEDICATION

To my father, late mum, my wife, my son, brothers, sisters, relatives and friends, with all my love and that of my Heavenly Father.

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ABSTRACT

French bean (*Phaseolus vulgaris* L.) is among the leading export vegetables in Kenya, intensively grown by small scale farmers. Despite the economic importance of the crop, many growers are still not able to achieve maximum yield and quality due to unfavourable weather and heavy infestation by insect pests as the crop is predominantly grown in open fields. Coloured net technology is an emerging technology, which introduces additional benefits on top of the various protective functions of nettings. To determine the potential of coloured net covers in improving French bean production under tropical field conditions, this study was undertaken in the Horticulture Research and Teaching Field, Egerton University, Njoro from July to October, 2015 (trial 1) and November, 2015 to February, 2016 (trial 2). The experiment was set in a Randomized Complete Block Design (RCBD) with six treatments replicated four times. French bean 'Source' was grown under different coloured nets (white, blue, yellow, grey, and tricolour) and control (open field). Variables measured included; water use efficiency, pest infestation, growth variables, yield components, yield and quality. Data obtained were subjected to analysis of variance (ANOVA) and means of significant treatments separated using Tukey's Honestly Significant Difference Test at $P \leq 0.05$. French bean grown under the different coloured net covers showed relatively better growth, enhanced water use efficiency and crop performance marked by more pods and higher total yields and percentage of marketable yields compared to open field plants. Populations of silverleaf whitefly and black bean aphids were reduced under different coloured agronet covers as compared with control treatment. Growing the crop under the different coloured agronet covers substantially improved French bean marketable yields by between 97.65 – 175.17% and 28.85 – 94.42% in trial 1 and 2 respectively. Coloured nets especially light-coloured nets also hastened the rate of French bean pod maturation with the potential of reducing harvest interval. The study recommends use of the white and yellow net covers for maximizing French bean pod yield and quality.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABREVIATIONS AND ACRONYMS

AEZ	-	Agro Ecological Zone
ANOVA	-	Analysis of Variance
CAN	-	Calcium Ammonium Nitrate
CCIs	-	Chlorophyll Concentration Index Units
CIAT	-	Center for International Agricultural Technology
DAP	-	Days after Planting
EU	-	European Union
FAO	-	Food and Agriculture Organization of the United Nations
HCDA	-	Horticultural Crops Development Authority
LRWC	-	Leaf Relative water content
MOARD	-	Ministry Of Agriculture and Rural Development
MRL	-	Maximum Residue Level
MT	-	Metric Tons
PAR	-	Photosynthetic Active Radiation
RCBD	-	Randomized Complete Block Design
RWC	-	Relative Water Content
SAS	-	Statistical Analysis System
VWC	-	Volumetric Water Content
WUE	-	Water Use Efficiency

CHAPTER ONE

INTRODUCTION

1.1 Background Information

French bean is a dicotyledonous plant, and member of the Fabaceae family, forming part of the species *Phaseolus vulgaris* L. It is believed to have originated from Peru, and spread to South and Central America by migrating Indian tribes. It was introduced to Europe by the Spanish explorers around the 16th century, and further spread to different parts of the world including Africa by Spanish and Portuguese traders. The first bean variety was introduced in Kenya in the late 1960 from Tanzania (http://bioinnovate-africa.org/blog/m0bG9).

Cultivated forms of French bean are herbaceous annuals which can be determinate or indeterminate in growth habit with the determinate forms commonly grown for commercial purposes. The determinate French bean has a short growing season of between 65 and 110 days depending upon variety and planting season. On germination, the plant is initially tap-rooted, but adventitious roots emerge soon thereafter, and dominate the tap root which remains within the range of 10-15 cm in length (Gomez, 2004). This makes the crop able to draw water which is available only within this depth exposing it to water stress within short periods of dry spells. Roots also form nodules that contain bacteria of the *Rhizobium* sp. that is capable of converting free nitrogen from the atmosphere to chemically combined nitrogen, which is used by the plant. Pods develop from the ovary and style and are about 8-20 cm long and 0.6-1.5 cm wide. The pod fiber content increases with seed maturation and varies according to cultivar and prevailing moisture conditions. For fresh market French bean, pods are considered of best quality when they are less fibrous and range between 6 to 9 mm in pod thickness and 14 to 17 cm in pod length (http://www.infonet-biovision.org).

French bean is grown as a cash crop by both large and small holder farmers in Kenya and Africa in general (CIAT, 2006). Much of Kenyan French bean is, however, intensively grown by small scale farmers who own between 0.5-5.0 acres of land (Ndegwa *et al*., 2010). Estimates indicate that up to 50,000 smallholder families are involved in French bean production in the country (HCDA, 2011) mainly for fresh export and as a source of family income (Monda *et al*., 2003; Okello *et al*., 2007; Wahome *et al*., 2011). Small proportion of about 11% of total produce is consumed locally mainly in urban centers (Odero *et al*., 2012; HCDA, 2012). French bean is an important crop in the social economic systems and livelihoods of many Kenyans (Odero *et al*., 2012). It is the most important vegetable crop, both in terms of production and income generation with regard to export vegetables (HCDA, 2012). In 2013, the crop accounted for 52% of the value and 61% of the volume of total vegetable exports. Likewise, it accounted for 42% of the total value and 44% of total volume of fruit and vegetable exports. Kenya exported 31,974 metric tons (MT) of French beans in 2013, representing 42% increase over the 2012 volumes (HCD, 2014). Kenya exports French beans mainly to the United Kingdom, Netherlands, France, Belgium and Germany (HCDA, 2012). Total world production exceeds 17 million tonnes, with China, Indonesia, Turkey, India and Egypt among the largest producers and consumers of the crop (FAOSTAT, 2010). The European Union (EU) is the largest importer of Kenya's high quality French bean product that is now branded as "Kenya Green Beans", which accounts for 49.6% of the world green bean market.

Beside income and foreign exchange, French bean growing creates on-farm employment opportunities for the rural communities especially women and youth. Lenne *et al*. (2005) estimated that more than 1 million people benefit from the French bean in Kenya. Moreover, the bean is relatively rich in vitamin A, ascorbic acid, iron, calcium and dietary fibre which form an integral part of a healthy diet (Kelly and Scott, 1992).

Despite the economic importance and potential of French bean in addressing food insecurity, improving incomes and alleviating poverty, low yields remain a common scenario with most growers in many sub-saharan countries. As low as 6 to 8 tonnes per hectare of French bean have been realised in Kenya (Wahome *et al*., 2013) compared to 15 to 20 tonnes per hectare recorded in developing countries in South America and South East Asia as a result of better selection of adaptable varieties and crop management (Ndegwa *et al*., 2009; Wahome *et al*., 2013). Throughout its production cycle, French bean is subject to many abiotic and biotic stresses, including erratic rainfall, prolonged dry spells and heavy infestation by insect pest, which present major challenges to French bean growers, particularly in the tropics as the crop is predominantly grown in open fields.

French bean yield losses due to insect pests alone have been estimated to range from 35% to 100% annually (Singh and Schwartz, 2011). In addition, more than 50% of the average yield of the crop globally is lost due to drought stress (Zlatev and Lidon, 2012) as the crop is predominantly grown in open fields subject to the unfavourable conditions that prevail. To overcome some of these challenges, French bean production systems are characterized by the use of high input levels. The crop is grown almost throughout the year but mostly under irrigation, high fertilizer doses and repeated sprays of insecticides in a bid to realize high yield and physical quality (Monda *et al*., 2003; Nyakundi *et al*., 2010).

Indiscriminate application of pesticides has been the norm among many French bean growers (Dinham, 2003). However, emerging food safety and quality issues in the EU market have led to stringent standards for fresh fruits and vegetables entering the EU with regards to pesticide residue and environmental conservation. The EU has pegged Maximum Residue Levels (MRLs) for Endosulphan and Cypermenthrin; some of the most commonly used insecticides in French bean production at as low as less than 0.05ppm and at less than 0.02ppm for Dicofol. This has led to rejection of some of the produce at the export market produced under cocktail and repeated sprays of insecticides (Monda *et al*., 2003; Nyakundi *et al*., 2010). Besides, spray drifts and non-targeted sprays during production of vegetable crops often lead to contamination of non-target areas, enter the soil or are washed into river systems and marine environments, thus raising concerns with environmental lobby groups.

Use of nets has a long history in agricultural production with among documented benefits being the enabling of passive control of flying insect pests of crops by creating a physical barrier between the plants and pests (Vincent *et al*., 2003; Boiteau and Vernon, 2004), thus reducing the need for pesticide sprays (Martin *et al*., 2006; Licciardi *et al*., 2008; Weintraub, 2009). Nets have also been shown to have indirect impacts on the behavior of pests by modifying the visual and olfactory signal (Mazzi and Dorn, 2012) where they mask the crop, thus deterring pests that detect their prey via visual signals (Weintraub and Berlinger, 2004). Studies in Benin have reported lower insect pest population on cabbage grown under nets compared with use of foliar insecticides or unsprayed controls, thus reducing the need for insecticide sprays under net production (Martin *et al*., 2006; Licciardi *et al*., 2008). In Kenya, net covers have also proved effective in reducing insect pest pressure leading to improved tomato seedling growth (Gogo *et al*., 2012) and yields and quality (Gogo *et al*., 2014).

On the other hand, world food production from irrigated agriculture is increasing due to increased human population and climate change. In Kenya, irrigation uses over 69 percent of the limited developed water resources (Torori *et al*., 1995). As a consequence of climate change, it is anticipated that higher temperatures will result to increased evaporation and consumption of natural water for agricultural use (Perry *et al*., 2009) on the one hand, while the ever increasing population will on the other hand push up the demand for food. Water for food production must therefore be used more efficiently if a balance between the two scenarios has to be struck (Steduto *et al*., 2007). Technologies that stand to improve on agricultural water use efficiency (WUE) would therefore be key in alleviating the pressure of the ever-expanding world population on water resources (Zeggaf and Filali, 2010).

As defined by Stanhill (1987), water use efficiency refers to the amount of biomass produced per unit of water added to the crop. It can also be estimated as the amount of water consumed per unit of carbon dioxide fixed. Water use efficiency is determined by how well environmental factors such as temperature, relative humidity, wind speed, soil fertility (mineral nutrition), soil moisture and biotic factors within the immediate crop environment are manipulated in order to maximize yield for every unit of available moisture.

The use of net technology in agricultural production has been documented to reduce wind speed and modify and stabilize crop microclimate marked by lower diurnal temperature ranges and higher air temperatures and volumetric water content (Saidi *et al*., 2013; Gogo *et al*., 2014). Coloured net technology is on the other hand, an emerging technology, which introduces additional benefits, on top of the various protective functions of nettings. Photoselective nets which include the coloured nets are unique in that they both spectrally-modify, as well as scatter the transmitted light, absorbing spectral bands shorter or longer than the visible range. This spectral manipulation has a potential for promoting physiological responses in plants while the scattering of light improves penetration into the inner canopy, all of which contribute towards better crop performance (Rajapakse and Shahak, 2007). Field experiments on cabbage (Muleke *et al*., 2014) and tomato (Saidi *et al*., 2013), have demonstrated an increase of up to 11% higher soil moisture content and 74% increase in yields with the use of net covers compared to open field production presenting a potential for lowering crop irrigation requirement while maximizing on yields per unit of land and water supplied.

1.2 Statement of the problem

Despite the economic importance of French bean, many growers are still not able to achieve maximum yield and quality. Unfavourable weather, characterized by fluctuating temperatures, humidity, wind flow, moisture and high insect pest populations which prevail under open field production contribute to the reduced yield and quality of the crop. In a bid to manage the pest problem, farmers have indiscriminately applied pesticides which in the recent years have often led to rejection of some of the produce at the export market due to stringent maximum residue levels (MRL) measures.

In Kenya, French bean is produced throughout the year but mostly under irrigation. However urbanization and the ever-expanding population is putting high pressure on the dwindling water resources rendering less water available for irrigation by the day; a scenario that could threaten the continuous supply of French bean to the international market. Technologies for reducing on pesticide usage and maximizing on production per unit of available water are thus imperative if French bean has to maintain its leading role as a foreign exchange earner for the country. Net technology has successfully been used in other parts of the world to minimize such challenges in vegetable production. However, the potential benefits of coloured agronet covers on improving water use efficiency and reduction of irrigation need by the crop as well as their impact on pest infestation and subsequent need for insecticide sprays under Kenyan conditions remain to be established.

1.3 Objectives of the Study

1.3.1 Broad Objective

To contribute towards improved French bean yield and quality by improving on water use efficiency and reducing insect pest population through the use of different coloured agronet covers.

1.3.2 Specific Objectives

i. To determine the effects of different coloured agronet covers on growth, yield and quality of French bean.
ii. To determine the effects of different coloured agronet covers on insect pest population on French bean.
iii. To determine the effects of different coloured agronet covers on yield and quality of French bean.
iv. To determine the effects of different coloured agronet covers on water use efficiency of French bean.

1.4 Hypotheses

i. Different coloured agronet covers have no effect on growth, yield and quality of French bean.
ii. Different coloured agronet covers have no effect on insect pest population on French bean.
iii. Different coloured agronet covers have no effect on yield and quality of French bean.
iv. Different coloured agronet covers have no effect on water use efficiency of French bean.

1.5 Justification of the Study

French bean is an important vegetable and a source of income especially for small scale farmers who are involved in all aspects of its production and utilization. An increase in French bean production and quality is, therefore an important step towards increased income as well as improving the standards of living especially for low-income families. Threat of MRL noncompliance by Kenyan small-holder French bean producers discourages exporters from buying French bean from small-holders. Exports to the EU have declined following the amendment of the EU regulation 669/2009 subjecting Kenyan fresh beans and peas to a 10 percent increase on physical checks at designated ports of entry. Thus with insecticide residues becoming increasingly unacceptable in the international market, alternative measures of pest control need to be implemented if French bean is to maintain its vital position in improving livelihood of the rural poor growers.

For French bean to maintain its important economic role in the country, environmental friendly production systems for the crop need to be developed and promoted. Use of nets is not only an environmental friendly technology, but also provide resource poor farmers with low cost pest control and better crop performance through modified crop microclimate. Nets have the potential of reducing the need for frequent watering through effective soil moisture conservation and reduction in wind speed while better crop growth and performance favoured by the modified microclimate stands to improve yield. The use of agronets in French bean production could therefore increase water use efficiency of the crop thereby increasing growers' yield per unit of water applied which could go along in reducing the pressure on water resources besides the reduction of insect pest pressure. Further, findings of the study will contribute to the existing scientific knowledge on French bean production.

CHAPTER TWO

LITERATURE REVIEW

2.1 Taxonomy and Botany of French bean

French bean is an annual dicotyledonous and leguminous plant that belongs to the genus *Phaseolus*, forming part of the species *Phaseolus vulgaris* L. It is grown worldwide for its edible pods. It is a highly polymorphic warm-season and annual herbaceous. It has a taproot with many adventitious roots (Ecoport, 2013) and the stems are rather slender and pubescent. The leaves are borne on long green petioles and are green or purple in colour and trifoliate with leaflets of 6-15 cm long and 3-11 cm broad. The inflorescence is axillary or terminal in long racemes of 15-35 cm. It is largely a self-pollinated plant though cross-pollination is possible if the stigma contacts with pollen coated bee when extended (Ecoport, 2013). The flowers are arranged in pairs or solitary along the rachis, white to purple and typically papillonaceous (Ecoport, 2013; Wortmann, 2006). Once pollinated, each flower gives rise to one pod and the pods are slender, green, cylindrical, 0.6-1.5 cm wide and up to 20 cm in length (Wortmann, 2006).

2.2 Utilization and Nutritional Value of French bean

Legumes play an important role in human nutrition as they are rich source of protein, calories, certain minerals and vitamins (Baloch and Zubair, 2010). French bean protein is high in lysine, which is relatively deficient in maize, cassava and rice, making it a good complement to these staples in the diet. Consumption of French bean is high mostly because it is relatively inexpensive compared to meat (Pachico, 1993). Regular consumption of French bean and other pulses is now promoted by health organizations because it reduces the risk of diseases such as cancer, diabetes or coronary heart diseases (Leterme and Munoz, 2002). This has been attributed to the fact that French bean is low in fat and is cholesterol free. It is also an appetite suppressant since it digests slowly and causes a low sustained increase in blood sugar. Researchers have found that French bean can delay the reappearance of hunger for several hours, enhancing weight-loss programs. French bean is important for staggering food supply all the way from leaf stage to pods. It is consumed as boiled green leaves, or green immature pods (Leterme and Munoz, 2002).

Legumes are also used as fodder material for feeding animals (Ruselle, 2001). They are, therefore, important to man both directly as a source of food, and indirectly through provision of fodder to the livestock industry, or in supplying nitrogen to soil for better performance of associated and/or subsequent crops. According to Smil (1999), some 40 to 60 metric tons of Atmospheric Nitrogen are fixed by Agricultural important legumes annually.

2.3 Environmental Requirement of French bean

French bean is a warm-season crop that does not tolerate frost or long periods of exposure to near-freezing temperatures at any stage of growth. High temperatures do not affect it if adequate soil water is present, although high nocturnal temperatures will inhibit pollination (Buruchara, 2007). French bean requires an optimum mean daily temperature range of between 15 and 20°C. The minimum mean daily temperature for growth is l0°C and the maximum is 27°C with high temperatures tending to increase the fibre content in the pod (FAO, 2013). The crop requires moderate amounts of rainfall (300 – 600 mm) but adequate amounts are essential during and immediately after the flowering stage. Generally, French bean is considered a short-season crop with most varieties maturing in a range of 65 to 110 days from emergence to physiological maturing (Buruchara, 2007).

The crop is not sensitive to soil type as long as it is reasonably fertile, friable, and deep with high levels of organic matter, well drained and lack conditions that interfere with germination and emergence (Wortmann *et al.*, 1998). Crop cultivation is concentrated at altitude above 1000 metres above sea level and soil pH of 5.5 - 6.5 is ideal. The flowering stage is the critical moisture requirement stage for the crop. Fertilizer requirements for high production are 20 to 40 kg/ha N, 40 to 60 kg/ha P and 50 to 120 kg/ha K. French bean is capable of fixing nitrogen which can meet its requirements for high yields. However, a starter dose of N is beneficial for good early growth (FAO, 2013). Fertilizer application for French bean production recommended by Ministry of Agriculture and Rural Development (MOARD, 2003) is 200 kg DAP/ha at planting and top dressing with CAN at a rate of 200 kg/ha in two equal split applications; at the trifoliate leaf stage and onset of flowering.

