INTEGRATED APPROACH TO NEMATODE (*Meloidogyne spp*) MANAGEMENT AND CARBON DIOXIDE ENRICHMENT FOR FIELD GROWN TOMATO (*Solanum lycopersicum* L.)

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented before in this University or any other for the award of a degree.

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Recommendation

This thesis has been submitted with our approval as University supervisors.

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DEDICATION

This work is dedicated to my loving and caring wife, Blessing Mueni Ngelenzi, and our children: Bob and Archie Ngelenzi, who have been and will always be my comforters and the source of my strength. To my father Bob M. Mutua, late mum Teresia Lucia Bob, brothers, sisters, relatives and friends, with all my love and that of my Heavenly Father.

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) production is major source of income, creation of employment as well as improving food security. The objective of the study was to come up with an integrated approach for managing nematode (*Meloidogyne spp*) and carbon dioxide (CO_2) enrichment for field grown tomato, conducted at Egerton (0º23′ S; 35º35′ E), Kenya. The experiment was a 2 × 3 × 2 factorial arranged in a Randomized Complete Block Design (RCBD). The factors under study were agronet cover at 2 levels (net and no net cover), fresh organic manure at 3 levels (cow dung, goat dung and no organic manure) and cropping regime at 2 levels (tomato intercropped with slender leaf (*Crotalaria brevidens* var. *Brevidens* Benth.) and monocrop tomato). Use of the agronet cover, fresh organic manure and slender leaf intercrop resulted in higher CO_2 concentration within the tomato plant vicinity, showed suppressive effect on nematode population and significantly improved tomato growth and yield when used alone and in combinations compared to the control treatment (monocrop tomato grown in the open with no fresh manure applied). Using agronet cover, fresh organic manure and slender leaf intercrop alone or in combination resulted in a 23.5% to 86.3% reduction in nematode population in trial 1 and a 33.9% to 89.3% reduction in experiment 2, a 59.1% to 78.9% reduction in number of root galls in trial 1 and a 56.3% to 77.7% reduction in trial 2 and 19.7% to 145.5% increase in fresh fruit weight in trial 1 and 23.6% to 90.3% increase in trial 2 compared to the control treatment. Among the treatments, the combination of agronet cover, goat dung and slender leaf intercrop resulted in the highest CO_2 concentration within the tomato crop vicinity, highest reduction in nematode population, highest increase in fruit yield and better postharvest quality of tomato fruit. Findings of this study demonstrate integrated use of agronet cover, fresh organic manure and slender leaf intercrop as a viable alternative method for the management of tomato root-knot nematode and enhanced CO_2 levels in the immediate crop environment of open field grown tomato leading to improved growth, fruit yield and quality.

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LIST OF ABBREVIATIONS AND ACRONYMS

AfDB	-	African Development Bank
ANOVA	-	Analysis of Variance
FAO	-	Food and Agriculture Organization of the United Nations
HCDA	-	Horticultural Crops Development Authority
KARI	-	Kenya Agricultural Research Institute
LRWC	-	Leaf Relative water content
MOARD	-	Ministry of Agriculture and Rural Development
RWC	-	Relative Water Content
TA	-	Titratable Acidity
TSS	-	Total Soluble Solids

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Tomato (*Solanum lycopersicum* L.) is a popular and extensively cultivated vegetable worldwide (Rothan *et al*., 2019). It is grown either in open field or under greenhouse conditions. Tomato yield globally in 2018 was estimated at 182, 256, 458 tonnes, accounting for 16.74% of world vegetable production (FAO, 2019). The crop is consumed by most families as a source of vitamins A and C and lycopene (Asante *et al*., 2013). In the year 2018, Africa's average tomato yield stood at 16.08 tonnes/ha, which fell way below the world average yield of 38.27 tonnes/ha for that year (FAO, 2019). Kenya was amongst the leading producers of tomato in sub-Saharan Africa, producing 599,458 tonnes out of Africa's total yield of 20.8 million metric tonnes in 2018 (FAO, 2019). During the same year, Kenya's average yield was 21.21 tonnes/ha with the comparable low yields attributed to various challenges including abiotic and biotic constraints.