2.4 An Overview of Protected Crop Production

Protected agriculture is a broad category of production methods in which there is some degree of control over one or more environmental factors. Protected agriculture dates back to 1437A.D when Romans used hydrous magnesium silicate to cover windows in order to screen out light so as to extend growth of plants (Garnaud, 1988). Production of crops under protection has since grown in many countries, as a result of the increasing demand for continuous supply of high-quality fresh produce (Garnaud, 1988). The benefits of protected agriculture currently being realized include: reduced excessive solar radiation, increased yields, improved quality and consistency of crops, improved land and water use efficiency, increased control over crop nutrition, decreased use of chemicals and pesticides, improved resistance to adverse weather conditions, increased control over insects and diseases and reduced external and biological crop threats (Garnaud, 1988).

Protected cropping reduce wind speed, modify and stabilize crop microclimate and also enables passive control of flying insect pests of crops by creating a physical barrier between the plants and pests (Vincent *et al*., 2003; Boiteau and Vernon, 2004). Nets provide barrier which disrupts feeding and mating habits of many pests, thereby lowering their population (Martin *et al*., 2006). According to Antignus and Ben-Yakir (2004), the light spectrum plays an important role in aspects of insect behavior including navigation and orientation. Screen covers have 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*., 2004).

Screens reduce the mixing of outside and inside air, hence effectively reducing loss of heat to the surrounding atmosphere, which leads to a temperature increase (Tanny *et al*., 2003). In addition, covering crops reduces instantaneous solar radiation through shading (Shahak *et al*., 2004a), which lowers evaporation from the ground, thus maintaining higher soil moisture contents (Moreno *et al*., 2002). Thus, producing vegetables under protective structures reduces yield losses from insect pests, diseases, and heavy rains, and results in higher productivity and returns per unit area. Protective structures enable growers to produce vegetables successfully during the off-season, which enhances the availability of fresh produce at times when vegetables are usually in short supply (http://www.spipm.cgiar.org).

The structures under which protected agriculture takes place can vary from the most costly, high-tech greenhouse with automated climate control to the simplest, least expensive temporary net tunnels constructed with U-shaped iron or aluminum bars, covered with nylon netting over each bed (Talekar *et al*., 2003).The use of net covers in crop production offers a cheaper and less energy consuming technology than greenhouses (Shahak, 2008). Netting technology has been used in agriculture to protect crops against environmental hazards like wind, hail, excessive solar radiation and flying insects. Nets also improve plant microclimate through reduction in heat, chill and drought stresses leading to improved crop yield and quality (Shahak *et al*., 2004a). Most commonly used nets have been the black nets and anti-hail and insect proof nets typically made of either clear or white threads or a combination of the two (Shahak, 2008). Photoselective nets which include the coloured nets are an emerging technology, which introduces additional benefits, on top of the various protective functions of nettings. Although black nets are most frequently used, growers are experimenting with coloured, grey, and white dispersive netting in an attempt to impact vegetative vigor, dwarfing, branching, leaf variegation, and timing of flowering (Leite *et al*., 2008; Oren-Shamir *et al*., 2000; Stamps, 2009). Coloured nets are being intensively tested primarily because of their ability to manipulate the spectra of radiation reaching the crops. They can be used to change red to far-red light ratios that are detected by phytochromes, the amounts of radiation available to activate the blue/ultraviolet-A photoreceptors, blue light involved in phototropic responses mediated by phototropins, and radiation at other wavelengths that can influence plant growth and development (Stamps, 2009).

Arthurs *et al*. (2013) studying environmental modification inside photoselective shade houses showed that photosynthetic active radiation (PAR) values (µmol.m^{-2}.s^{-1}) were reduced most under black nets and least under red nets with blue and pearl nets recording intermediate values. Stamps and Chandler (2008) recorded reduced PAR less by 70% in red netting, black or blue netting compared with uncovered structure. Average daily maximum air temperatures were higher inside shadehouses covered with colored nets compared with black nets or ambient temperature with the highest air temperatures recorded under red net. Areas under black nets were consistently cooler compared with ambient while blue and pearl recorded similar temperatures and were intermediate between red and black nets (Arthurs *et al*., 2013). Oren-Shamir *et al*. (2001) on the other hand reported no significant differences in air temperatures inside the canopies of plants growing under six (green, red, blue, grey, black and reflective) different net covers.

2.5 Effects of Protected Production on Microclimate Moisture Content and Water Use Efficiency

Protected production conserves soil moisture by manipulating environmental factors within the immediate crop environment. This maximize yield for every unit of available moisture hence improving water use efficiency of a crop. In cabbage field experiments using net covers, Muleke *et al*. (2014) recorded up to 11% higher soil moisture content under agronet covers compared to open field. Net technology in agricultural production has been documented to reduce wind speed and modify and stabilize crop microclimate marked by lower diurnal temperature ranges and higher volumetric water content (Saidi *et al*., 2013; Gogo *et al*., 2014). Elad *et al*. (2007) recorded higher relative humidity 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 were higher than the outside.

Changes in the water balance and the amount of water available in soil can be crucial for crop yield (Fuhrer, 2003). On the other hand, physiological characteristics of plants are correlated with the water potential (Hsiao, 1973). Low water potential due to reduced water availability negatively affects plant growth (Ohashi *et al*., 2000), photosynthesis (Ogen and Oquist, 1985), plant cell enlargement (Nonami *et al*., 1997), and hormone balance (Munns and Gramer, 1996). Tanny *et al*. (2003) concluded that, the effects of shading screens on the microclimate of Apple orchard conserved soil moisture by enhancing atmospheric stability as compared to the uncovered orchard where solar heating of the ground presumably induced a more unstable atmosphere suggesting a potential reduction of atmospheric water demand and possible saving of irrigation water under shading.

Improving water use efficiency in agriculture requires an increase in crop water productivity (an increase in marketable crop yield per unit of water removed by plant) and a reduction in water losses from the plant rooting zone. A study by Pellitero *et al*. (1993) on pepper reported higher water use efficiency values for shoot dry matter production and for total fresh fruit production under the greenhouse than for field grown pepper. Appreciably reduced evaporative demand has also been reported inside greenhouses compared to open field (Montero *et al*., 1985; Castilla *et al*., 1990). According to FAO (1991), crop water requirements are considerably less in greenhouses than in open fields for similar levels of production which has been attributed to the much lower evapotranspiration inside greenhouses on account of there being considerably less wind, reduced solar radiation, and higher atmospheric humidity (Montero *et al*., 1985) which leads to appreciably higher water use efficiencies for greenhouse grown compared to open field grown crops.

2.6 Effect of Protected Production on Insect Pest Population

High insect pest pressure is a barrier to the proliferation of the vegetable production industry. Use of nets enables passive control of flying insect pests of crops by creating a physical barrier between the plants and pests (Vincent *et al*., 2003; Boiteau and Vernon, 2004). The use of net technology in agriculture is a form of protected agriculture that has been shown to have indirect impacts on the behavior of pests by modifying the visual and olfactory signal (Mazzi and Dorn, 2012) where they mask the crop, thus deterring pests that detect their prey via visual signals (Weintraub and Berlinger, 2004). A study by Setiawati *et al*. (2014) on shallots using shade nets reported that nets reduced pest damage and number of sprays by up to 100% and produced higher shallot yields. The physical exclusion of insects reduces the incidences of direct crop damage and also of insect transmitted viral diseases (Teitel, 2008).

Protecting vegetables with a screen in tropical countries may reduce or even eliminate often indiscriminate insecticide applications by small-scale farmers (Licciardi *et al*., 2008). This approach protects human health by reducing insecticide sprays, reducing environmental pollution from insecticide residues and increasing effectiveness of crop protection. Screens act as a mechanical barrier and can be used to prevent migratory insects from reaching the plants. A study by Amna *et al*. (2012) reported that, alternative cover provide better protection against arthropod pests where the light inside the screen-house contains less UV and therefore becomes "invisible" to the pest. According to Matteson *et al*. (1992), higher levels of reflected/scattered sunlight also deter pest landing.

Photoselective shade nets differently affect vegetative pest infestation. Studies have shown that different insect pests respond differently to different shades of net covers. Ben-Yakir *et al*. (2008) reported higher whitefly populations under yellow nets compared with black, blue and red netting. Contrary to these observations, a study conducted in Besor region Israel on tomato using yellow, black, red and pearl nets reported lower aphid and whitefly infestation under tunnels covered by yellow or pearl nets compared with black or red nets (Ben-Yakir *et al*., 2012). In an attempt to establish pest preference in coloured nets (yellow, blue, black and red), Ben-Yakir *et al*. (2008) observed that yellow and blue shade nets (ChromatiNet) were preferred by thrips compared with black and red nets while whiteflies preferred yellow shade nets compared with black, blue and red nets.

2.7 Effect of Protected Production on Crop Growth, Yield and Quality

Protected production improves crop performance by manipulating the immediate crop environment thus modifying crop microclimate. Setiawati *et al*. (2014) reported significant effects of shade nets on shallot growth. Treatments where white nets were used produced the highest vegetative characteristics in terms of plant height followed by blue nets treatments. Nissim-Levi *et al*. (2008) reported that shade nets increase light scattering but do not affect the light spectrum and increase branching, plant compactness, and the number of leaves per plant.

A study in Serbia conducted to evaluate the influence of different colours of shade nets (pearl, red, blue and black) on plant development, yield and quality of bell pepper (*Capsicum annum* L.) reported significantly higher yield under red and yellow shade nets compared with black nets (Ilic *et al*., 2011). Similarly, Fallik *et al*. (2009) reported higher export quality pepper fruit yield under red and yellow shade nets with pepper grown under net covers resulting in a 113% to 131% increase in total fruit yield compared to open field. In another study on tomato using pearl, red, blue and black coloured nets, Milenkovic *et al*. (2008) reported that shading increased the marketable yields of tomato by about 35% compared to non-shaded conditions. Red and pearl shade nets significantly increased the total yield which was associated with both higher fruit numbers per plant and larger fruits. The total fruit yields under the coloured shade nets were higher by 11.9-22.8%.

Investigation by Abdrabbo *et al*. (2013) on potato under net house as an adaption procedure of climate change impacts showed that using white net increased potato tuber yield per plant compared to other net colors. Research in Israel suggested that coloured net-houses may reduce temperature fluctuations and promote better physiological growth of plants (Shahak *et al*., 2004a). In studies with several crops under various coloured shade nets of the same shading factor (50 to 80% shade), it was reported that black net had higher yields than the other coloured nets. Compared with black net, red and yellow nets stimulated overall vegetative growth, while blue caused dwarfing. Grey, on the other hand, enhanced branching, yielding “bushy” plants with short branches, smaller leaves and less variegation. In cut flower crops, coloured nets also differentially affected the flowering time and quality (Oren-Shamir *et al*., 2001; Shahak *et al*., 2004a). Kong *et al*. (2013) found that at postharvest, pepper grown under pearl netting had significantly reduced water loss, decay incidence and titratable acidity and increased fruit firmness, elasticity, ascorbic acid level and antioxidant activity compared to that grown under black netting. Additionally, fruits grown under pearl netting effectively maintained postharvest fruit quality than fruits under the traditional black netting.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Site

Two experiments were conducted at the Horticulture Research and Teaching field of Egerton University, Njoro, Kenya. The field lies at latitude of $0^{o}23'$ S and longitude $35^{o}35'$ E in the Lower Highland III Agro Ecological Zone (LH3) at an altitude of ≈ 2238 m above sea level. The soils are predominantly vitric mollic andosols with a pH of 6.0 to 6.5 (Jaetzold *et al*., 2006). Temperature and rainfall data recorded for the site during the study period are presented in Table 1.

3.2 Planting Materials

French bean seeds of cultivar Source [Amiran (K) Ltd., Nairobi, Kenya] were used. 'Source' is a determinate variety and one of the most popular among the French bean growers in the country.

3.3 Agronet Covers

The agronets used are made from high-density polyethylene fully recyclable monofilament of 100 denier knitted into a mesh with 0.9 mm x 0.7 mm average pore size. They are ultraviolet protected for extended shelf life. They were obtained from A to Z Textile Mills Ltd., Arusha, Tanzania.

3.4 Experimental Design and Treatment Application

The experiment was laid out in a Randomized Complete Block Design (RCBD) with six treatments replicated four times. The treatments comprised of growing French bean under white net, blue net, yellow net, tricolour net, or grey net cover, and no net as the control. The experiment covered an area of 20.5 m by 11 m with individual blocks measuring 20.5 m by 2 m separated by a 1 meter buffer. Individual experimental units within a block measured 3 m by 2 m with an inter-plot spacing of 0.5 m. On net covered treatments, poles of 75 cm long and ≈ 5 cm thick were installed before planting to provide support for the net covers. The poles were driven 25 cm into the ground at each corner and at the center of the plot to anchor the agronets. Agronets were then mounted completely covering the plots. Once covered, the nets were pegged at each corner to minimize wind interference and nets were only opened for routine plant management and during data collection periods. The field layout was as shown in the figure 1.

Table 1: Average monthly air temperature (^{o}C) and precipitation (mm) during the two trials (July to Oct. 2015 and Nov. 2015 to Feb. 2016).

	Trial 1				Trial 2			
	July	August	September	October	November	December	January	February
Air Temperature	20.2	20.8	21.7	21.2	19.1	20.2	20.6	22.0
Precipitation	53.4	41.6	85.7	90.31	198.8	82.9	86.6	23.4

Source: Egerton University Engineering Department (2016)

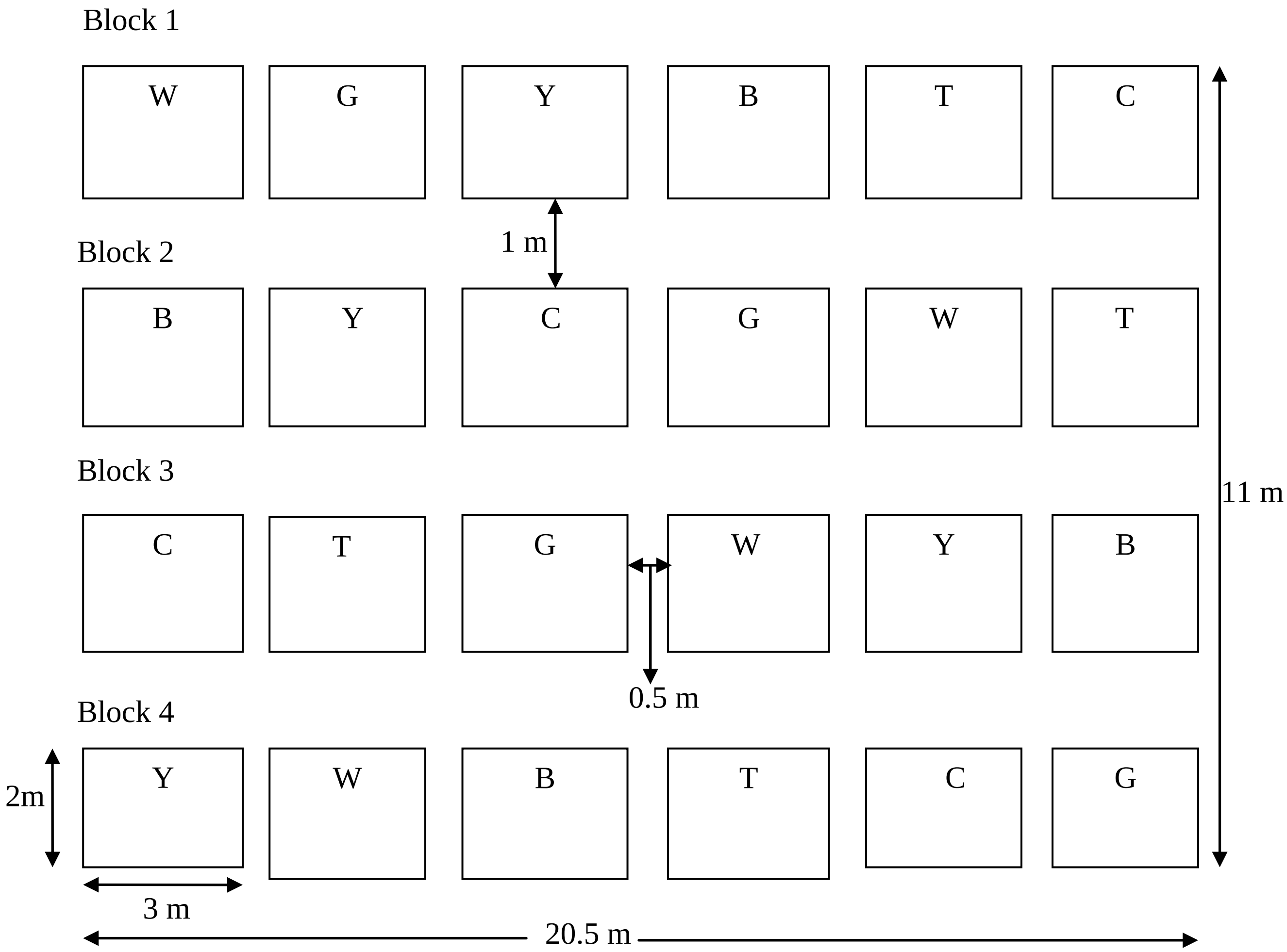


Figure 1: Experimental Field Layout

Key: W- White net, B- Blue net, Y- Yellow net, T- Tricolour net, G- Grey and C- Control (No net).