Tomato production can be improved by increasing output per unit area of land or by putting more land under production. Arable land in sub-Saharan Africa has, however been declining over the years especially in the high rainfall areas due to rapid population growth (Naab *et al*., 2013). Food security amid scarcity of arable land could thus be achieved through intensification as a way of maximizing productivity per unit area of available arable land. For this to be achieved optimum management of resources such as water, light, temperature, nutrients and carbon dioxide (CO_2) concentration need to be enhanced (Atwell *et al*., 1999). Moreover, tomato productivity is limited by several biotic constraints such as root-knot nematodes (*Meloidogyne spp*), which is common particularly in tropical and subtropical countries (Sikora & Fernandez, 2005). Root-knot nematodes can cause up to 80% yield losses especially in heavily infested crop fields (Kaskavalci, 2007). The life cycle of 6 to 8 weeks allows root-knot nematodes to thrive and build up quickly before the crop reach especially in presence of an appropriate host crop (Bello *et al*., 2014; Shurtleff & Averre 2000). Control of root-knot nematodes is difficult since the pathogen is soil-borne with a wide host range and usually attacks the underground parts of the plant (Sikora & Fernandez, 2005).

Currently, the primary control measures employed against root-knot nematodes are nematicides as a pre-plant fumigation of soil and crop rotation (Seid *et al*., 2015). Although crop rotation can be an effective method of managing root-knot nematode, it is not feasible among smallholder crop production systems due to limited land resource. Nematicides on the other hand are effective and respond quickly but are now being reevaluated with reverence to their effects on the environment and human health as well as the high cost (Idorenyin & Ugwuoke, 2010). There is therefore need for development of alternative sustainable management strategies for the pest that are ecofriendly and relatively affordable to smallholder tomato growers. Alternative strategies for control of root-knot nematodes such as heat treatment, soil solarization, crop rotation, mixed planting and application of organic soil amendments of crop and/or animal origin (Singh & Khurma, 2007) that do not pollute the environment have been emphasized to researchers, farmers and scientists (Mashela *et al*., 2008). Studies have revealed that main plants can be protected against root-knot nematode infestation when grown with intercrop plants with nematicidal or nematostatic properties (Bello *et al*., 2014).

Intercropping refers to spatially diverse growing of crop species in the same field, usually by growing of one plant species adjacent to another plant species (Wang *et al*., 2002) for cultural gains which includes reduction of pests (Kuepper & Dodson, 2001). Intercrop crops regulates insect pests by reducing pest development and establishment and/or by enhancing natural enemies capable of killing the insect pest. Slender leaf (*Crotalaria brevidens* var. *brevidens* Benth.) belongs to family Fabaceae and its growth behaviors vary from shrubs to herbs. The genus is common in the tropics and subtropics, with the highest number of species being found in Africa. It possesses many characteristics of a cover crop, being a poor or non-host for a great group of insect pests and pathogens, compete with weeds, growing vigorously, performing symbiosis with rhizobium in the rhizosphere to fix nitrogen, and being a green manure.

Use of organic manure has also been shown to reduce negative effects of soil borne pests like root-knot nematode on host crop with a resultant increase on growth and yield of the crop (Abolusoro & Abolusoro, 2012). Amendments such as organic manure affect the dynamics of soil borne pathogens by promoting antagonistic soil organisms, stimulating the competitive status of the non-pathogenic organisms, or by direct toxic effects on soil borne pathogens during decomposition (Bailey & Lazarovits, 2003; Bonamoni *et al*., 2010). Predatory nematodes tend to be higher in organic amended soil thus suppressing parasitic nematodes in the soil (Summer, 2011). Composted organic manure are stable and mineralize gradually releasing low concentrations of toxic nematicidal compounds (Widmer & Abawi, 2002). Raw organic manures can be more efficient than composted organic manures as toxic compounds can quickly build up to reach toxicity threshold level for root-knot nematodes (Nahar *et al*., 2006). Beside organic soil amendments showing the potential in pest management, they can also serve as source of carbon dioxide (CO_2) enrichment in a crop production system. According to Mapanda *et al*. (2011) applications of organic manure in the soil triggers emissions of CO_2. Type and amount of organic manure used determine the volume of soil CO_2 being emitted (Diacono & Montemurro, 2010), as well as the amount of carbon present in that soil (Li *et al*., 2013). Carbon dioxide enrichment result in increased photosynthetic efficiency (Drake *et al*., 1997; Long *et al*., 2004), which increases the photoassimilate supply resulting to higher dry mass and yield production.