3.5 Land Preparation, Planting and Crop Maintenance

The field was manually dug using hand hoes to ≈ 20 cm depth and prepared to a fine tilth using rakes. Drills were then made 45 cm apart giving a total of five rows in each experimental unit. Diammonium phosphate [18% nitrogen (N), 46% P_2O_5] was then applied at a rate 200 kg DAP/ha (20 g/m^2 of bed) and thoroughly mixed with soil before seeding. Seeds were sown at a spacing of 10 cm within the drills giving a total of 134 plants per experimental unit (23 plants/m^2). Calcium ammonium nitrate (26% N) was applied later as a top dress at a rate of 200 kg/ha in two equal split applications; at the trifoliate leaf stage and onset of flowering as recommended by Ministry of Agriculture and Rural Development (MOARD, 2003). The first weeding was done three weeks after seedling emergence, followed by a second weeding three weeks later. Care was taken to avoid damaging the shallow roots, during weeding. Weeding was avoided when the crop got to flowering stage and when the field was wet to minimize shedding of flowers, spread of diseases and soil compaction. The crop was rain-fed with supplemental irrigation given only during periods of extended dry spells. In this case, watering was done manually using watering cans ensuring that equal amount of water was applied in each experimental unit.

3.6 Data Collection

Four plants from the inner rows of each experimental unit were randomly selected at the start of data collection and tagged for collection of data on pest counts, growth, yield and quality.

3.6.1 Environmental Data

WatchDog 2000 series Plant Growth Station data loggers model 2475 (Spectrum Technologies, Inc.) were used to collect environmental data. Each data logger was screwed 0.5m high on a wooden post at the center of each experimental unit. The Data loggers were set to collect data hourly which was averaged daily. The data was downloaded into the computer on a weekly basis. Microclimate data of interest were air temperature (^oC), Photosynthetic active radiation PAR (µmol.m^{-2}.s^{-1}) and relative humidity (%). Data on soil moisture was also determined using an external moisture sensor (WaterScout™ SM 100) connected to the port of the WatchDog Plant Growth Station as percentage volumetric water content (VWC).

3.6.2 French Bean Crop Growth and Physiological Characteristics Variables

(a) Days to First Emergence and Emergence Percentage

The number of days from sowing to first emergence of French bean in the different experimental units were counted and recorded. Thereafter, seedling numbers were counted at two day intervals for a week and progressive emergence percentages computed for each treatment using the formula by Copeland and McDonald (2001) where;

$$\%\ \text{emergence} = \frac{\text{Number of emerged seedlings}}{\text{Number of seeds sown}} \times 100$$

(b) Stomatal Conductance

Stomatal conductance was determined on three recently fully expanded leaves of each of the tagged plants using a steady state leaf porometer (SC-1; Decagon Devices, Pullman, WA, USA) on a two week interval beginning at 29 DAP. Stomatal conductance readings were taken directly from the leaf porometer and recorded in $mmol.m^{-2}sec^{-1}$.

(c) Total Chlorophyll Concentration

Chlorophyll a and b were determined in fresh leaf samples at the trifoliate leaf stage, flowering stage and podding stage. One-half gram of youngest fully expanded fresh leaves were ground in a mortar and placed in centrifuge tubes. 15 ml of an extractant, acetone- hexane mixture in a ratio of 4:5 was added into the tubes and centrifuged for 10 minutes at 4000 revolutions per minute. The supernatant was then transferred using a pipette into 25 ml volumetric flasks and the residues washed with 5mls acetone-hexane and centrifuged again for 10 minutes, filtered and made up to a final volume of 25 ml.

Pigment concentrations [in mg/g fresh weight (FW)] were calculated [based on absorbance (E) of extract at 663 and 645 nm] using the formula by Goodwin and Britton (1988):

$$\text{Chlorophyll a: } \{(10.1 \text{ x } E_{663}) - (1.01 \text{ x } E_{645})\} \text{ x V/FW}$$

$$\text{Chlorophyll b: } \{(16.4 \text{ x } E_{645}) - (2.57 \text{ x } E_{663})\} \text{ x V}\}\text{/FW}$$

(d) Collar Diameter

The stem collar diameter of each tagged plant was measured at ≈ 4 cm from the ground level on a weekly basis using a digital vernier caliper (Model 599-577-1/USA) beginning at 21 DAP to first harvest. Data obtained were used to compute the average stem collar diameter for the different treatments in millimeters (mm).

(e) Plant Height and Number of Branches

The height of the tagged plants in each experimental unit was measured in centimeters (cm) on a weekly basis using a meter ruler from the ground level to the point of growth of the main stem beginning at 21 DAP to first harvest. During each data collection date, the number of branches on each of the tagged plants were also counted and recorded as number of branches per plant (no./plant).

(f) Internode Numbers and Length

The number of internodes of the tagged plants in each experimental unit was counted on a weekly basis starting at 21 DAP to first harvest. Data obtained were recorded as number of internodes per plant. The length of each internode was also measured using a ruler and data obtained were used to compute the average internode length per plant in cm.

3.6.3 Insect Pest Counts

The major insect pests counted were black bean aphids (*Aphis fabae*), silverleaf whitefly (*Bemisia tabacci*) and bean thrips (*Megalurothrips usitatus*). The number of black bean aphids at the nymph stage, adult silverleaf whitefly and bean thrips at nymph and adult stage were counted on all the leaves of the selected plants once every two weeks beginning at 21 days after planting (DAP) and data obtained recorded as number per plant (no./plant). Counting of insect pests was done early in the morning before 8.00 am when most pests are still inactive. Hand held lenses were used to magnify the pests for ease of counting.

3.6.4 Yield

Pod numbers, pod weight and total plant biomass were used as the yield variables in this study.

(i) Pod Numbers and Pod Weight

The crop was harvested thrice per week for four weeks removing pods that had attained horticultural maturity stage beginning at 62 DAP. At each harvest, the pods harvested from each tagged plants were separately counted and the number of pods obtained recorded and later used to compute the average number of pods per plant (no./plant). The pods were then weighed in grams (gms) using a weighing balance (Advanced Technocracy Inc. Ambala). Obtained weights were recorded in grams per experimental unit and later converted to tonnes per hectare (t/ha). Thereafter, a composite sample was made from the harvest of tagged plants of each experimental unit and 100 grams of fresh pods drawn from the sample for determination of pod dry weight in gms which was later used in the computation of total plant biomass.

(ii) Total Plant Biomass

Total plant biomass was determined at three different plant growth stages; at the trifoliate leaf, flowering and podding stage using four plants from each experimental unit. The plants were dug out recovering most of the roots, cleaned and oven dried at 70^{o}C to constant weights and their dry weights determined. The data obtained were used to compute the average total biomass per plant as;

$$\text{Total Biomass (g DW/plant)} = \frac{\text{Total Plant Biomass + Total Pod Dry Weight}}{4}$$

Where; Total pod dry weight was computed by multiplying pod dry weight of the 100 grams of fresh pods drawn from the composite sample for biomass determination at each harvest multiplied by the total fresh weight obtained for the individual treatments at that harvest divided by 100.

3.6.5 Leaf Relative Water Content and Water Use Efficiency for Plant Growth

(i) Leaf Relative Water Content

Relative water content (RWC) is the appropriate measure of plant water status in terms of the physiological consequence of cellular water deficit (Sibomana *et al*., 2013). French bean leaf relative water content (LRWC) determination in this study was done on the same days as total plant biomass determination. Leaf samples used for LRWC determination were taken from each experimental unit between 6:30 and 7:30 am, sealed in plastic bags, and taken to the laboratory. The youngest fully expanded leaves were used. In the laboratory, LRWC was determined according to the method described by Barrs and Weatherley (1962), based on the following equation;

$$\text{LRWC} = [(\text{FW} - \text{DW}) / (\text{SW} - \text{DW})] \times 100$$

Where, FW is leaf fresh weight, DW is dry weight of leaves after drying at 70°C until a constant weight is achieved, and SW is the turgid weight of leaves after soaking in water for 4 h at room temperature. In other words, RWC is a ratio of the amount of water in the leaf tissue at sampling to that present when fully turgid.

(ii) Water Use Efficiency for Plant Growth

Water use efficiency for plant growth (WUE DW) was determined at the three plant growth stages (trifoliate leaf, flowering and podding stage) using the four plants from each experimental unit used to establish total plant biomass and LRWC. A period of three days after rainfall or irrigation was allowed before collecting plants for determination of plant biomass and LRWC which would be used to compute WUE DW. Water Use Efficiency for plant growth was then calculated as the ratio of total plant biomass (g DW) to leaf water content (mL g^{-1} DW) as described by (Krouma, 2010) where;

$$\text{WUE for Plant Growth} = \frac{\text{Total Plant Biomass (g DW)}}{\text{Leaf Water Content (mL g}^{-1}\text{ DW)}}$$

3.6.6 French Bean Pod Quality and Grading

At each harvest, French bean pods harvested from each experimental unit were separately sorted out as marketable and non-marketable. The non-marketable pods included the overgrown pods, off type, those damaged by pest or disease and those with physical damage or physiological defects. The weight of marketable and non-marketable pods was measured and recorded as weight per treatment and later converted to tonnes per hectare (t/ha). Thereafter, the marketable French bean pods were graded based on pod sizes as extra fine grade, fine grade and bobby beans according to the French bean grading system (HCDA, 2011) and the weight of each grade measured and recorded as weight in grams per grade per treatment. The weight of the extra fine and fine pods per treatment for each week was computed and converted into percentage by dividing with total weekly marketable weight. Pod width was determined by passing the pods through holes of 6 mm and 9 mm diameters. Extra fine grade pods had a width (determined by diameter of pod cross section) of between 4 - 6 mm and length of between 8 - 10 cm, Fine grade pod had a width of between 6 - 9 mm and length of between 10 - 17 cm and Bobby pods had a width of more than 9 mm and seeds were not too large (http://www.infonet-biovision.org).

3.7 Data Analysis

The Proc univariate procedure of SAS (Version 9.1; SAS Institute, Cary, NC) was used to check for normality and equal variances assumptions of analysis of variance (ANOVA) of the data before analysis. Data were then subjected to ANOVA using the GLM procedure of SAS at $P \leq 0.05$. Means for significant treatments, at the F test, were separated using Tukey's honestly significant difference (THSD) test at $P \leq 0.05$. The RCBD model fitted for the experiment was:

$$\mathbf{Y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}}$$

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

Where; Y_{ij} – French bean response,

μ - is the overall mean,

α_i - is the effect due to the i^{th} treatment,

β_j - is the effect due to the j^{th} block,

ε_{ij} - random error component which is normally and independently distributed about zero mean with a common variance σ^2.

CHAPTER FOUR

RESULTS

In this chapter, results obtained are presented following the order; environmental variables, crop growth and physiological characteristics variables, insect pest counts, yield variables, leaf relative water content, water use efficiency, pod quality and grading.

4.1 Effect of different Coloured Agronet Covers on Environmental Variables

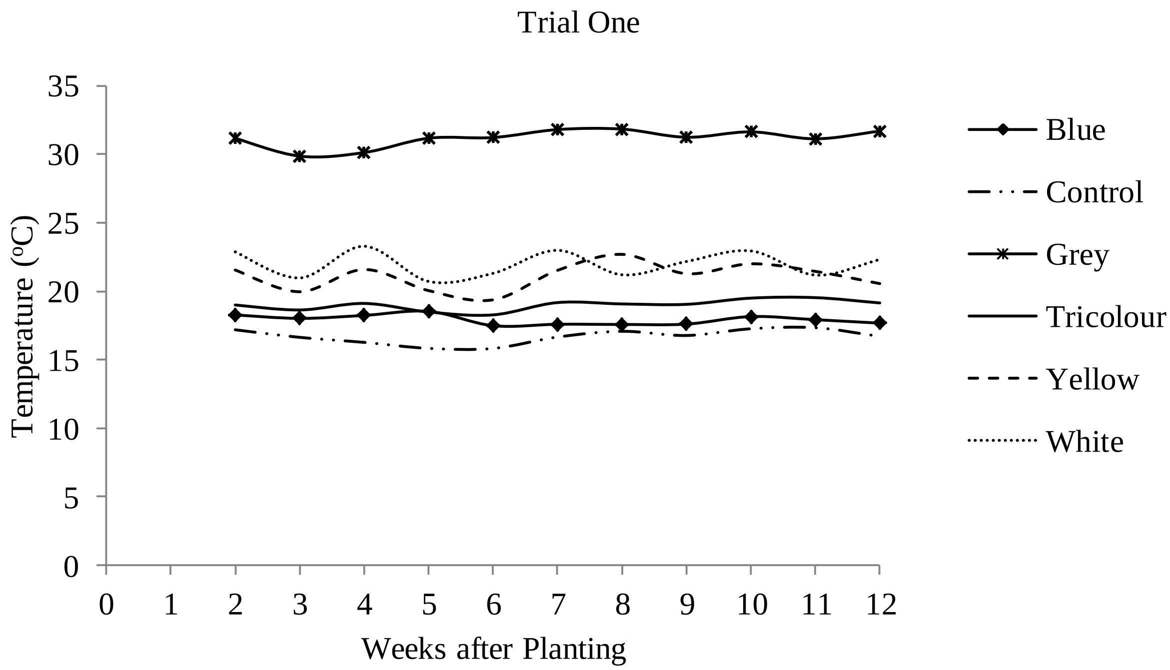
Aspects of environmental conditions studied included; air temperature, soil moisture, relative humidity and photosynthetic active radiation.

(i) Air Temperature

The use of different coloured agronet covers influenced air temperature within the French bean plant proximity. Regardless of the colour of the agronet cover used, net covered plots recorded higher temperature than the control treatment throughout the study in both trials (Fig. 2). Among the net covers, temperatures were highest under the grey net cover and lowest under the blue net covers throughout the study. In most days of data collection, temperatures were slightly higher under the white net cover than under the yellow net cover while the tricolour net cover had lower air temperature than the white and yellow net cover but slightly higher than the blue cover. The average air temperatures for grey net cover during the production period was 31.17^{o}C in trial one and 29.72^{o}C in trial two compared to 16.95^{o}C in trial one and 16.69^{o}C in trial two for the control treatment. Higher air temperatures were recorded in trial one than in trial two.

(ii) Soil Moisture

Similar to air temperature, soil moisture within the immediate vicinity of French bean plants was also influenced by the use of different coloured agronet covers. In both trials, soil moisture was higher under the different coloured agronet covers compared to under open field production throughout the study (Fig. 3). The highest soil moisture content (25.53% and 36.24% VWC in trial one and two respectively) was recorded under the blue net cover while the lowest moisture content (17.09% VWC in trial one and 19.50% VWC in trial two) was observed under the control treatment in both trials. Among the other net covers, moisture content tended to be higher under the yellow net cover compared to under the grey, tricolour and white covers during most



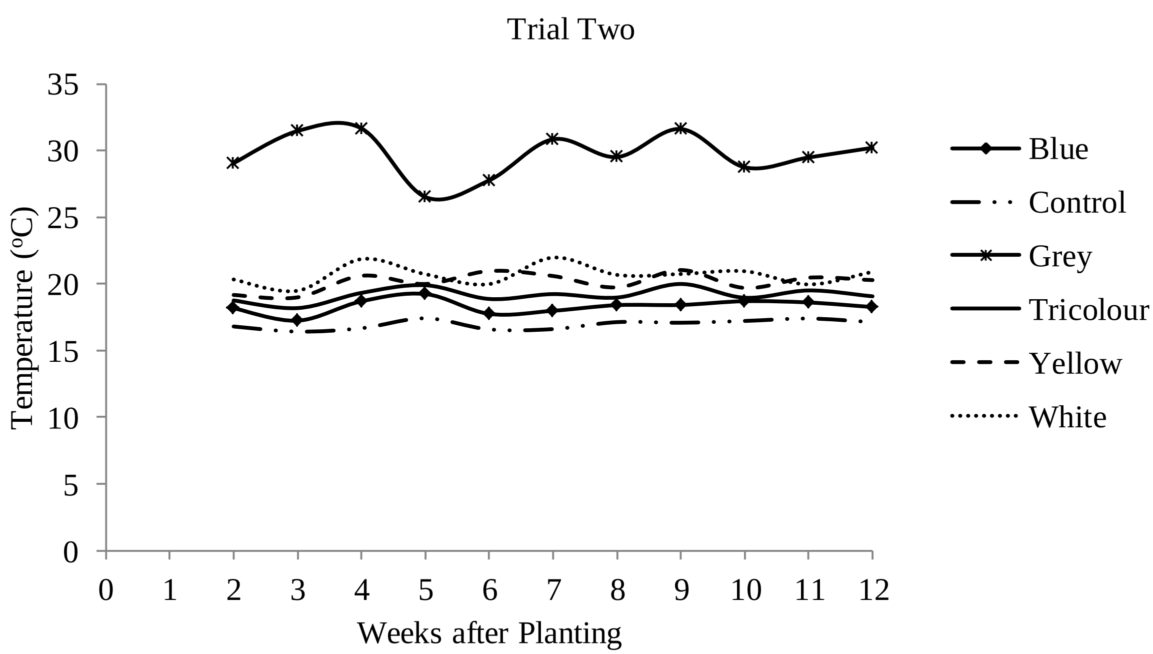
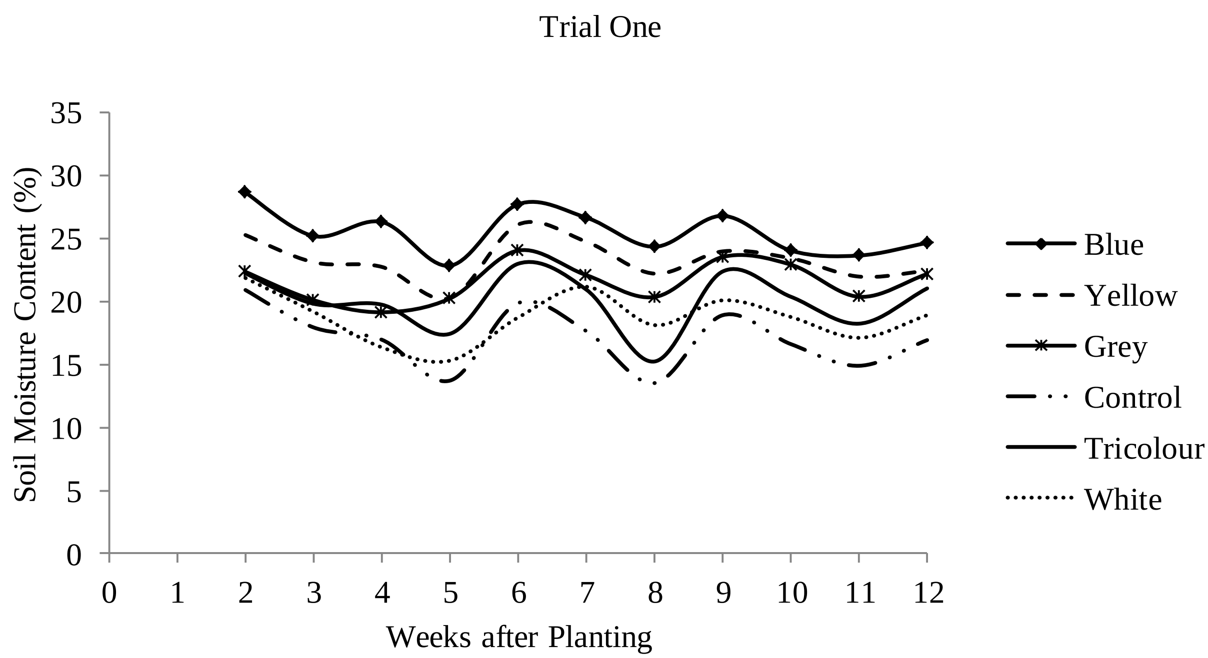


Figure 2: Effect of different coloured agronet covers on air temperature during French bean production in trial 1 (July to Oct. 2015) and trial 2 (Nov. 2015 to Feb. 2016).



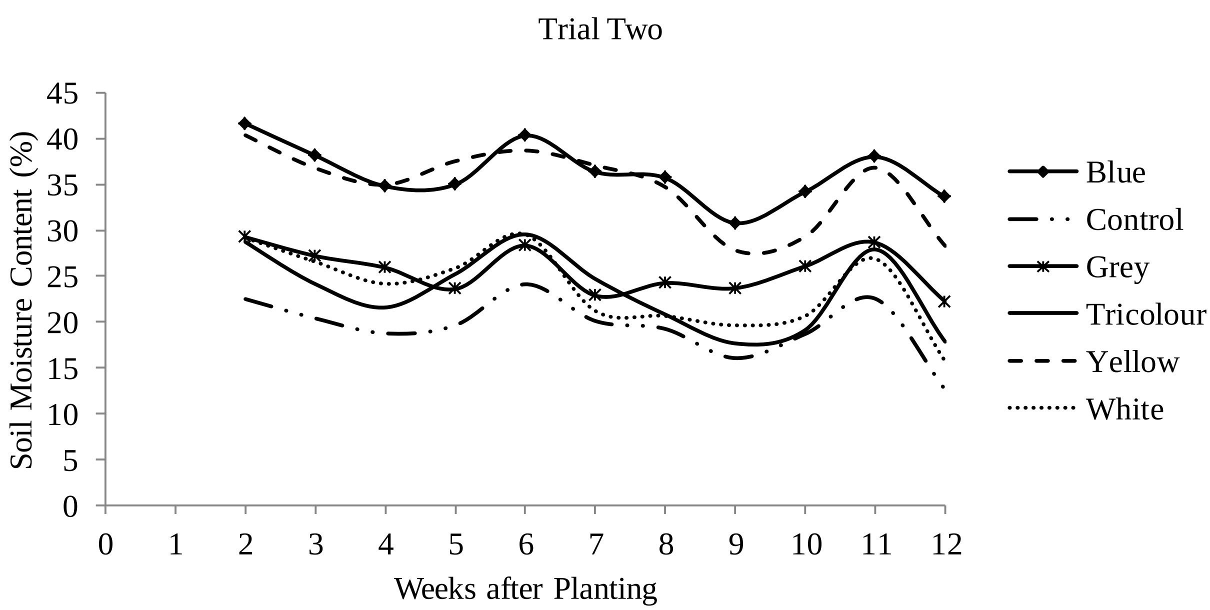


Figure 3: Effect of different coloured agronet covers on soil moisture during French bean production in trial 1 (July to Oct. 2015) and trial 2 (Nov. 2015 to Feb. 2016).

sampling dates, with no much difference between the soil moisture content recorded for this net cover with that recorded for the blue net cover in most sampling days of trial two. No much difference was observed in the soil moisture content recorded under the tricolor and white nets but soil moisture tended to be slightly higher under the grey net cover compared to that recorded for these two net covers in most sampling dates of the two trials.

(iii) Relative Humidity

Growing French bean under the different coloured agronet covers also influenced the relative humidity content within the vicinity of the plants (Fig. 4). In both trials, relative humidity tended to be highest in the immediate vicinity of French bean plants grown under the blue net cover in most data collection dates of the trials. The lowest relative humidity was on the other hand recorded under the grey net cover in all data collection dates of the two trials. Among the other treatments, relative humidity tended to be higher under the yellow and tricolor net covers with no much differences noted in the relative humidity content of the air surrounding French bean crop grown under these net covers compared to that of the crop grown under the blue net cover in some sampling dates. Growing French bean under the white net cover also resulted in higher relative humidity in the vicinity of the crop than the control treatment but the relative humidity recorded under this net cover was lower than that recorded under the yellow and tricolour net covers throughout the study.

(iv) Quantity of Light within the Photosynthetic Active Radiation (PAR) Range

Using different coloured agronet covers influenced the amount of photosynthetic active radiation (PAR) reaching the canopy of the French bean crop. The quantity of light within the PAR range differed among the different net colours with some net colours reducing the amount of PAR reaching the crop more than others (Fig. 5). In both trials, French bean plants under the control treatment received light with higher levels of PAR range of 686.04 - 816.99 $\mu mol.m^{-2}.s^{-1}$ while those under blue cover received light with lower levels of PAR range 364.08 - 453.28 $\mu mol.m^{-2}.s^{-1}$ in all data collection days. Among the other treatments, plants grown under tricolour and white net covers received higher ranges (592.97 – 728. 13 $\mu mol.m^{-2}.s^{-1}$ for tricolour and 617.76 – 713.46 $\mu mol.m^{-2}.s^{-1}$ for white net) of PAR than those grown under the yellow (481.62 – 624.30 $\mu mol.m^{-2}.s^{-1}$) and grey net cover (512.30 – 667.01 $\mu mol.m^{-2}.s^{-1}$) in both trials.

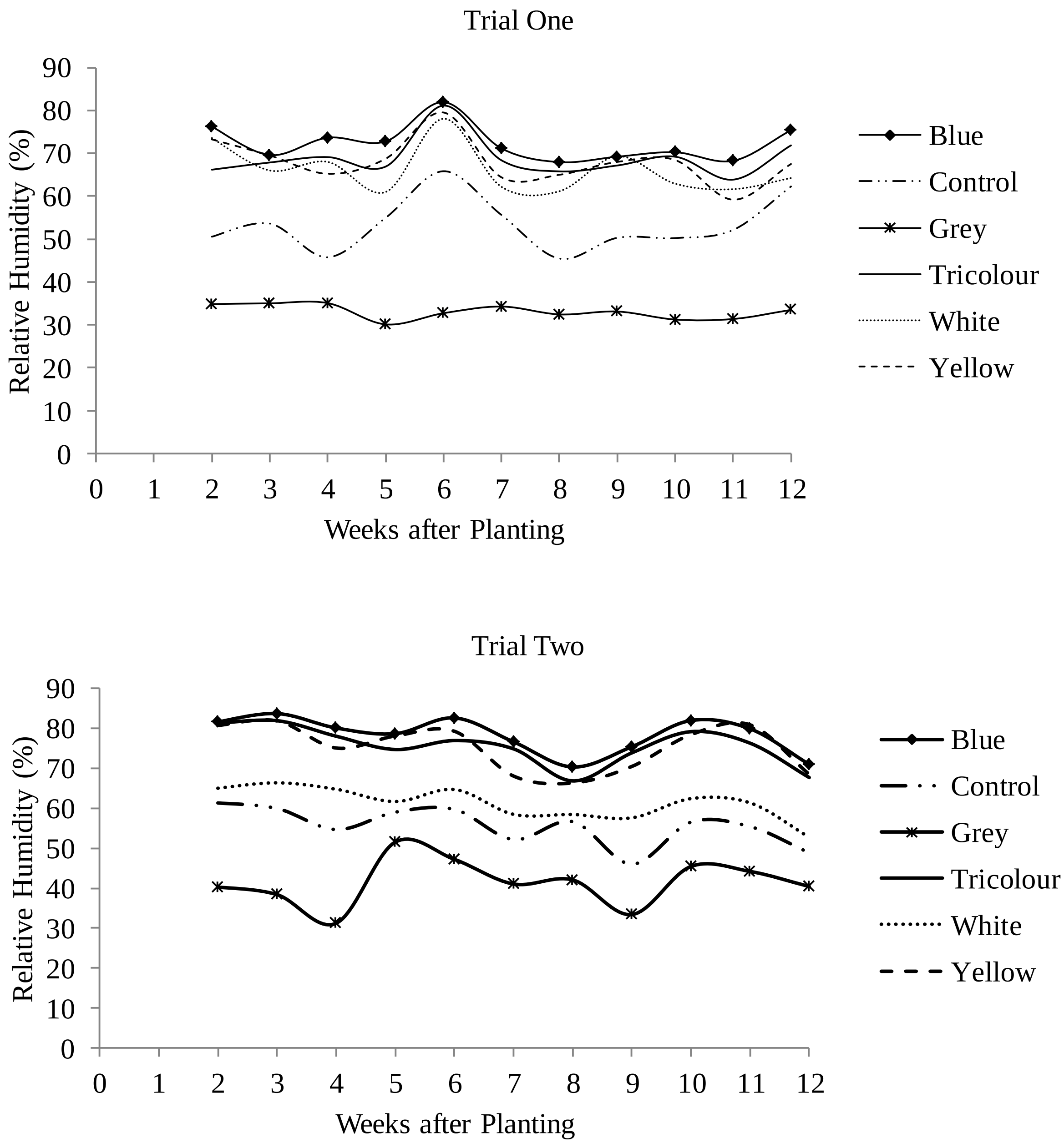
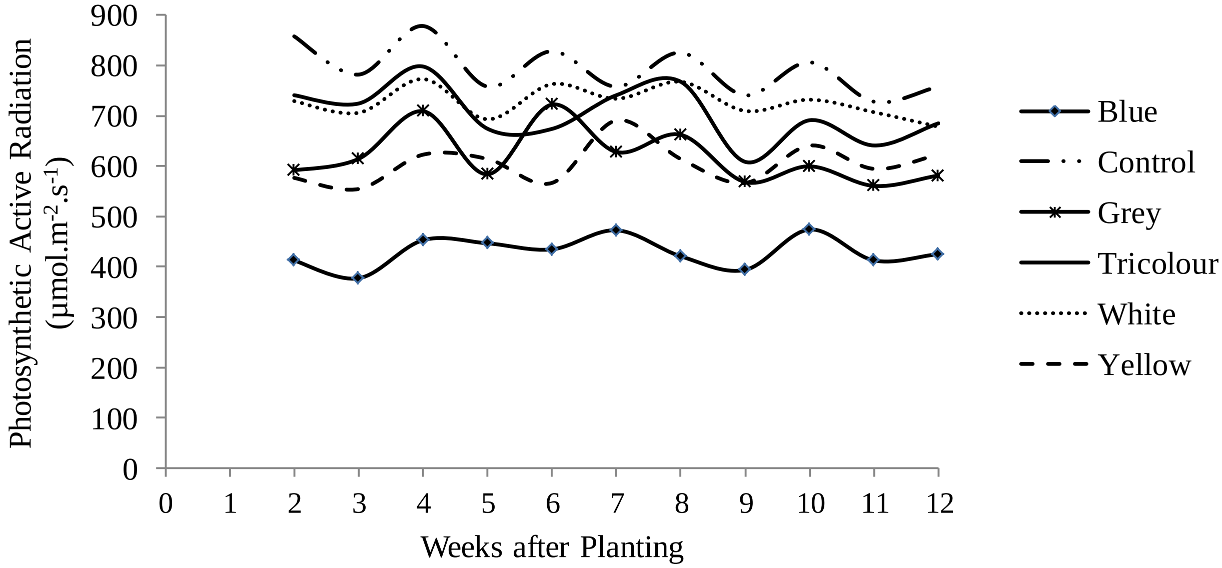


Figure 4: Effect of different coloured agronet covers on relative humidity during French bean production in trial 1 (July to Oct. 2015) and trial 2 (Nov. 2015 to Feb. 2016).

Trial One



Trial Two

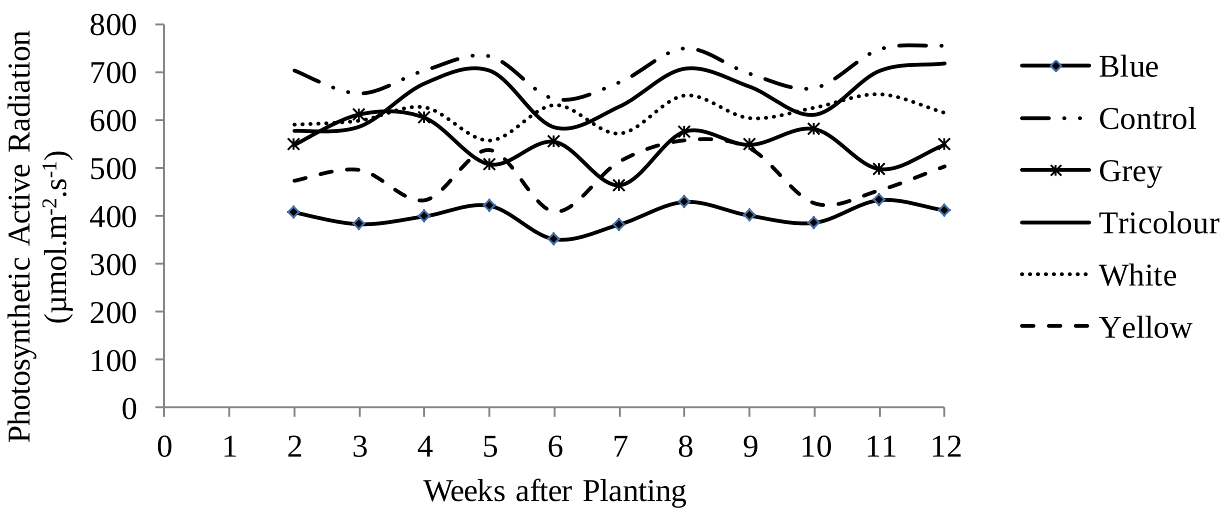


Figure 5: Effect of different coloured agronet covers on photosynthetic active radiation during French bean production in trial 1 (July to Oct. 2015) and trial 2 (Nov. 2015 to Feb. 2016).

4.2 Effects of Different Coloured Agronet Covers on Growth and Physiological Characteristics of French bean

French bean growth variables measured in this study were days to first emergence and emergence percentage, plant height, plant collar diameter, number of branches and internode number and length while leaf stomatal conductance and chlorophyll content were the only physiological characteristics measured.

(i) Days to First Emergence and Emergence Percentage

French bean seedling emergence was improved by the use of different coloured agronet covers (Fig. 6). First seedling emergence was observed at 5 DAP under the white and tricolor net covers compared to after 7 DAP under the control in trial one. Under the other net covers (yellow, blue and grey) first seedling emergence was observed at 6 DAP. At 7 DAP in this trial, the number of emerged seedling under white net cover was significantly different from those of the control treatment. During the second trial, first seedling emergence was observed at 5 DAP under all net covers compared with 6 DAP in the control treatment. Thereafter, seedling emergency proceeded at different rates for the different treatments in both trials (Table 2). During the early stages of seed emergence (up to 7 DAP), emergence rate was significantly ($P \leq 0.05$) higher under net covers than under the control treatment in both trials. Percentage emergence of seedlings remained generally lower under control treatment compared to under the different coloured agronet covers at 9 and 11 DAP, although the difference was not significant. On overall, the highest germination percentage of 75.5% in trial one and 89.1% in trial two was obtained under the blue net cover by the final day of data collection.