Carbon dioxide enrichment under open field production has not been achieved. Carbon dioxide enrichment and other environmental manipulations during crop production are mostly feasible under greenhouse production. Adoption of greenhouse production by small scale farmers has however, been slow, especially in developing countries such as Kenya due to the high costs involved in purchase and installation of the structures (Jadhav & Rosentrater, 2017). The use of net covers in crop production offers a cheaper and less energy consuming technology than greenhouses (Shahak, 2008). Net covers create a barrier for free exchange of gases within and outside the net (Harmanto *et al*., 2006). Changes on the local microclimate under net covers modify CO_2 concentration and assimilation consequently influencing crop growth and development (Kittas *et al*., 2012). Besides, net covers have the ability to minimize other abiotic and biotic stresses, which affect crop production and subsequent quality of that produce (Rajasekar *et al*., 2013). Netting technology has regularly been used to protect tomato crops from extreme solar radiation, provide shelter to plants against strong wind and hail stone (Shahak, 2014) and effectively reduce insect pest pressure (Gogo *et al*., 2012).

Integrated Crop Management (ICM) approaches have been established for many crops that have led to reduction in pesticide usage, increased crop yields and economic value, and lower risks for farm management in order to reduce variation in the pest problem severity (Dent, 1995; Koul *et al*., 2004). Further improvement of such programs will promote their wide-spread applicability and improve on the performance of crop production systems. Integrating intercropping, fresh organic manure sources and agronet cover in tomato production has the potential to offer a feasible alternative management strategy for root-knot nematodes and CO_2 concentration in the immediate crop environment leading to improved tomato fruit yield and quality.

1.2 Statement of the Problem

Increasing crop productivity is presently a main challenge towards meeting food requirements of the growing population as arable land sizes continue to decline amid population growth. This situation is expected to worsen in future, hence need to increase crop productivity per unit area of arable land in order to achieve food security amid the scarcity of arable land. Although tomato is vital for food and cash crop for many small holders in Kenya, most growers are not able to realize higher yields and quality fruits from their small holdings due to various biotic and abiotic constraints. As low as 7 tonnes $hectare^{-1}$ has been recorded in the country compared to average of 75 tonnes $hectare^{-1}$ in developed countries. Nematode is amongst the major biotic constraints to tomato production and can cause yield loss of up to 80%. Currently many growers have mostly relied on the use of nematicides for nematode control in order to increase yield. Although use of chemicals is effective and eliminate insect pest quickly, they are being reevaluated with reverence to being hazardous to the environment and human health besides being too expensive for most small-scale tomato growers. Crop rotation which would have been an alternative method of managing nematodes is currently not feasible within small holder crop production systems due to limited land resource which leaves farmers with limited options for nematode management. There is evidence from other areas of the ability of intercropping and organic soil amendment to control nematodes, but their role under tropical conditions is yet to be established. Yield increase can also be achieved through proper management of abiotic factors including CO_2 levels. Carbon dioxide enrichment has been achieved under greenhouse production but it has not been possible under open field production. While smallholder farmers in the tropics and sub-tropics annually generate large volumes of organic manure which release substantial amount of CO_2 during decomposition, use of such CO_2 in improving crop performance is still limited under our farming systems which are predominantly open field based.

1.3 Objectives

1.3.1 General Objective

To contribute towards enhanced tomato yield and quality by providing different nematode management and CO_2 enrichment strategies for open field production systems.

1.3.2 Specific Objectives

i. To determine the effects of cropping regime, fresh organic manure sources and agronet cover on the CO_2 concentration in the canopy of field grown tomato.

ii. To determine the effects of cropping regime, fresh organic manure sources and agronet cover on nematode population in tomato.

iii. To determine the effects of cropping regime, fresh organic manure sources and agronet cover on tomato performance and quality.

1.4 Hypotheses

i). Cropping regime, fresh organic manure sources and agronet cover have no effect on the CO_2 concentration of the immediate tomato crop environment.

ii). Cropping regime, fresh organic manure sources and agronet cover have no effect on nematode population during tomato production.

iii). Cropping regime, fresh organic manure sources and agronet cover have no effect on tomato performance and quality.