(ii) Plant Height

French bean plant height was generally influenced by the different coloured agronet covers at the different sampling dates in both trials (Table 3). In all data collection dates, plants grown under the yellow, grey and blue net covers were significantly ($P \leq 0.05$) taller than those of the control treatment in trial one. During this trial, the tallest plants were obtained under the yellow net cover while the shortest plants were obtained under the control treatment in all sampling dates. Plants under the grey cover tended to be taller than those under blue cover in all sampling dates except at 21 DAP. Among the other net covers, plants grown under the tricolour cover tended to have taller stems than those under white cover. Similarly, the tallest plants during the second trial were also obtained under the yellow net cover and the shortest under the control

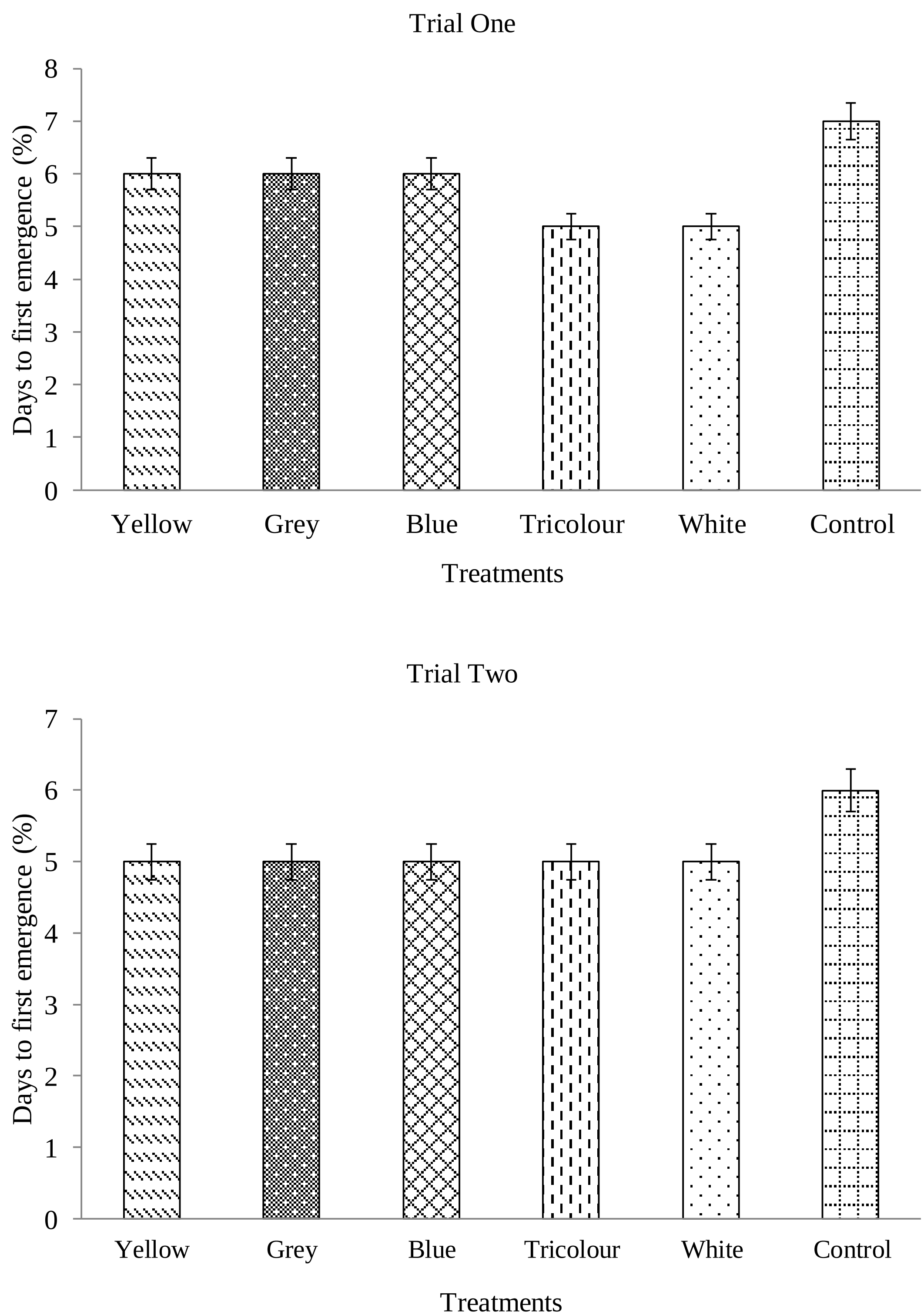


Figure 6: Effects of different coloured agronet covers on days to first emergence of French bean

Table 2: Effects of different coloured agronet covers on percent emergence of French bean

Treatment	Day after Planting			
	5	7	9	11
		TRIAL 1		
White	0.7*	44.8a	65.0	70.7
Tricolour	0.4	37.2ab	61.9	67.9
Grey	0.0	32.9ab	63.1	70.4
Yellow	0.0	33.5ab	58.5	63.5
Blue	0.0	41.0ab	68.6	75.5
Control	0.0	10.5b	55.2	66.6
		TRIAL 2		
White	6.0ab	71.4a	85.9	88.3
Tricolour	8.3a	69.3a	84.0	86.5
Grey	4.3ab	62.2a	83.1	86.6
Yellow	5.2ab	69.7a	86.7	85.9
Blue	6.7a	71.6a	87.4	89.1
Control	0.0b	34.0b	78.5	84.0

*Means followed by the same or no letters within a trial sampling date are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$. Data were subjected to arcsine transformation before analysis but values presented are original means.

Table 3: Effects of different coloured agronet covers on French bean plant height (cm)

Treatment	Days after planting					
	21	28	35	42	49	56
			TRIAL 1			
White	5.38cd*	7.78bc	12.33cd	23.03c	32.73b	38.08b
Tricolour	5.70bcd	8.59b	13.82c	25.06c	33.91b	39.65b
Grey	6.01abc	11.02a	20.28ab	34.26b	43.51ab	48.68ab
Yellow	7.19a	11.88a	24.89a	43.85a	52.93a	57.99a
Blue	6.63ab	9.69ab	16.56bc	29.61bc	39.91b	44.41b
Control	4.71d	5.80c	7.26d	11.05d	16.18c	19.74c
			TRIAL 2			
White	6.77b	10.24b	13.38b	20.37ab	25.86ab	32.26a
Tricolour	7.26b	10.89b	13.94b	20.67ab	25.82ab	32.63a
Grey	7.13b	11.33ab	13.63b	17.53bc	22.18abc	28.81a
Yellow	8.63a	13.83a	17.35a	24.17a	28.44a	35.76a
Blue	7.54ab	10.63b	13.05b	17.99bc	21.72bc	29.36a
Control	5.08c	6.61c	8.27c	13.18c	16.18c	20.20b

*Means followed by the same letters within a trial sampling date are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$.

treatment during all data collection dates. Plants grown under the tricolour, white, grey and blue net covers were also significantly taller than control plants in most sampling dates.

(iii) Plant Collar Diameter

French bean plant collar diameter was also influenced by the different coloured agronet covers at the different sampling dates (Table 4). In all data collection dates, collar diameter was higher for plants grown under the different coloured agronet covers compared to those grown in the open field in both trials. In all sampling dates, collar diameter was significantly ($P \leq 0.05$) higher under the white net cover and lowest under the control treatment. During early sampling dates up to 42 DAP collar diameter tended to be higher for plants grown under the tricolour cover compared to those under grey cover in trial one. However, beyond 42 DAP, plants under grey cover tended to have thicker stems than those under tricolour net cover.

Among the other net covers plants grown under the yellow cover tended to have thicker stems than those under blue cover. Although slightly thicker, plants under blue net cover were not significantly different in collar diameter from control plants in most sampling dates. During the second trial, plants under the white net cover also had the thickest stems with those grown under the tricolour net cover being consistently thicker than those under the grey net throughout the study. Plants grown under the grey cover tended to be thicker than those grown under the yellow cover in most sampling dates. Generally, plants grown under the blue cover had the thinnest collar diameter among the net covered treatments in all sampling dates. The white net cover treatment was significantly ($P \leq 0.05$) superior to control in all sampling dates.

(iv) Number of Branches per Plant

Growing French bean under the different coloured agronets also influenced the branching ability of the plants at the different sampling dates (Table 5). During the first trial, plants grown under the coloured agronet covers were significantly ($P \leq 0.05$) different from the control. However, beyond 42 DAP, plants under the white net cover developed more branches than those under the yellow net cover. Among the other net covers plants grown under the grey cover tended to have more branches than those under tricolour cover while blue cover had the least number of branches in most sampling dates. The lowest number of branches was recorded in plants grown under the control treatment in all sampling dates. During the second trial, plants grown under the white net cover had the highest number of branches while the control plants had the lowest number of branches in all sampling dates. Number of branches recorded for plants

Table 4: Effects of different coloured agronet covers on French bean plant collar diameter (mm)

Treatment	Days after Planting					
	21	28	35	42	49	56
			TRIAL 1			
White	2.91a*	3.46a	4.16a	5.04a	5.69a	6.21a
Tricolour	2.89a	3.46a	4.07a	5.03a	5.52a	5.98ab
Grey	2.82ab	3.40ab	4.01ab	4.76ab	5.58a	6.16a
Yellow	2.68ab	3.28ab	3.91ab	4.64ab	5.38ab	5.87ab
Blue	2.56bc	3.07bc	3.57bc	4.18bc	4.82b	5.31b
Control	2.34c	2.85c	3.24c	3.64c	3.94c	4.24c
			TRIAL 2			
White	2.59a	3.28a	4.03a	5.03a	5.79a	6.45a
Tricolour	2.43ab	3.18ab	3.93ab	4.69ab	5.44ab	6.14a
Grey	2.27bc	2.91bc	3.63abc	4.30bc	4.84bc	5.45b
Yellow	2.28bc	2.85c	3.53bc	4.21bc	4.74c	5.33b
Blue	2.15c	2.77c	3.32c	4.04c	4.54c	5.18b
Control	2.08c	2.74c	3.30c	3.93c	4.50c	5.13b

*Means followed by the same letters within a trial sampling date are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$.

Table 5: Effects of different coloured agronet covers on number of branches of French bean plant (no./plant)

Treatment	Days after Planting					
	21	28	35	42	49	56
			TRIAL 1			
White	3.50a*	5.56a	7.13a	7.69a	8.13a	8.44a
Tricolour	3.31a	5.44a	6.44a	7.38a	7.63a	8.13a
Grey	3.44a	5.81a	6.75a	7.56a	7.81a	8.13a
Yellow	3.56a	6.31a	7.25a	7.69a	7.69a	7.880a
Blue	3.06a	5.50a	6.38a	6.94a	7.31a	7.50a
Control	0.94b	2.63b	3.31b	4.31b	4.88b	5.56b
			TRIAL 2			
White	3.00a	4.88a	6.25a	7.69a	8.31a	8.94a
Tricolour	2.75a	4.50ab	5.69ab	7.19ab	7.88ab	8.56ab
Grey	2.56a	4.13ab	5.38ab	6.81ab	7.50ab	7.81ab
Yellow	2.38a	4.38ab	5.44ab	7.06ab	7.56ab	7.75ab
Blue	2.75a	3.56ab	5.00ab	6.56ab	7.06b	7.50b
Control	1.19b	3.13b	4.56b	6.19b	6.94b	7.69b

*Means followed by the same letters within a trial sampling date are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$.

under the other net covers (yellow, grey, blue and tricolour) was also higher than those of the control plants in all sampling dates although the difference was not statistically significant ($P \leq 0.05$) during most sampling dates. Among the net covered treatments, branching was least enhanced under the grey and blue net covers.

(v) Number of Internodes per Plant

The different coloured agronet covers significantly influenced the number of internodes produced by French bean plants at the early stages of plant growth as compared to control, while at flowering and podding stages, there was no significant difference during the first trial (Table 6). During the vegetative stage of the plants up to 35 DAP, plants grown under the yellow net cover tended to have the highest number of internodes while during the reproductive stages (flowering and podding), plant under the white net cover had the highest number of internodes. Throughout the trial period, plants grown in the control treatment had the lowest number of internodes. Up to 42 DAP internode numbers of plants grown under all the different coloured net covers were significantly ($P \leq 0.05$) higher than those of control plants. Beyond 42 DAP internode numbers remained higher for plants grown under net covers but the difference with those of the control plants was not significant. During the second trial, French bean internode numbers were highest for plants grown under the white net cover and lowest for control plants throughout the trial. Significantly ($P \leq 0.05$) higher internode numbers were also recorded for plants grown under the tricolor net cover compared to control plants during most sampling dates. Internode numbers recorded for the other net covers was also higher compared to those of the control plants although the difference was not significant ($P \leq 0.05$) during most sampling dates. Among the different colours of the net covers, plants under the blue net cover had the lowest number of internodes during most sampling dates.

(vi) Internode Length

Contrary to internode numbers, internode length of French bean plants was consistently highest for plants grown under the yellow net cover but also lowest for control plants during all data collection dates for trial one and two (Table 7). Plants grown under blue and grey net covers also tended to have longer internodes than those grown under white or tricolor net covers in most sampling dates of both trials. Among the net covered treatments, plants grown under the white cover tended to have the shortest internodes throughout the study.

Table 6: Effects of different coloured agronet covers on the number of internodes of French bean plant (no./plant)

Treatment	Days after planting					
	21	28	35	42	49	56
			TRIAL 1			
White	3.88ab*	5.25a	6.94a	8.00a	8.19a	8.44
Tricolour	3.75ab	5.13a	6.75a	7.75a	7.88ab	8.06
Grey	3.88ab	5.56a	6.94a	8.00a	8.00ab	8.00
Yellow	4.00a	5.63a	7.06a	7.63a	7.75ab	7.75
Blue	3.88ab	5.00a	6.50a	7.56a	7.75ab	7.75
Control	3.38b	4.13b	5.56b	6.69b	7.19b	7.69
			TRIAL 2			
White	4.06a	5.63a	6.75a	7.69ab	8.38a	8.50a
Tricolour	4.06a	5.75a	6.75a	7.75a	8.19ab	8.31ab
Grey	3.94a	5.56ab	6.38ab	7.44abc	7.88ab	8.00ab
Yellow	4.06a	5.63a	6.44ab	7.25abc	7.63b	7.88b
Blue	3.81a	5.25ab	6.13ab	7.13bc	7.63b	7.94ab
Control	3.13b	4.81b	5.94b	6.88c	7.50b	7.81b

*Means followed by the same or no letters within a trial sampling date are not significantly different according to Tukey's Honestly Significant Difference Test at P≤0.05.

Table 7: Effects of different coloured agronet covers on internode length of French bean plant (cm)

Treatment	Days after planting					
	21	28	35	42	49	56
			TRIAL 1			
White	1.40bc*	1.49c	1.78de	2.87c	4.00c	4.52c
Tricolour	1.54abc	1.68bc	2.05cd	3.23c	4.30bc	4.91bc
Grey	1.55abc	1.98ab	2.92ab	4.28b	5.43b	6.08b
Yellow	1.80a	2.11a	3.53a	5.76a	6.82a	7.48a
Blue	1.72ab	1.94ab	2.54bc	3.91bc	5.15bc	5.73bc
Control	1.39c	1.40c	1.30e	1.64d	2.23d	2.55d
			TRIAL 2			
White	1.66c	1.82b	1.98b	2.65ab	3.08ab	3.79ab
Tricolour	1.79bc	1.89b	2.07b	2.67ab	3.16ab	3.93ab
Grey	1.81bc	2.03b	2.13b	2.35bc	2.81bc	3.60b
Yellow	2.13a	2.46a	2.69a	3.33a	3.71a	4.53a
Blue	1.97ab	2.02b	2.12b	2.51bc	2.84b	3.70ab
Control	1.63c	1.38c	1.39c	1.91c	2.15c	2.58c

* Means followed by the same letters within a trial sampling date are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$.

(vii) Leaf Stomatal Conductance

French bean leaf stomatal conductance was generally influenced by the use of the different coloured agronet covers at the different sampling dates in trial 1 (Table 8). In all data collection dates, plants grown under the blue net covers had significantly higher leaf stomatal conductance than those of the control treatment in trial one. During this trial, plants grown under the grey and yellow net cover also registered significantly ($P \leq 0.05$) higher stomatal conductance than control plants in most sampling dates while stomatal conductance for plants under white and tricolour net covers was only significant at 43 DAP. Similarly, the lowest leaf stomatal conductance during the second trial was obtained under the control treatment in all data collection dates although the difference in stomatal conductance among the different treatments was not significant ($P \leq 0.05$). During this trial, leaf stomatal conductance tended to be highest on plants under blue and white net covers while those under tricolour net cover had the least leaf stomatal conductance in most sampling dates. Plants grown under the yellow net cover recorded higher leaf stomatal conductance than those under the white and grey net covers at 43 DAP and 57 DAP.

(viii) Leaf Chlorophyll Content

French bean leaf chlorophyll content data was collected only in trial two. Growing French bean under the different coloured agronet covers during this trial also influenced the leaf chlorophyll content of the plants at the different sampling dates (Table 9). Regardless of the colour of the net cover used, plants grown under the net covers had higher leaf chlorophyll content than control plants. In all data collection dates, leaf chlorophyll content (chlorophyll a and b) for plants grown under the yellow net cover was significantly ($P \leq 0.05$) higher than that of control plants. Among the net covers, highest chlorophyll a content was registered on plants grown under the yellow net cover and the least was obtained under the tricolour net cover while the other net covers recorded intermediate leaf chlorophyll a contents. On the other hand, leaf chlorophyll b content was highest under the yellow net cover at the trifoliate leaf (30 DAP) stage and under the blue net cover at flowering (50 DAP) and podding (80 DAP) stages. During all sampling stages, leaf chlorophyll b was higher for plants grown under the grey net cover than for those under the white and tricolour net covers. Among the net covers, the lowest chlorophyll b content was obtained under the white net cover in most sampling dates.

Table 8: Effects of different coloured agronet covers on stomatal conductance (mmol/m^2s) of French bean leaves

Treatment	Days after planting		
	29	43	57
	TRIAL 1		
White	138.25ab*	147.37a	97.27ab
Tricolour	136.43ab	144.98a	96.27ab
Grey	159.13a	158.17a	100.49ab
Yellow	148.36a	150.73a	101.05ab
Blue	150.74a	160.46a	121.62a
Control	94.43b	94.24b	90.07b
	TRIAL 2		
White	124.75	144.25	136.33
Tricolour	107.33	141.61	133.09
Grey	116.63	139.49	136.9
Yellow	109.89	140.56	137.98
Blue	130.31	148.85	148.19
Control	101.08	127.08	121.06

*Means followed by the same or no letters within a trial sampling date are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$.

Table 9: Effects of different coloured agronet covers on chlorophyll (mg/g) of French bean leaves

Treatment	Trifoliate stage (30 DAP)	Flowering stage (50 DAP)	Podding stage (80 DAP)
		Chlorophyll a	
White	9.94ab*	13.74a	14.25ab
Tricolour	7.80b	11.63ab	12.62b
Grey	9.20b	11.99ab	17.90a
Yellow	12.08a	13.86a	18.26a
Blue	8.85b	12.83ab	16.36a
Control	7.69b	9.49b	10.47b
		Chlorophyll b	
White	4.64bc	6.47ab	9.58a
Tricolour	4.68bc	7.16ab	10.08a
Grey	7.00a	8.54ab	10.16a
Yellow	7.90a	8.84a	10.41a
Blue	5.74ab	9.20a	12.27a
Control	3.55c	4.67b	5.78b

*Means followed by the same letters within a trial sampling date are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$.

4.3 Effects of Different Coloured Agronet Covers on French Bean Insect Pest Population

Aphids, whiteflies and thrips were the major French bean insect pests identified during this study.

(i) Aphids

Growing French bean under the different coloured agronet covers reduced the number of aphid population on the crop in both trials (Table 10). During early sampling dates up to 35 DAP aphid populations were generally low on all treatments during both trials. Beyond 35 DAP, aphid population registered a marked increase with the highest increase observed under the control treatment and the lowest increase under the blue net cover. Plants grown under the yellow and tricolour net cover had significantly ($P \leq 0.05$) lower aphid population compared with the control plants by 49 and 63 DAP in trial two while in trial one only blue net covered plants had significantly ($P \leq 0.05$) lower aphid population compared with the control plants by 63 DAP.

Aphid populations also remained low under all other net covers compared to the control treatment but with no statistical difference observed. Among the net covers, plants grown under the grey net cover had the highest population of aphid while plants under the white net cover registered higher population than those under yellow net cover but lower than those under the tricolour net cover in trial one. In the second trial, aphid population was also consistently lower on plants grown under net covers than the control plants. Among the net covers, the highest aphid population was also recorded under the grey net cover while the lowest was under the tricolour net in all data collection dates. The number of aphids observed on plants under the white net cover tended to be lower than those under the blue net cover but slightly higher than those under the yellow net cover in all sampling dates of the trial.

(ii) Whitefly

Similar to aphid, whitefly population on French bean plants was highest on open field grown plants compared to net covered plants during all data collection dates in both trials (Table 11). In most data collection dates, whitefly population for open field grown plants was significantly ($P \leq 0.05$) higher than that of net covered plants in both trials. The yellow net covered plants recorded the lowest population of whitefly while the highest population was on open field grown plants throughout the study. Among the net covered treatments, the highest population of whitefly was mostly observed on plants grown under blue net cover with intermediate population

Table 10: Effects of different coloured agronet covers on French bean aphid population (no./plant)

Treatment	Days after Planting			
	21	35	49	63
		TRIAL 1		
White	0.00*	3.22	7.72	21.53ab
Tricolour	0.00	2.94	13.47	25.39ab
Grey	0.00	9.75	23.91	37.09ab
Yellow	0.00	0.62	4.75	11.03ab
Blue	0.00	0.00	1.47	5.53b
Control	0.00	10.69	33.50	82.53a
		TRIAL 2		
White	0.00	3.94	9.44ab	31.50ab
Tricolour	0.00	0.00	1.94b	5.19b
Grey	1.13	14.00	36.31ab	107.19a
Yellow	0.00	0.69	4.50b	16.06b
Blue	0.00	4.38	19.63ab	68.06ab
Control	1.69	16.88	54.00a	120.56a

*Means followed by the same or no letters within a trial sampling date are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$. Data were subjected to square root transformation before analysis but values presented are original means.

Table 11: Effects of different coloured agronet covers on French bean whitefly population (no./plant)

Treatment	Days after Planting			
	21	35	49	63
		TRIAL 1		
White	1.56*	0.81b	0.38b	17.94ab
Tricolour	1.44	3.38b	1.06b	10.88ab
Grey	1.38	5.06b	1.75b	12.81ab
Yellow	0.56	0.50b	0.25b	5.88b
Blue	1.63	1.81b	2.06b	14.38ab
Control	2.25	22.69a	14.37a	30.56a
		TRIAL 2		
White	0.78	0.41b	1.34b	1.59b
Tricolour	0.72	0.69b	0.53b	2.25b
Grey	0.69	0.53b	0.91b	2.19b
Yellow	0.28	0.25b	0.16b	0.78b
Blue	0.81	0.98b	1.28b	2.44b
Control	1.66	5.13a	6.38a	8.22a

*Means followed by the same or no letters within a trial sampling date are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$. Data were subjected to square root transformation before analysis but values presented are original means.

recorded under the white, tricolour and grey net covers although the difference in whitefly population observed among the net covers was not statistically significant ($P \leq 0.05$) within all data collection dates of both trials. Generally, the number of whiteflies were lower in trial two than in trial one.

(iii) Thrips

Contrary to aphid and whitefly populations, growing French bean under the different coloured agronet covers resulted in an increase in the number of thrips on the French bean crop in both trials (Table 12). Generally, plants grown under the control treatment had the lowest thrip population while among the net covered plants, those grown under the yellow net cover had the lowest population of thrips in all data collection dates. During the first trial, plants grown under the tricolour net cover recorded the highest number of thrip population in most data collection dates followed by those under the white net cover. In most sampling dates during this trial, thrip population on plants under white and tricolour net covers was significantly ($P \leq 0.05$) higher than those of control plants. In trial two, the white net cover also registered the highest thrip population all through followed by the tricolour net cover and then the grey net cover. In most sampling dates, thrip population under the white, tricolour and grey net covers were significantly higher than those under the control treatment.

4.4 Effects of Different Coloured Agronet Covers on Yield of French bean

French bean yield variables measured in this study were French bean pod numbers, pod weight and total plant biomass.

(i) Pod Number

French bean pod numbers per plant were generally influenced by the different coloured agronet covers. French bean pod numbers were higher for plants grown under the different coloured agronet covers compared to those of the control treatment in both trials (Table 13). Among the net covers, plants covered with blue net cover registered the lowest number of pods in both trials. In the first trial, the highest number of pods was recorded under the yellow net cover while the lowest was under the control treatment. Pod numbers for plants grown under yellow, white and grey net covers were significantly ($P \leq 0.05$) higher than those of the control plants in this trial. Plants grown under the tricolour and blue net covers also yielded higher pod

Table 12: Effects of different coloured agronet covers on French bean thrips population (no./plant)

Treatment	Days after Planting			
	21	35	49	63
		TRIAL 1		
White	1.00ab*	24.00a	75.06ab	135.94a
Tricolour	1.31a	9.50ab	133.25a	147.31a
Grey	0.19ab	10.00ab	24.56bc	45.19b
Yellow	1.13ab	7.75ab	12.69c	19.56b
Blue	0.19ab	8.31ab	22.00bc	47.38b
Control	0.00b	0.81b	3.13c	4.06c
		TRIAL 2		
White	0.20	9.75a	19.19a	32.25a
Tricolour	0.13	4.78abc	15.22a	27.63ab
Grey	0.07	5.28ab	12.81ab	20.69b
Yellow	0.03	1.28cd	3.84c	7.22cd
Blue	0.00	2.41bcd	7.38bc	12.19c
Control	0.00	0.29d	0.65c	0.94d

*Means followed by the same or no letters within a trial sampling date are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$. Data were subjected to square root transformation before analysis but values presented are original means.

Table 13: Effects of different coloured agronet covers on French bean pod number (no./plant) and pod weight (tha^{-1})

Treatment	Pod yield	
	Total pod number (no./plant)	Total pod weight (tha^{-1})
	TRIAL 1	
White	81.56a*	25.83a
Tricolour	67.63ab	19.88ab
Grey	77.00a	23.77a
Yellow	82.81a	26.21a
Blue	63.81ab	18.63ab
Control	38.50b	10.94b
	TRIAL 2	
White	93.38a	37.09a
Tricolour	71.56ab	28.27ab
Grey	69.88ab	26.18ab
Yellow	78.19ab	32.09ab
Blue	64.25ab	24.14ab
Control	58.25b	21.84b

*Means followed by the same or no letters within a column in a given trial are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$. Data were subjected to square root transformation before analysis but values presented are original means.

numbers than the control but the difference was not statistically significant ($P \leq 0.05$). In the second trial, the white net cover registered the highest number of pods followed by the yellow net cover with the least pod numbers obtained under the control treatment. Among the other net covers, plants grown under the grey net cover recorded slightly higher numbers of pod than those grown under the tricolour net cover with the least number of pods was obtained under the blue net cover.

(ii) Pod Weight

French bean plant pod weight was also influenced by the different coloured agronet covers. The weight of pods was higher for net covered treatments than those of the control treatment in both trials (Table 13). During the first trial, the highest pod weight was obtained in plants grown under the yellow net cover followed by the white net and then the grey net cover. Among the other net covers, plants grown under the tricolour net cover tended to have higher pod weight than those under the blue net cover. Pod weight for plants grown under tricolour and blue net covers were however not significantly ($P \leq 0.05$) different from those of the control plants. During the second trial, the highest weight of pods was recorded under the white net cover followed by the yellow net cover. Among the other net covers, plants grown under the tricolour net cover registered slightly higher pod weight than those under the grey net cover and the least was recorded under the blue net cover.

(iii) Total Plant Biomass

Growing French bean plants under the different coloured agronet covers influenced the total plant biomass at the different plant growth stages. Higher plant biomass was obtained on plants grown under net covers compared to the control treatment plants in both trials (Table 14). In all sampling dates, control plants had the least total plant biomass among the treatments while the least biomass among the net covered treatments was obtained in plants grown under the blue net cover. In the first trial, the total plant biomass was significantly ($P \leq 0.05$) higher for all net covered plants than for control plants at the trifoliate and flowering stages but at podding stage there was no statistical difference between biomass of plants grown under the tricolour or blue net cover and the control plants. At trifoliate stage, plants grown under the tricolour net cover had the highest plant biomass while at flowering and podding stages, the highest plant biomass was obtained under the yellow net cover. Plants grown under the grey net cover recorded higher

Table 14: Effects of different coloured agronet covers on French bean total plant biomass (tha^{-1})

Treatment	Trifoliate stage	Flowering stage	Podding stage
		TRIAL 1	
White	0.25a*	1.66a	6.40a
Tricolour	0.28a	1.65a	5.17ab
Grey	0.25a	1.67a	6.12a
Yellow	0.26a	1.77a	7.26a
Blue	0.23a	1.38a	4.82ab
Control	0.14b	0.49b	2.70b
		TRIAL 2	
White	0.40a	1.37a	6.72a
Tricolour	0.41a	1.29a	5.70ab
Grey	0.36ab	0.94ab	5.33ab
Yellow	0.39a	1.31a	6.32a
Blue	0.27bc	0.89ab	4.55ab
Control	0.20c	0.74b	3.93b

*Means followed by the same letters within a trial sampling stage are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$.

biomass than those under tricolour net cover in most sampling dates of this trial. During the second trial, plants grown under the tricolour net cover had the highest plant biomass at the trifoliate stage while at flowering and podding stages, those under white net cover had the highest plant biomass. In all data collection dates, biomass for plants grown under the white and yellow net covers were significantly ($P \leq 0.05$) higher than of the control plants with no statistical difference in biomass noted for plants grown under the blue net cover and the control plants. In this trial plants grown under the tricolour net cover produced slightly higher biomass than those under grey net cover in all sampling dates.

4.5 Effects of Different Coloured Agronet Covers on Leaf Relative Water Content and Water Use Efficiency for Plant Growth of French Bean

French bean plant leaf relative water content (LRWC) and water use efficiency for plant growth (WUE DW) in this study were determined at three different growth stages; trifoliate leaf (30 DAP), flowering (50 DAP) and podding (80 DAP) stages.

(i) Leaf Relative Water Content

Growing French bean under net covers improved leaf relative water content of French bean plants compared to open field production. In all sampling dates, percent LRWC was higher under the different coloured net covers and lowest under the control treatment in both trials although the difference was not significant ($P \leq 0.05$) in most sampling dates (Table 15). In both trials, plants grown under blue net cover registered highest percent LRWC followed by those grown under grey net cover in most sampling dates. In trial one, plants grown under blue and yellow net covers had registered significantly ($P \leq 0.05$) higher percent leaf water content during the trifoliate phase. Among the net covered treatments, percentage LRWC for plants grown under the blue and grey net covers tended to be slightly higher than for those grown under other net covers during the flowering and podding stages. During the first trial, plants grown under the tricolour net cover recorded higher percent LRWC than those under the white net cover in most sampling dates while in the second trial white net cover grown plants had higher LRWC level than tricolour net cover grown plants at trifoliate and podding stages.

Table 15: Effects of different coloured agronet covers on leaf relative water content of French bean (%)

Treatment	Trifoliate stage	Flowering stage	Podding stage
		TRIAL 1	
White	89.71ab	90.81	82.23
Tricolour	90.44ab	91.66	80.04
Grey	91.67ab	92.08	83.89
Yellow	94.89a	90.96	83.21
Blue	95.52a	93.07	84.13
Control	86.56b	89.57	76.09
		TRIAL 2	
White	94.14	89.32	88.70
Tricolour	93.04	89.99	87.05
Grey	94.31	89.04	89.40
Yellow	94.29	88.09	89.48
Blue	94.59	90.57	88.94
Control	90.74	84.71	85.93

*Means followed by the same or no letters within a trial sampling stage are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$. Data were subjected to arcsine transformation before analysis but values presented are original means.

(ii) Water Use Efficiency for Plant Growth

French bean WUE DW measured at the different growth stages was also influenced by the use of the different coloured agronet covers. French bean plants grown under the net covers had higher WUE DW compared to control plants in both trials (Table 16). In all sampling dates for both trials, plants grown under the white net cover had significantly ($P \leq 0.05$) higher WUE DW compared to the other treatments. Plants grown under the blue net cover on the other hand had the lowest WUE DW among the net covered treatments. Although slightly higher, WUE DW values for plants grown under blue net cover were not significantly ($P \leq 0.05$) different from those of the control plants at all French bean growth stage of both trials.

In trial one, WUE DW for plants grown under the grey and yellow net covers was also significantly higher than that of the control plants in all sampling dates. During this trial, the WUE DW for plants grown under the white and tricolour net covers were significantly ($P \leq 0.05$) higher than those of plants grown under the blue net cover at the trifoliate stage. During the second trial, plants grown under the white net cover recorded significantly higher values of WUE DW than that of the control plants in all sampling dates. In most sampling dates, plants grown under the tricolour net cover also registered higher WUE DW than those under the yellow net cover. Plants grown under the grey net cover recorded slightly lower WUE DW than that of yellow covered plants. The WUE DW for plants grown under the white net cover were significantly higher from that of plants grown under the blue net cover at the trifoliate and podding stages.

4.6 Effects of Different Coloured Agronet Covers on French Bean Pod Quality and Grading

French bean pods were sorted out as marketable and non-marketable. Thereafter, the marketable French bean pods were graded based on pod sizes as extra fine, fine and bobby bean grades.

(i) Pod Quality

Growing French bean plants under the different coloured net covers improved the pod quality compared to open field production in both trials (Table 17). Regardless of the colour of the net cover used, plants grown under the net covers produced higher marketable pod weights compared to control plants. The different coloured agronet covers substantially improved marketable French bean yield by between 97.7 - 175.2% in trial one and between 28.9 – 94.4%

Table 16: Effects of different coloured agronet covers on French bean water use efficiency for plant growth (WUE DW)

Treatment	Trifoliate stage	Flowering stage	Podding stage
		TRIAL 1	
White	0.18a*	1.36a	7.75a
Tricolour	0.17a	1.29a	6.70ab
Grey	0.14ab	1.21a	7.30a
Yellow	0.15ab	1.29a	8.74a
Blue	0.12bc	1.04ab	5.88ab
Control	0.09c	0.35b	3.14b
		TRIAL 2	
White	0.28a	1.14a	8.59a
Tricolour	0.26a	1.12a	7.00abc
Grey	0.23ab	0.97ab	6.21abc
Yellow	0.25ab	0.90ab	8.01ab
Blue	0.17bc	0.75ab	5.10bc
Control	0.15c	0.61b	4.67c

*Means followed by the same letters within a trial sampling stages are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$.

Table 17: Effects of different coloured agronet covers on French bean pod quality

Treatment	Pod quality		
	Marketable (t/ha)	% increase in marketable yields	Non-marketable(t/ha)
		TRIAL 1	
White	24.02a*	168.68	1.81
Tricolour	18.21ab	103.69	1.67
Grey	22.29a	149.33	1.48
Yellow	24.60a	175.17	1.61
Blue	17.67ab	97.65	0.96
Control	8.94b		2.01
		TRIAL 2	
White	33.42a	94.42	3.67ab
Tricolour	25.78ab	49.97	2.49ab
Grey	23.00ab	33.80	3.18ab
Yellow	30.13ab	75.28	1.96b
Blue	22.15ab	28.85	1.99b
Control	17.19b		4.65a

*Means followed by the same or no letters within a column in a given trial are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$.

in trial two. The highest increase in marketable pod yield of 175.2% was obtained under the yellow net cover in the first trial and 94.4% under white net cover in the second trial while the lowest increase of 97.7 and 28.9% in trial one and two, respectively was obtained under the blue net cover. Other net covers registered intermediate increament in marketable yields with no statistical difference in marketable yields registered among the net covered treatments.

The weight of non-marketable pods was also influenced by the use of the different coloured agronet covers with higher non-marketable pod weight recorded for plants grown under the control treatment compared to net covered treatments in both trials (Table 17). Among the net covered treatments, plants grown under the white net cover recorded the highest non-marketable pod weight while the blue net cover registered the least non-marketable pod weight during the first trial. Plants grown under the tricolour, yellow and grey net covers registered intermediate values of non-marketable pod weight. In the second trial, plants grown under the yellow and blue net cover registered significantly ($P \leq 0.05$) lower non-marketable pod weight compared to control plants. Although slightly lower, non-marketable pods for plants grown under white, tricolour and grey net cover were not significantly ($P \leq 0.05$) different from those of control plants.

(ii) Pod Grades

Growing the crop under the different coloured nets also showed some effect on the rate of pod maturation judged by the differences in the proportions of pod weight under the different pod grades (Fig. 7). In both trials, more extra fine than fine grade pods were obtained for the control treatments compared to net covered treatments at each harvest. Among net covered treatments the highest amount of extra fine grade pod was obtained under the blue net cover while the white net cover registered the lowest quantity of extra fine grade pods at each harvest. On the other hand, more fine grade pods were obtained under the white net cover while the tricolour, yellow and grey net covers registered intermediate values of pods under the extra fine and fine grades.