1.5 Justification of the Study

Tomato growing in Kenya is a major source of income for smallholder farmers, creates employment, earns foreign exchange and improves food security. Its productivity per unit area has however remained low especially among smallholders who comprise the majority of tomato growers in the country. Production per unit area of land can be maximized through proper cultural practices and management of major pests of tomato among them being root-knot nematodes. Nematodes are capable of causing as high as 80% yield loss (Kaskavalci, 2007; Sikora & Fernandez, 2005). At present, the key control measures used against root-knot nematodes are synthetic chemicals and crop rotation. Synthetic nematicides are effective but are presently being reassessed with reverence to their effects on the environment and human health. Although crop rotation can be an effective method of controlling plant parasitic nematodes, it is not feasible among smallholder crop production systems due to limited land resource. Studies have revealed that host plants can be protected against root-knot nematode attack by intercropping with plants with nematicidal or nematostatic properties and organic manure. Less attention has, however been paid on how intercropping with such plants and fresh organic manure can be used for pest management, especially for management of root-knot nematodes and enhancement of crop performance in our local agricultural ecosystems, yet nematodes have continued to be a major pest for many crops in the country. There is therefore need for development of alternative sustainable nematode management strategies that are relatively affordable to smallholder tomato growers and are environmentally friendly.

Crop productivity is also limited by plant capacity to exploit sufficient carbon during their life cycle. To increase CO_2 concentration to crops, various strategies have been used under greenhouse mostly in developed countries. Nevertheless, these measures have limitations such as being expensive and difficult to operate, besides the need for a greenhouse cover which is also costly for smallholder farmers to afford. This makes such technologies inadaptable for open field production situation. Agronet covers are affordable to small scale farmers and due to their barrier effect have ability to manipulate gaseous exchange in the crop environment. By creating a barrier, there is potential for using net cover in enhancing CO_2 concentration level in the air around the crop canopy but has not been practiced. Knowledge on use agronet has led to stabilization of air temperatures, increase humidity, improved water content as well as reducing sun light reaching the plant. To maximize on the positive effect of net technology on crop yield and quality, further improvement on its applicability through combining it with other crop management practices stand to benefit small scale farmers in improving tomato productivity. The use of agronet cover and fresh organic manure in tomato production could provide affordable technologies for minimizing nematode attack and manipulating CO_2 concentration of the immediate plant environment thus improving farmers' yield per unit of available arable land.

1.6 Scope and Limitation of the Study

This research evaluated use of agronet cover, cropping regime and fresh organic manure as a potential strategy for use in CO_2 enrichment, suppressing root-knot nematode populations and enhancing open field tomato crop performance. Materials used were agronet cover of 0.4 mm pore diameter sourced from A to Z Textile Mills Ltd., Arusha Tanzania, Slender leaf (*Crotalaria brevidens* var. *brevidens* Benth.) intercrop, and fresh cow and goat dung obtained from the Tatton Agriculture Park (TAP). The study was undertaken in Egerton University, Njoro but the findings can be applied to other areas with similar conditions. Generally, the study aimed at improving tomato crop performance by providing alternative nematode management and CO_2 enrichment strategies for open field production systems. However, health concerns for growers and consumers due to use of manure in its fresh state may be a limitation of the study. Secondly, Integrated Crop Management (ICM) strategies varies from one area to another. Post-harvest analysis studies of tomato produce grown with fresh manure need to be conducted to determine its safety for human consumption.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Tomato Production and Uses

Tomato belongs to Solanaceae family (Tindall, 2000). It is indigenous to South America, used as food in Mexico and it is grown all over the world following the Spanish colonization of the America (Ekpenyong *et al*., 2016). Tomato is a perennial plant and are dicot plants with some having compound leaves while others have simple leaves. Shape of tomato fruit varies from circular to oblong depending on the cultivar with fruit color ranging from yellow to red. Tomato is the world's major vegetable crop after Irish potato (*Solanum tuberosum*) and it's the most canned vegetable crop (Fawusi, 1987). It is produced as a major commercial crop in most countries including Kenya as revealed by (MOARD, 2003). The largest producer in the world China (37,979,062.34 tonnes), accounted for about one quarter of the global production followed by United States (11,704,497.52 tonnes) and India (10,867,801.03 tonnes) (FAO, 2013). Tomato production globally in 2018 was estimated at 182, 256, 458 tonnes, accounting for 16.74% of world vegetable production (FAO, 2019). In the year 2018, Africa's average tomato yield stood at 16.08 tonnes/ha, which fell way below the world average yield of 38.27 tonnes/ha for that year (FAO, 2019). Kenya was amongst the leading producers of tomato in sub-Saharan Africa, producing 599,458 tonnes out of Africa's total yield of 20.8 million metric tonnes in 2018 (FAO, 2019). During the same year, Kenya's average yield was 21.21 tonnes/ha with the low yields being attributed to various challenges including abiotic and biotic constraints. The tomato is grown in nearly all parts of the Kenya, with main growing areas being Nakuru, Nyeri and Taita Taveta (Ssejjemba, 2008). Tomato grown in the open field accounts for 95% of the total yield while greenhouse technology accounts for 5% (Seminis, 2007).