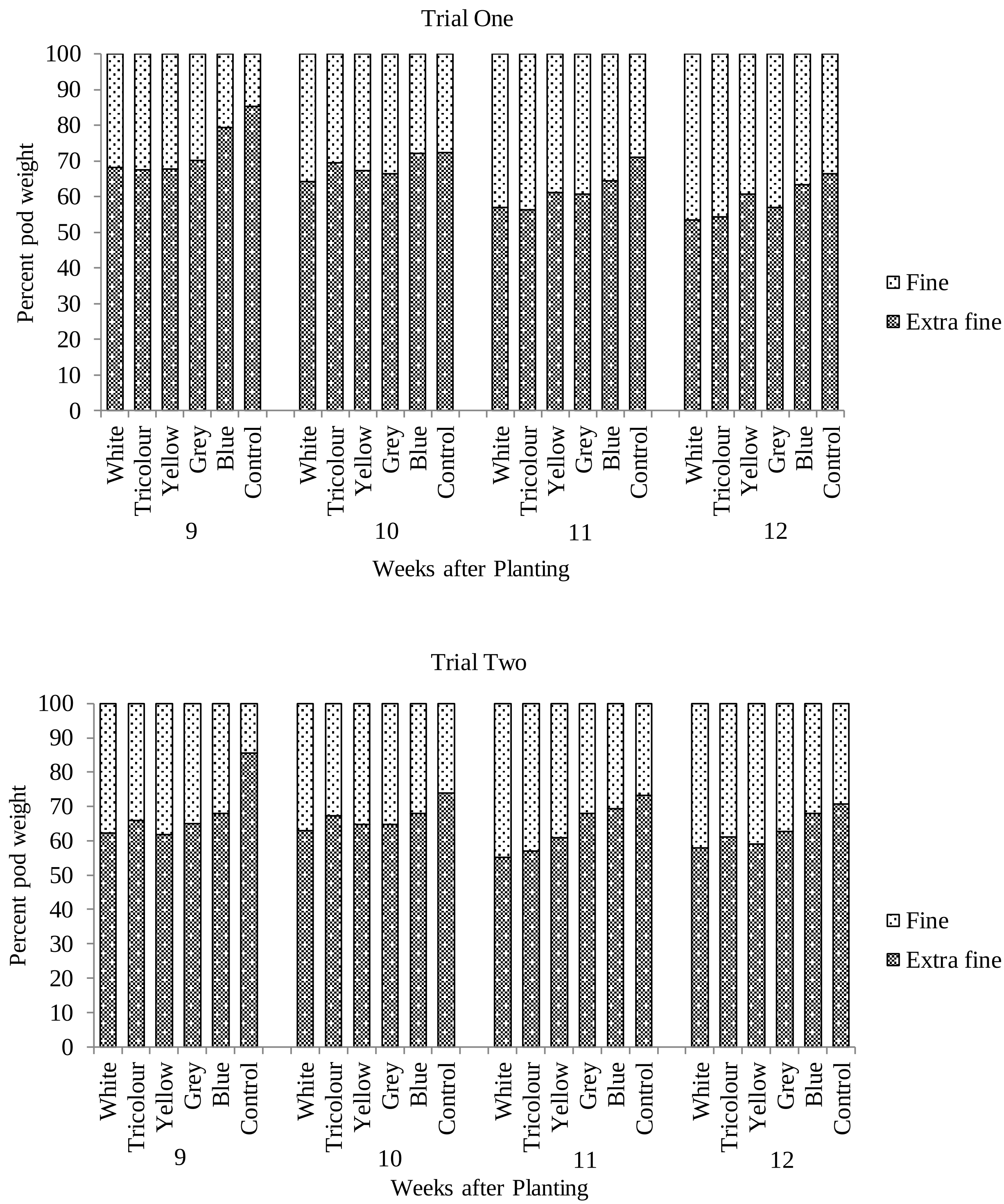


Figure 7: Effect of different coloured agronet covers on marketable pods during French bean production in trial 1 (July to Oct. 2015) and trial 2 (Nov. 2015 to Feb. 2016).

CHAPTER FIVE

DISCUSSION

In this chapter, the results presented in chapter four are discussed. The same order of presentation of results has been used in the discussion.

5.1 Effects of Different Coloured Agronet Covers on Environmental Variables

Growing French beans under the coloured agronet covers modified all crop microclimate variables under study. Air temperature, relative humidity and volumetric water content remained higher under the agronet covered treatments than in the control treatment throughout the study. On the other hand, quantity of light within the photosynthetic active radiation (PAR) was reduced by the use of net covers compared to under open field production. Coloured nets absorb spectral bands shorter, or longer than the visible light (Shahak *et al*., 2008). The existence of a screen has also 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 reducing heat loss to the surrounding atmosphere, which leads to a temperature build up (Tanny *et al*., 2003). Coloured net covers create a particular microclimate that modifies the air temperature and relative humidity during the day and night. In the current study, average air temperatures were generally higher under the grey and white net cover during most sampling dates. Higher average air temperatures observed under neutral-colour nets (white and grey) compared to coloured-colour nets (yellow and blue) in the current study is attributed to the ability of neutral-colour nets to maintain slightly higher air temperatures under the net covers during the night hours which could be as a result of the reflective nature of these net covers; a property that allows them to absorb heat very slowly but also lose it very slowly, resulting in higher average air temperature. Similar to observations of the current study, Zoratti *et al*. (2015) reported increased air temperature over the crop under white nets during the night hours and in the morning compared to open-field temperature.

Relative humidity was also higher under net covers than in the uncovered experimental units. Relative humidity is often higher under net covers than outside as a result of water vapour being transpired by the crop and reduced mixing with drier air outside the netted area even when the temperatures under the net covers are higher than outside (Elad *et al*., 2007; Stamps, 1994).

Abdrabbo *et al*. (2013) reported an increase in relative humidity in coloured nets compared with open field. In the current study, higher atmospheric humidity inside net covers could be as a result of less wind and reduced solar radiation. Coloured agronet block excess sunlight (Antignus and Ben-Yakir, 2004) and produce a humid blanket (Allen, 1975), which contribute to decreased environmental evaporative demand thus maintaining higher relative humidity content. The higher values of relative humidity recorded under the blue and yellow net cover could have been as a result of these net covers imposing a higher shading factor and greater resistance to air movement than other net covers.

Volumetric soil water content remained higher under the coloured agronet covered treatments than in the control treatment throughout the study. Soil water availability is critical to crop production and any practice which increases the available soil water supply will have a positive impact on crop production. According to Akpo *et al*. (2005) one of the potential benefits of net covers above crops is creation of a shading effect. The shading effect combined with high atmospheric water content slows the rate of evaporation and retains higher water content in the soil. In addition, shading reduces instantaneous solar radiation through net covers (Waterer *et al*., 2003), which lowers evaporation from the ground, thus maintaining higher soil moisture contents (Moreno *et al*., 2002).

The shading effect created by the coloured net covers may thus have reduced evaporation rate under the net covered areas and together with restricted air movement, resulting in higher soil water retention. The highest levels of soil moisture content was observed under the blue and yellow net cover which could have been as a result of these net covers imposing a higher shading factor and greater resistance to air movement than other net covers. Other possible explanation for high soil moisture content under net covers could be reduction in transpiration resulting in decreased soil water uptake by plants leading to increased moisture retention in the soil (Kittas *et al*., 2009; Iglesias and Alegre, 2006). This attribute of net covers presents a potential for lowering French bean crop irrigation requirement. Similar to the findings of the current study, Muleke *et al*. (2014) observed increased volumetric water content in soils under nets than in the open.

Contrary to temperature, relative humidity, and soil moisture levels, quantity of light within the PAR range that reached the French bean crop was reduced by the use of coloured net covers compared with the control in the current study. Quantity of light within the PAR range passing through the net covers differed among the different net colours with the higher levels recorded under white and tricolor net covers and the least under the blue net cover. Reduction in quantity of light within the PAR under net covers observed in the current study is attributed to the light blocking properties of the materials used. Agronet covers block light as well as reduce the light quality (Antignus and Ben-Yakir, 2004). Coloured shade nettings exhibit special optical properties that allow the control of light (Oren-Shamir *et al*., 2001) offering physical protection against excessive solar radiation and environmental changes (Shahak *et al*., 2004a,b). Reduction in PAR could also be attributed to reflection of solar radiation by the coloured net covers, which decreases solar radiation incidence inside the net covers. The obtained results are in agreement with those of Stamps (2009) who reported that nettings, regardless of color, reduce radiation reaching crops underneath. The elevated quantity of light within the PAR range in the white and tricolour net covers than other net covers may be attributed to the transparent nature of the net covers as transparent nets have been shown to scatter light transmitted through them but do not alter its spectral composition (Shahak *et al*., 2004a; Shahak, 2008).

5.2 Effects of Different Coloured Agronet Covers on Emergence of French Bean

Growing French bean under the different coloured agronet covers proved of potential benefit in French bean production. Regardless of the colour of agronet cover used, net covers advanced seedling emergence by two days and resulted in a higher percent emergence compared with the open field (control). In the current study, temperatures and moisture conditions remained higher under the coloured net covers compared to the control treatment throughout the study period. Other studies have also documented modified crop environment under net covers characterized by higher soil moisture content and air temperatures compared to open field conditions (Saidi *et al*., 2013; Gogo *et al*., 2014). Adequate moisture and warmth are necessary conditions for activation of enzymes involved in seed germination (Raven *et al*., 2005). Moisture also ensures reduced resistance for the cotyledons of developing seedling as they move through the soil to reach the surface. These arguments lend support for the early and higher emergence registered under the different coloured net covers compared to open field production observed in the current study. Similar to these findings, Muleke *et al*. (2013) observed early emergence and higher percent emergence of cabbage (*Brassica oleracea* var. *capitata*) seeds under net covered compared to open field nurseries.

Among the different coloured net covers, final percent seedling emergence was highest under the blue net and lowest under the yellow net cover. Coloured shade netting not only influence the microclimate to which the plant is exposed but also exhibit special optical properties to optimize desirable physiological responses of plants (Costa *et al*., 2010). Depending on the pigmentation of the plastic threads, coloured nets provide varying mixtures of natural unmodified light together with spectrally modified scattered light which improves light penetration into the inner canopy of plants as well as promotes specific photomorphogenetic and physiological responses in plants (Rajapakse and Shahak, 2007). Coloured shade nets absorbs spectral bands shorter, or longer than the visible light (Shahak *et al*., 2008).

Differences in the final percent emergence of seedlings observed in the current study may thus be attributed to the differences in light intensity and quality under the different coloured nets marked by differences in the amount of filtered red, far-red or blue light by the different net covers. Yellow net covers have been documented to scatter more far-red light than red light thus decreasing the R/FR ratio (Goran *et al*., 2011). On the other hand, R/FR ratio under blue net cover has been shown to be the same as under natural light (Oren-Shamir *et al*., 2001). According to Yerima *et al*. (2012) seed germination is inhibited by far-red light and stimulated by red light while the effects of blue light cannot be reversed by far-red light possibly explaining the higher and lower final emergence percentages recorded for the blue and yellow net covers, respectively under the current study.

5.3 Effects of Different Coloured Agronet Covers on French Bean Growth and Crop Physiological Characteristics

French bean plant growth in the current study was also enhanced by the use of net covers compared to open field production. Plants under net covers had more branches and internodes, longer internodes length, thicker and longer stems compared to those grown in the open. Net covers have been reported to improve crop performance as a result of modified and stabilized crop microclimate under the covers marked by lower diurnal temperature ranges and higher volumetric water content (Gogo *et al*., 2014) as well as reduced wind speed (Arthurs *et al*., 2013). Besides the general advantages associated with net covers, colored nets selectively filter solar radiation to promote specific wavelengths of light (Arthurs *et al*., 2013) and increase light scattering which influences plant branching and crop compactness (Abul-Soud *et al*., 2014). In the current study, plant growth variables were influenced differently by the different coloured net covers. Growing plants under the yellow net cover stimulated stem and internode elongation resulting in taller but slender French bean plants. Growing plants under the white and tricolour nets, on the other hand enhanced stem collar diameter and internode numbers, resulting in stout and compact plants while those under the blue net cover exhibited reduced stem collar diameter, branching and number of internodes. Longer and thin plants observed under the yellow net elicit elongation of stems at the expense of their thickness which can be attributed to reduction of R/FR ratio (Kasperbauer, 1994). Yellow net covers scatter more far-red light that penetrates into the plant canopy which stimulates internode and stem elongation (Goren *et al*., 2011).

Far-red light promotes conversion of inactive gibberellins (GA) to active forms (Rajapakse *et al*., 1999) which are potent promoters of stem elongation (Cummings *et al*., 2008) and regulate internode length in response to altered light condition (Maki *et al*., 2002). Despite having the highest internode numbers, plants under the white and tricolour (predominantly white) net covers tended to be shorter and bushy compared to plants under the other net covers which is attributable to the lower internode lengths recorded for plants under these treatments. According to Oren-Shamir *et al*. (2001), light transmitted through neutral nets (grey, Aluminet net) is the same as natural light but with increased scattering over the natural light, making the light to reach a larger volume of the plant, in a more homogenous way.

Inhibition effects of blue net on plant growth were expressed in form of reduced internode numbers, branching and collar diameter of plants. Blue net covers substantially reduce radiation reaching the plant underneath (Abul-Soud *et al*., 2014) and the lack of RF or high R/FR ratio under blue net cover have been implicated as major inducers of reduced plant growth (Oren-Shamir *et al*., 2001), possibly explaining the lower growth observed under blue net in the current study. It is possible that some of the effects of the nets are due to changes in the quality of the transmitted light, since it has been demonstrated that colored shading nets alter the quantity and quality of light that reaches the plants (Oren-Shamir *et al*., 2001; Shahak *et al*., 2004a). Plants can detect the quality, quantity and orientation of light and use it as a signal to optimize their growth and development in a given environment (Rajapakse *et al*., 1999).

Better growth under most net covers can also be attributed to improved physiological characteristics of the plants grown under net covers. Growing French bean under coloured net covers enhanced leaf stomatal conductance and chlorophyll content compared to growing the crop in the open field. Similar to these findings, Smith (2007) also reported increased stomatal conductance in blushed apple cultivars under netting compared to open-field production. At all stages of French bean growth, relative humidity remained higher under most agronet covers than under the control treatment. 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 and vice versa (Bunce, 1999). Control of leaf stomatal conductance is a crucial mechanism for plants as it is essential for both carbon dioxide acquisition and utilization in the process of photosynthesis and subsequently plant biomass production and yield (Dodd *et al*., 2004). Stomatal response to atmospheric humidity is further intensified by the effect of high wind speed, which depletes the moist boundary layer close to the leaf surface and reduces the leaf water potential. Low stomatal conductance observed in French bean plants produced in the open field in the current study could therefore have been a reaction of the plants to low relative humidity, higher wind levels and reduced soil moisture content levels resulting in stomatal closure.

Similar to observations of the current study, Gitlin *et al*. (2006) and Otieno *et al*. (2002) also reported that soil moisture reduction leads to a decline in gaseous exchange and leaf water potential. Stomatal conductance is known to be affected by factors such as carbon dioxide (CO_2) concentration, light, humidity and temperature. Although the use of coloured agronet covers generally increased stomatal conductance, differences occurred among the net covers with highest increase observed on plants under the blue net cover. The differences in stomatal conductance following the use of the different coloured net covers could be attributed to the differences in the levels of these factors under the different net covers. Highest increase in stomatal conductance observed in French bean plants under blue net cover in the current study could be attributed to the high relative humidity and soil moisture levels recorded under the blue net cover.

Higher values of chlorophyll content were also observed for plants under the different coloured net covers than for control plants at all growth stages. Leaf chlorophyll content also tended to be higher under the coloured-colour nets (blue and yellow) than under the neutral-colour nets (white, tricolor and grey). Higher leaf chlorophyll contents under coloured-colour nets may be attributed to leaf response to impaired light regime (reduced PAR) via the phytochrome system (Solomakhin and Blanke, 2008) beneath coloured-colour nets. Leaf chlorophyll synthesis depends on the genotype and phenotype, more specifically, the variety and the light transmitted by the coloured net during leaf growth. Marks and Simpson (1999) showed that increasing irradiance suppressed growth and leaf chlorophyll content of *Disanthus* and *Rhododendron*, in vitro. Increase of leaf chlorophyll content by coloured net covers has also been reported in citrus and ornamental plants (Li and Syvertsen, 2006; Stamps and Chandler, 2008). Greater leaf area and higher chlorophyll content are other common responses of plant leaves to reduced irradiance (Solomakhin and Blanke, 2008).

In the current study, leaves of French bean plants grown under the different coloured net covers were of a softer texture and had a darker green colouration. Although net-grown leaves are not directly exposed to sunlight, they produce additional chlorophyll to capture diffuse radiation to produce the carbohydrates needed for a plant to grow (Ilic *et al*., 2015). Similar results were reported by Bergquist *et al*. (2007) who observed significantly higher concentrations of total chlorophylls in baby spinach leaves under nettings. Since coloured nets have holes, in addition to translucent photoselective plastic threads, coloured net covers create mixtures of natural unmodified light, which passes through the holes together with the diffused and spectrally modified light (Shahak, 2008). According to Camejo and Torres (2001), increase in chlorophyll a and b in plants grown under net covers might be associated with the protection of photosynthetic system under net covers, due to a lesser radiation absorption at shorter wave length to improve the photosynthetic performance.

5.4 Effects of Different Coloured Agronet Covers on French Bean Insect Pest

Covering French bean with coloured agronet covers reduced populations of silverleaf whitefly and black bean aphid and increased the number of thrips compared with the control treatment. The physical barrier provided by net covers disrupts feeding and mating habits of many insect pests, thereby lowering their population (Martin *et al*., 2006). In addition, the reduction in population of aphids and whitefly could also be attributed to light scattering and diffusion by the coloured nets (Shahak *et al*., 2004a,b), which might have affected the ability of aphids and whiteflies to find their host plants besides the physical barrier provided by the netting material. Light spectrum plays an important role in aspects of insect pest behavior including navigation and orientation (Antignus and Ben-Yakir, 2004). Flying aphids and whiteflies are repelled by a high intensity of reflected light (Summers *et al*., 2004; Simmons *et al*., 2010). According to Shahak *et al*. (2009), penetration of, and infestation by thrips, aphids and whiteflies are differentially affected by photoselective nets. Preliminary studies by Ben-Yakir *et al*. (2008) and Shahak *et al*. (2009) reported that yellow shading nets have the ability to protect crops from aphids and whiteflies. In the current study, French beans grown under yellow agronet cover had lower silverleaf whitefly and aphid populations than the other agronet covers. This could be attributed to the lack of correlation between the number of pests landing on their preferred coloured nets and the number penetrating through these nets. Lower number of whiteflies recorded in trial two than trial one could be as a result of higher amount of rainfall received in trial two than in trial one.