Tomato is grown in cool and dry climatic condition. Nevertheless, tomato can be grown in an extensive climatic condition ranging from temperate conditions to hot and humid tropics. Most tomato varieties thrive well at the optimum temperature of between 21^{o}C and 24^{o}C although the plant tissues are damaged when the temperatures are below 10^{o}C and above 38^{o}C (Naika *et al*., 2005). The crop can be grown in an extensive diversity of soils so long as they have high organic matter with good drainage, and a pH of 5 to 7.5 (KARI, 2006). In the tropics, tomato is subjected to extreme abiotic condition which prevail under this tropical conditions and also biotic stresses (Premachandra *et al*., 2005). In Kenya, low yields of 7 tonnes per hectare have been reported especially under open field conditions against a world average of

75 tonnes per hectare (FAO, 2008; 2010). This is due to both biotic, mainly insect pests and plant parasitic nematodes and abiotic factors, which include exceeding rainfall, severe crop drought and high solar radiation (HCDA, 2006). Plant growth can be damaged by high solar radiation which cause hormonal malfunction resulting to lower plant yield with reduced quality (Harmanto *et al*., 2006). High solar radiation coupled with expensive pesticides have compelled farmers and research scientist to discover farming systems that allows them to deal with the hostile climatic conditions as well as reducing usage of pesticide and optimum management of resources such as water, light, temperature, nutrients and carbon dioxide (CO_2) concentration.

Tomato production is one of the most promising areas for horticultural expansion and development in Kenya (HCDA, 2006; MOARD, 2003). It's produced by both small scale and extensive cultivation with intention of improving their income and creating job opportunities, hence improving living standards in rural areas where poverty is prevalent (Ortiz & Hartmann, 2003). The crop is consumed by nearly all households (Asante *et al*., 2013). Tomatoes are consumed in fresh state or used in production of a varied variety of factory-made products (Helyes *et al*., 2009; Ray *et al*., 2011). It's a good seasoner in most foods and rich in vitamins (Saltveit, 2003). Tomato fruit is composed of large amount of water, calcium and niacin which play an important role in the metabolic activities of human being (Ekpenyong *et al*., 2016) besides carotene and lycopene that help in preventing prostate cancer (Mourvaki *et al*., 2005) and phenolics complexes such as coumarine and chlorogenic acid (Tucker *et al*., 2007). Lycopene is the highest profuse antioxidant in the mature tomato fruit accounting for roughly 85% of the tomato fruit color (Helyes *et al*., 2009). Besides, tomato is also rich in vitamins, total soluble solids and nutrition (Khan *et al*., 2007).

2.2 Plant Parasitic Nematodes

Plant parasitic nematodes which include root-knot nematodes cause significant yield losses of crops (Fourie *et al*., 2001; Koenning *et al*., 2001) particularly in the tropics where condition favour their growth and development (Luc *et al*., 2005). They attack wide range of host crops (Dickson & De Waele, 2005; Kratochvil *et al*., 2004) which makes their control more difficult. Nematodes are microscopic circular worms found in nearly all habitats. The nematode species are estimated to be more than half a million, several of which are free living species found in the soils, oceans and fresh water. Among the nematodes, the destructive nematodes belong to a smaller group and are more harmful to plants (Ehwaeti *et al*., 2000). A few of plant parasitic nematodes are endoparasitic hence, they feed and live inside the plant tissues while others are ectoparasitic hence, they freely live and feed externally through the plant walls. Olsen (2000) found that one endoparasitic nematode can kill a plant and highly decrease crop yield whereas ectoparasitic nematode feeds on a plant without causing any effect on its production. Generally, most plant parasitic nematode species such as root-knot nematodes have extensive range of host and a few of plant parasitic nematode species are host specific species. Root-knot nematodes (*Meloidoyne spp.*), the cyst nematode (*Heterodera spp.*) and the lesion nematode (*Pratylenchus spp.*) are economically important pest and feeds mostly on plant root (Debora *et al.*, 2008).