Among the net-covered treatments in the current study, lower thrip population were recorded on plants under the yellow and blue agronet covers which could have been as a result of higher relative humidity and lower average air temperatures recorded under these net covers compared to the other net covers. Thrip numbers is significantly affected by weather variables including rainfall, temperature, relative humidity and wind (Ananthakrishnan, 1993; Kirk, 1997; Legutowska, 1997). Relatively high temperatures and dry conditions have been associated with increase in thrips population, while high relative humidity and rainfall reduce thrips population and vice versa (Hamdy and Salem, 1994).

5.5 Effects of different Coloured Agronet Covers on Yield of French Bean

Better growth of French bean plants observed under the different net covers reflected in to higher total plant biomass and pod yields per plant compared to open field production. The higher biomass and pod yield obtained under net covers compared to control plants in the current study can be associated with the better plant growth and development recorded under net covers possibly favoured by the modified microclimate under these treatments. Plants under net covers tended to be taller with thicker collar diameters and more branches depicting better biomass accumulation and providing a greater bearing surface and more stored food reserves for translocation to developing pods compared to control plants.

Proper light distribution favours photosynthesis and metabolites translocation for better plant growth (Setiawati *et al*., 2014). Temperature and moisture are important in photosynthesis during which dry matter is produced and transported to the sinks (Berry and Bjorkman, 1980) as well as in the general physiological development of any given crop (Saidi *et al*., 2013). The higher air temperatures and moisture conditions together with higher chlorophyll levels and stomatal conductance recorded under agronet covers probably favoured these processes in the French bean crop leading to the better crop performance observed for the net covered treatments. Coloured agronet on the other hand better prevent excess sunlight and retain soil moisture for proper plant growth and productivity (Ilic *et al*., 2011). Better performance observed on plants under net covers could also be attributed to improved light compensation under net covers as a result of favorable microclimatic conditions. This further supports the role light compensation and better growth can play in yield development of plants (Nangare *et al*., 2015).

5.6 Effects of Different Coloured Agronet Covers on Leaf Relative Water Content and Water Use Efficiency for Plant Growth of French Bean

Leaf Relative Water Content (LRWC) expresses in percentage, the water content of a given tissue at a given time as related to the water content at full turgor hence a useful indicator of the state of water balance of a plant (González and González-Vilar, 2001). Water Use Efficiency (WUE) on the other hand, refers to the amount of biomass produced per unit of water. In the current study, growing French bean under coloured net covers improved LRWC and WUE for plant growth of the crop compared to open field production. Net covers have been shown to maintain higher soil moisture and relative humidity content within the immediate vicinity of crops (Gogo *et al*., 2014; Muleke *et al*., 2014) besides reducing the speed of wind blowing over the plants (Shahak *et al*., 2004a). High LRWC recorded for plants under net covers could therefore have been as a result of the high soil moisture and relative humidity and reduced wind speed under the net covers. This could possibly have contributed to reduced transpiration losses as a result of thick moist boundary layer close to the leaf surface which could in turn have increased the leaf water potential leading to better plant turgor under nets compared to open field production.

The higher values of LRWC observed for plants under yellow and blue net covers, which are the treatments that recorded highest relative humidity and soil moisture in the current study further support this argument. According to Allen (1975), net covers produce a humid blanket, which contribute to decreasing environmental evaporative demand. The lower values of RWC of leaves observed from open field grown plants compared to net grown plants could be as a result of higher evaporative demand under open field. In this regard, leaves for plants grown under coloured net covers are more water conserving than for open field plants.

According to Richards *et al*. (2002), WUE for plant growth can be increased by enhancing crop yield per unit of water used. Crop productivity is determined jointly by the amount of water available and the efficiency by which the water is used by the plant (Xu and Hsiao, 2004). Crop production can be sustained by interventions able to increase WUE in order to limit yield penalties under a changing climate of increased temperatures and decreased precipitation (Parry *et al.,* 2005). Water use efficiency is generally used to express the ratio of total dry matter production to evapotranspiration and is influenced by a variety of factors, such as crop type, atmospheric environment, cultivation practices and soil conditions (Liu *et al*., 2002).

Hatfield *et al*. (2001) proposed that practices which increase water availability would lead to improved WUE. High atmospheric humidity enhances atmospheric stability suggesting a potential reduction of atmospheric water demand thereby reducing evapotranspiration and increasing leaf water potential. High leaf water potential is a prerequisite for both leaf elongation and expansion (Gardner and Ehling, 1965) and thus improving the process of photosynthesis and subsequently increasing plant biomass production and yield. Coloured agronet block excess sunlight and, maintain higher soil moisture and relative humidity content for proper plant growth and productivity (Ilic *et al*., 2011) which could have contributed to higher water use efficiencies for net grown plants compared to open field grown plants. The higher values of WUE for plant growth observed for plants under the white and yellow net covers in the current study could be attributed to increased plant biomass production and higher yield under these treatments as a result of high leaf water potential favoured by high relative humidity and soil moisture and better light distribution as a result of light scattering which favours photosynthesis and metabolites translocation.

A number of studies have demonstrated that reducing excessive irradiance may increase WUE like in apricot (Nicolás *et al*., 2005), grape and citrus species (Jifon and Syvertsen, 2003; Alarcón *et al*., 2006). Shading has also been documented to reduce water requirements and increase irrigation water use efficiency in sweet pepper (Moller and Assouline, 2007). A study by FAO (1991) also revealed considerably lower crop water requirements in greenhouses than in open fields for similar levels of production which has been attributed to the much lower evapotranspiration inside greenhouses on account of there being considerably less wind, reduced solar radiation, and higher atmospheric humidity (Montero *et al*., 1985; Fernandez *et al*., 1994). Similarly, Gent (2008) reported decreased crop water use and increased water use efficiency with shading in greenhouse-grown tomato.

5.7 Effects of Different Coloured Agronet Covers on French Bean Pod Quality and Grading

French bean grown under net covers produced more flowers and pods and had higher yield and pod quality compared with the control plants. Growing French bean under net covers substantially improved marketable yields of the crop. Marketable pod yield improved by between 97.7 - 175.2% in trial 1 and between 28.9 - 94.4% in trial 2 under the net covers compared to control plants. Better marketable yields obtained under net covers in this study can be attributed to enhanced pod production rates and reduced number of non-marketable pods due to reduced pest damage and physiological defects. Similarly, Ilic *et al*. (2011) reported higher export quality pepper fruit yield under coloured shade nets with pepper grown under the net covers resulting in a 113% to 131% increase in total fruit yield compared to open field.

Apart from total and marketable yields, the different coloured nets affected the rate of pod maturation depicted by the proportion of marketable yield represented by extra fine and fine grade pods in different ways. A higher percentage of the weight of marketable yields of French bean represented by extra fine pods was obtained under the blue net cover and control treatments indicating delayed pod maturation under these treatments compared to other treatments. On the other hand, more fine grade pods were obtained under the white and tricolour net covers indicating enhanced rate of pod maturation under these treatments compared to the other treatments. According to these findings, growing French bean under net covers and especially light coloured covers hastens the rate of French bean pod maturation which can potentially reduce the harvest interval. Similar to these observations, Shahak *et al*. (2008) recorded advanced maturation of a number of table grape cultivars under light coloured nets (pearl, white) compared to blue netting and open field growing which have now been incorporated by the growers for earliness and improved quality.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the findings of this study, the following conclusions can be made:

i). Growing French bean under the different coloured agronet covers enhances growth of the crop. Covering French bean with blue net cover results in a higher seedlings emergence. Growing the crop under white net cover results in highest growth in terms of plant collar diameter, number of branches and internode number while covering the crop with yellow net cover results in highest plant height and internode length.

ii). Covering French bean with coloured agronet covers reduces populations of silverleaf whitefly and black bean aphid but increases thrips population. Generally, growing French bean crop under yellow net cover results in highest reduction of silverleaf whitefly and black bean aphid population while growing the crop under tricolour results in highest increase in thrips population.

iii). Growing French bean under the different coloured agronet covers improves pod yield and quality of the crop. Growing the crop under white and yellow net covers results in highest pod yield. Growing the crop under blue or yellow net covers results in least number of non-marketable pods. Covering the crop with white and tricolour net covers enhances the rate of pod maturation.

iv). Covering French bean with coloured agronet covers improves LRWC and WUE for plant growth of the crop. Growing the crop under yellow and blue net covers results in plants with higher levels of LRWC while covering the crop with white and yellow net covers improves WUE for plant growth.

6.2 Recommendations

From the above conclusions, the following recommendations can be made:

i). Farmers in regions with similar climatic conditions to those of the site of the current study are advised to use a white or yellow net cover for maximum production of French bean.

ii). French bean growers are also advised to use a yellow net cover to protect French bean crop against silverleaf whitefly and black bean aphids.

iii). Studies combining the use of blue net covers early in the growing period and a white or yellow net cover soon after emergence are also recommended to see if seedling emergence and growth and yields can be better optimized.

iv). Additional studies on the subject using different cultivars of French beans, other colours and mesh size of the net covers and in different agroecological zones are recommended to further validate the results.

v). An analysis of the effect of the different colours of net covers on the sensory attributes and nutritive value of French bean pods would also be beneficial.

vi). Cost-effective studies of French bean production under net covers and open field be done to establish the economic benefits of growing French bean under net covers.

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APPENDICES

Appendix A: Published Article

Improving French Bean (*Phaseolus Vulgaris* L.) Pod Yield and Quality Through the Use of Different Coloured Agronet Covers

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Abstract

French bean (*Phaseolus vulgaris* L.) is among important vegetables in supplying proteins, vitamins, minerals and dietary fiber to humans worldwide. Its successful production in the tropics is, however, constrained by abiotic and biotic stresses as the crop is predominantly grown in open fields. Netting technology has been proved successful in protecting crops against adverse weather and insect pests. Coloured net technology is an emerging technology, which introduces additional benefits on top of the various protective functions of nettings. Two trials were conducted at the Horticulture Research and Teaching Field, Egerton University, Kenya to evaluate the effects of different coloured agronet covers on growth, pod yield and quality of French bean. A randomized complete block design (RCBD) with six treatments and four replications was used. French bean plants were grown under a white, blue, yellow, tricolour or grey net cover with open field production as the control. Variables measured included days to emergence and emergence percentage (%), stem collar diameter, plant height, number of branches and internodes, internode length and crop yield. French bean grown under the different coloured net covers showed relatively better growth and crop performance marked by more pods and higher total yields and percentage of marketable yields compared to those grown in the open field. Growing French bean under net covers hastened the rate of pod maturation more-sounder the light-coloured colour-nets. Findings of this study demonstrate the potential of coloured net covers in improving French bean pod yield and quality under tropical field conditions.

Keywords: Snap bean, Green bean, Modified environment, yield, pod quality

Appendix B: Samples of ANOVA Tables

i). Effects of different coloured agronet covers on French bean plant height ANOVA at 56 DAP

Sources	DF	Type III SS	MSE	F Value	Pr > F
			Trial 1		
Total	23	3750.57			
Block	3	106.91	35.64	1.47	0.2618
Treatment	5	3280.87	656.17	27.13	<.0001
Error	15	362.79	24.19		
Coefficient of variation = 11.87					
			Trial 2		
Total	23	886.85			
Block	3	150.04	50.01	4.54	0.0187
Treatment	5	571.56	114.31	10.38	0.0002
Error	15	165.25	11.02		
Coefficient of variation = 11.13					

ii). Effects of different coloured agronet covers on French bean plant stem collar diameter ANOVA at 56 DAP

Sources	DF	Type III SS	MSE	F Value	Pr > F
			Trial 1		
Total	23	13.64			
Block	3	0.75	0.25	2.40	0.1089
Treatment	5	11.28	2.26	21.22	<.0001
Error	15	1.59	0.11		
Coefficient of variation = 5.79					
			Trial 2		
Total	23	7.29			
Block	3	0.16	0.05	0.73	0.5522
Treatment	5	6.05	1.21	16.74	<.0001
Error	15	1.08	0.07		
Coefficient of variation = 4.79					

iii). Effects of different coloured agronet covers on French bean number of branches ANOVA at 56 DAP

Sources	DF	Type III SS	MSE	F Value	Pr > F
			Trial 1		
Total	23	27.49			
Block	3	0.61	0.20	0.62	0.6098
Treatment	5	21.96	4.39	13.40	<.0001
Error	15	4.92	0.33		
Coefficient of variation = 7.53					
			Trial 2		
Total	23	10.96			
Block	3	0.25	0.08	0.30	0.8259
Treatment	5	6.52	1.30	4.67	0.0090
Error	15	4.19	0.28		
Coefficient of variation = 6.57					

iv). Effects of different coloured agronet covers on French bean number of internodes ANOVA at 56 DAP

Sources	DF	Type III SS	MSE	F Value	Pr > F
			Trial 1		
Total	23	4.62			
Block	3	0.15	0.05	0.27	0.8471
Treatment	5	1.61	0.32	1.68	0.1990
Error	15	2.86	0.19		
Coefficient of variation = 5.50					
			Trial 2		
Total	23	3.06			
Block	3	0.49	0.16	2.23	0.1267
Treatment	5	1.48	0.30	4.07	0.0155
Error	15	1.09	0.07		
Coefficient of variation = 3.34					

v). Effects of different coloured agronet covers on French bean leaves stomatal conductance ANOVA at 57 DAP

Sources	DF	Type III SS	MSE	F Value	Pr > F
			Trial 1		
Total	23	6068.82			
Block	3	952.04	317.35	1.71	0.2087
Treatment	5	2324.94	464.99	2.50	0.776
Error	15	2791.84	186.12		
Coefficient of variation = 13.49					
			Trial 2		
Total	23	10667.41			
Block	3	6694.51	2231.50	10.25	0.0006
Treatment	5	707.19	141.44	0.65	0.6662
Error	15	3265.71	217.71		
Coefficient of variation = 10.75					

vi). Effects of different coloured agronet covers on French bean aphid population ANOVA at 63 DAP

Sources	DF	Type III SS	MSE	F Value	Pr > F
			Trial 1		
Total	23	33787.71			
Block	3	10241.23	3413.74	6.29	0.0056
Treatment	5	15409.72	3081.94	5.68	0.0039
Error	15	8136.76	542.45		
Coefficient of variation = 74.42					
			Trial 2		
Total	23	176051.10			
Block	3	56758.84	18919.61	3.91	0.0302
Treatment	5	46739.37	9347.87	1.93	0.1483
Error	15	72552.89	4836.86		
Coefficient of variation = 119.72					

vii). Effects of different coloured agronet covers on French bean whitefly population ANOVA at 63 DAP

Sources	DF	Type III SS	MSE	F Value	Pr > F
			Trial 1		
Total	23	3041.35			
Block	3	392.03	130.68	1.60	0.2321
Treatment	5	1421.15	284.23	3.47	0.0278
Error	15	1228.17	81.88		
Coefficient of variation = 58.73					
			Trial 2		
Total	23	251.61			
Block	3	29.07	9.69	1.82	0.1875
Treatment	5	142.51	28.50	5.34	0.0051
Error	15	80.03	5.34		
Coefficient of variation = 79.33					

viii). Effects of different coloured agronet covers on French bean pod number (no./plant) ANOVA

Sources	DF	Type III SS	MSE	F Value	Pr > F
			Trial 1		
Total	23	12049.87			
Block	3	2201.90	733.97	2.52	0.0972
Treatment	5	5481.79	1096.36	3.77	0.0208
Error	15	4366.17	291.08		
Coefficient of variation = 24.89					
			Trial 2		
Total	23	6522.33			
Block	3	558.38	186.13	0.94	0.4468
Treatment	5	2987.86	597.57	3.01	0.0445
Error	15	2976.09	198.41		
Coefficient of variation = 19.41					

ix). Effects of different coloured agronet covers on French bean total pod weight (gm/plant) ANOVA

Sources	DF	Type III SS	MSE	F Value	Pr > F
			Trial 1		
Total	23	26850.57			
Block	3	4036.17	1345.39	2.24	0.1254
Treatment	5	13814.46	2762.89	4.60	0.0096
Error	15	8999.94	600.00		
Coefficient of variation = 26.12					
			Trial 2		
Total	23	25275.34			
Block	3	853.88	284.63	0.36	0.7825
Treatment	5	12572.77	2514.55	3.18	0.0372
Error	15	11848.69	789.91		
Coefficient of variation = 22.09					

x). Effects of different coloured agronet covers on French bean marketable pod weight (gm/plant) ANOVA

Sources	DF	Type III SS	MSE	F Value	Pr > F
			Trial 1		
Total	23	24680.57			
Block	3	3479.91	1159.97	2.35	0.1131
Treatment	5	13811.25	2762.25	5.61	0.0041
Error	15	7389.41	492.63		
Coefficient of variation = 25.57					
			Trial 2		
Total	23	28105.03			
Block	3	1815.00	605.00	0.76	0.5354
Treatment	5	14302.85	2860.57	3.58	0.0249
Error	15	11987.18	799.15		
Coefficient of variation = 25.03					

xi). Effects of different coloured agronet covers on French bean total plant biomass (gm/plant) ANOVA at 80 DAP

Sources	DF	Type III SS	MSE	F Value	Pr > F
			Trial 1		
Total	23	2080.08			
Block	3	483.11	161.04	4.20	0.0241
Treatment	5	1022.05	204.41	5.33	0.0052
Error	15	574.92	38.33		
Coefficient of variation = 25.42					
			Trial 2		
Total	23	1054.07			
Block	3	188.56	62.85	3.35	0.0475
Treatment	5	584.08	116.82	6.23	0.0026
Error	15	281.43	18.76		
Coefficient of variation = 17.46					

xii). Effects of different coloured agronet covers on French bean water use efficiency ANOVA at 80 DAP

Sources	DF	Type III SS	MSE	F Value	Pr > F
			Trial 1		
Total	23	150.42			
Block	3	35.94	11.98	4.61	0.0178
Treatment	5	75.48	15.10	5.81	0.0035
Error	15	39.00	2.60		
Coefficient of variation = 24.49					
			Trial 2		
Total	23	86.88			
Block	3	13.07	4.36	2.64	0.0877
Treatment	5	49.02	9.80	5.93	0.0032
Error	15	24.79	1.65		
Coefficient of variation = 19.49					