2.2.1 Root Knot Nematodes

Root-knot nematodes are most destructive pest of numerous agricultural crops in many parts of the world (Trifonova *et al*., 2009). Root-knot nematodes are the most successful plant parasites (Vovlas *et al*., 2005). In circumstances where their population exceed economic threshold level, they cause more damage to the plant and in severe cases they cause total crop failure (Sikora & Fernandez, 2005). Their life cycle is short lasting for six to eight weeks enabling them to thrive well under favourable conditions and their population can increase and reach the peak before the crop matures (Shurtleff & Averre, 2000) and in severe cases the crop dies before the crop attains maturity (Singh & Khurma, 2007). Lately, root-knot nematode is one of the main pathogens of tomato plants in most parts of the world (Jacquet *et al*., 2005). Among the genus *Meloidogyne* exist more than 90 known species, but most prominent species include *Meloidogyne incognita*, *M. arenaria*, *M. javanica* and *M. hapla* (Hunt *et al*., 2005; Karssen, 2000). *Meloidogyne arenaria*, *M. javanica* and *M. incognita* are found typically in tropical and subtropical areas but in temperate areas are found under protected farming. *Meloidogyne hapla* is typically found in temperate areas and in tropics they are found only in higher altitude (Hunt & Handoo, 2009). In heavily infested fields root-knot nematodes can cause vegetable yield loss of up to 80% (Kaskavalci, 2007). They limit fruit production in tomato (Sikora & Fernandez, 2005) and can cause yield loss in tomato ranging from 28 to 68% (Adesiyan *et al*., 1990).

Plants infested by root-knot nematode demonstrates symptoms such as stunting, yellowing, abnormal development of root with distinctive galls, unhealth appearance of the plant and reduced fruit production (Tisserat, 2006). Moreover, heavy infestation of root-knot nematode can cause death of the host plants. Plant roots infested with root-knot nematodes triggers a sequence of procedures that cause variations in the whole composition of the host plant. Plant root galls are formed when root-knot nematodes enter the cells of the cortex and pericycle the endodermis and reach the stele. About 5 to 7 cells adjacent to the root-knot nematode's head enlarges and become a specialized huge cell bigger than other cells. The nuclei of the giant cell expand, become polyploidy and undergoes a sequence of synchronized division (Mai & Mullin, 1996). Root galls resulting from root-knot nematode infection damage the vascular tissues of the root and consequently interfere with the normal uptake of water and nutrient by the plant throughout the vascular tissues (Olson, 2004). In addition, root-knot nematode infestation in plants may results in the presence of symptoms on above ground parts of the infected plant. Root symptoms may appear as root galls, root lesions, unnecessary branching of the roots (Ogallo *et al*., 1997). Root-knot nematode may damage the plant root tips leading to creation of secondary entry for other pathogens such as plant pathogenic or saprophytic bacteria of fungi which cause root rot (Cerkaukas, 2004).

2.2.2 Management of Nematode in Tomato

Management of root-knot nematodes with synthetic nematicides is the most effective method (Adegbite & Agbaje, 2007; Dubey & Trivedi, 2011; Sikora & Fernandez, 2005). A study on *Meloidogyne incognita* incidence in yam varieties reduced significantly after addition of carbofuran (3G) at 100 kg ha^{-1} (Adegbite & Agbaje, 2007). Nevertheless, high price of chemical nematicides together with their harmful effects on the ecosystem and non-target organisms are some of disadvantages against their usage (Idorenyin & Ugwuoke, 2010). As a result of this, it is clear that new alternative control methods of root-knot nematode which are as effective as chemical nematicides, harmless to farmers, safe for consumers and environment and affordable to small scale farmers (Fernandez *et al*., 2001). Some of alternatives found promising may include solarization, crop rotation and organic manure (Adekunle, 2011). Solarization is a thermal process of trapping solar radiation under clear polythene plastic mulch laid over moist soil for temperatures to build up to lethal conditions which can easily kill the root-knot nematodes together with other soil borne pathogens (Benlioglu *et al.,* 2005). The heat dosage of solarization depend mostly on soil temperature and duration of solarization. The effectiveness of solarization is also affected by soil texture, color, moisture and characteristics of film used. On the other hand, organic amendments are readily available with little or no adverse effects on human being and the environment unlike chemical nematicides (Amulu & Adekunle, 2015).

Organic soil amendments have direct influence on soil properties such as soil fertility, soil structure and soil biology. Besides, they also great impact on the dynamics of soilborne pathogens such as root-knot nematodes, by encouraging unfriendly soil organisms, stimulation of competitive status of non-pathogenic organisms, and toxic compound produced during decomposition may have direct effect on soilborne pathogens (Bailey & Lazarovits, 2003; Bonamoni *et al*., 2010), thus suppressing the plant parasitic nematode population in the soil hence improving plant growth and development. Jatak (2002) reported increased population of predatory microorganism on root-knot nematode after addition of organic manure. Non-pathogenic microorganisms compete with root-knot nematode for space, water and/or food. On the other hand, toxic compound released by the microorganism has negative impact on the root-knot nematodes thus affecting root-knot nematode mobility, survival mechanism and population density hence improving plant growth and development (Abolusoro *et al*., 2013).

Pakeerathan *et al*. (2009) found that use organic manure amendments in root-knot nematode infested plant improves their performance. This enhancement plant performance could be attributed to direct stimulation of plant parasitic nematode predators leading to suppression of root-knot nematode population densities and subsequent increase in plant growth and yield. Study by Olabiyi *et al*. (2007) on how different organic manure affect nematode pests on cowpea established significant decrease in population densities of plant parasitic nematode such as *Meloidogyne spp*., *Helicotylenchus spp*. and *Xiphinema spp*. in fields applied with organic amendments. According to Widmer and Abawi (2002), fully decomposed organic manure are stable and mineralize slowly releasing toxic nematicidal compounds slowly and this could lead to very low toxic concentrations that are unable to control nematodes (Akhtar & Malik, 2000). Nahar *et al*. (2006) anticipated that fresh organic soil amendments may be more effective than fully decomposed organic soil amendments, since toxic compounds can quickly build up and reach the toxicity threshold level that can easily control root-knot nematodes hence reducing their populations and at the same time increasing beneficial microorganism and microbial activities. A study by Aktar and Malik (2002) using cow dung, domestic waste and poultry manure reported a positive effect of these organic manures in suppression of plant parasitic nematode with a resultant increase in plant performance.

Studies by Wang *et al*. (2002, 2003a, 2003b) found that incorporation of *Crotalaria juncea* and *Tagetes erecta* into the soil enhanced nematode-trapping fungi (NTF) under protected and open field conditions. Though, *Crotalaria juncea* under open field conditions enhanced nematode-trapping fungi populations more successfully and over extended period of time than *Tagetes erecta*, perhaps owing to the larger volume of biomass produced by *Crotalaria juncea* than *Tagetes erecta* (Wang *et al*., 2002, 2003a). *Crotalaria* increases bacterivorous nematode population densities and nematode trapping fungal propagules, thus enhancing microbial activities against *Meloidogyne* species (Wang *et al*., 2002). Besides pest management, other related benefits of intercropping other crops with *Crotalaria* are better yield stability, more land use efficiency, improved competitive ability toward weeds and enhancement of soil fertility (Mousavi & Eskandari, 2011).

2.2.3 Mechanisms of Nematode Suppression

Modes of nematode suppression by antagonistic plants could be linked to provision of non-host or poor host environment for plant parasitic nematodes (Rodriguez-Kabana *et al*., 1988, 1994), production of allelochemicals (Halbrendt, 1996), and enhancing nematode antagonistic flora and fauna (Kloepper *et al*., 1991; Linford, 1937), or may act as a trap crop to plant parasitic nematode (Gardner & Caswell-Chen, 1994; LaMondia, 1996). A perfect crop to grow as cover crop should possess more than one mechanism involved in nematode management. The measures for main plant resistance are failure of the nematode to live inside the host or early nematode death in the host, reduced egg production, or prevention of nematode growth and development (McSorley, 1999; Rich & Rahi, 1995; Trudgill, 1991).

The modes of action for organic manure are not always clear, and application modes are often empirical (Collange *et al*., 2011). Numerous mechanisms have been suggested to describe how organic manure amendments affects plants growth in the presence of root-knot nematodes. Studies show release of nematicidal compounds by organic manure during decomposition and activation of microbial activities in the soil, as well as stimulation of root-knot nematode natural enemies and competitors that depend on microbial actions, and improved soil nutrients and water holding capacity resulting in vigorous plants with increased tolerance to root-knot nematodes (Akhtar & Malik, 2000; Oka, 2010; Thoden *et al*., 2011). Sometimes it's hard to differentiate which are most important mechanism as numerous mechanisms may occur simultaneously (Akhtar & Malik, 2000; McSorley, 2011). Applying higher dosages of organic manure could increase its effectiveness in root-knot nematode management until a point where phytotoxicity is experienced. At higher dosages, root-galling may be reduced, but yield is reduced because of phytotoxicity (Collange *et al*., 2011).

2.3 Organic Manure as a Source of Carbon Dioxide

Carbon mineralization process in soil signifies volume of organic material existing in the earth and is perceived as a sign of microbial activity (Choudhary *et al*., 2021). High microbial population densities and biomass present in the soil can be associated with high organic matter which enhances biological activity as organic materials are incorporated into the soil every year hence adding of fresh carbon source (Liu *et al*., 2018). Organic manure can serve as source of carbon dioxide (CO_2) during decomposition. The degree of CO_2 emission is highly enhanced by the quantity and characteristics of organic manure materials applied together with other factor such as soil growths and ecological conditions which includes temperature and water accessibility (Agehara & Warncke, 2005; Hossain *et al*., 2017). According to Rahman (2013) emission of different gases, especially CO_2 occurs immediately after residues are added to the soil as organic materials begin to decompose and also depends on microbial activities linked with soil moisture and temperature. CO_2 emissions depend on carbon mineralization of organic amendments applied in the soils (Hassan, 2013). In case of increased soil carbon storage, the rate CO_2 emission is reduced in a process known as carbon sequestration in agriculture or terrestrial carbon sequestration where plants capture atmospheric CO_2 and conservation of plant biomass in soil (Lal, 2004). The segment of crop incorporated into the soil is converted into further steady humic substances which lead to development of dissimilar organo-mineral complexes and microaggregates and this guard the soil carbon from more processes of mineralization thus increasing carbon sequestration (Lal, 2016). 99% of the total CO_2 emitted comes from microbial breakdown of organic materials in the soil (Hossain *et al*., 2017).

Soil amendment with organic manure like animal manure increases the buildup of organic carbon in the soil, which in turn encourages alteration in the microbial community structure thus increasing microbial population densities (Peacock *et al.,* 2001; Salehi *et al*., 2017). Addition of organic manure is crucial in improving soil efficiency and input use efficiency and this safeguards the soil vigor (Bandyopadhyay *et al.*, 2010). Animal organic manure contain easily accessible source of carbon for microbial organisms which in turn enhances emission of carbon dioxide (Rochette *et al*., 2004). Lee *et al*. (2007) established that the soil carbon dioxide fluctuation throughout the growing duration of switch grass was 472 g CO_2 C m^{-2} for the control treatment, 488 g CO_2 C m^{-2} for NH_4NO_3-N, and 706 g CO_2 C m^{-2} for manure-N plots. The amount of CO_2 emitted by organic manure is influenced by the particle size with higher CO_2 emissions being obtained from organic manure with smaller fractions after addition into soil (Fangueiro *et al*., 2007; Phan *et al*., 2012).

According to Fangueiro *et al*. (2008) CO_2 emitted from liquid fractions and untreated slurry was higher than that emitted by solid fractions and this could be as result of more interactions between soil microorganisms and liquid fractions or untreated slurry than the solid fractions. Similarly, Tejada *et al*. (2006) observed more cumulative CO_2 carbon emitted by saline soils applied with poultry manure in association to cotton gin compost. Cured composts (cured green waste (CGW) and cured dairy manure (CDM) produced lower carbon dioxide than the uncured amendments (active green waste (AGW) and active dairy manure (ADM) which are expected to contain more volatile carbon (Reddy & Crohn, 2019). According to Reddy and Crohn (2019) greater CO_2 emissions produced by active organic amendments was accredited to the higher decay percentage of organic matter. In an earlier study, Reddy and Crohn (2014) reported that the active green waste and active dairy manure amendments applied in a soil with EC_e of 30.6 dS m^{-1} produced 54% extra carbon dioxide than cured amendments.

An investigation by Ma *et al*. (2006) to examine the influence of sheep dung on carbon dioxide; it was established that values of CO_2 produced were recorded at 3170 mg m^{-2} h^{-1} for urine, 1798 mg m^{-2} h^{-1} for dung and 1225 mg m^{-2} h^{-1} for compost which was about one and half to three times as compared to that obtained under control treatment (813 mg m^{-2} h^{-1}), after 24 hours of their applications. However, during the 65-day period, no significant difference was reported in cumulative carbon dioxide produced amongst urine and control plots, but higher CO_2 was produced from fresh sheep dung and compost treated soil compared with control. Higher CO_2 produced from fresh sheep dung and compost treatments could be attributed to either fresh sheep dung and compost itself (Flessa & Beese, 2000) or carbon dioxide emitted by the soil as a result of microbial enhancement (Bol *et al*., 2003) or extra CO_2 respiration resulting from more aboveground and underground biomass (Ma *et al*., 2006). Studies on application of sheep fresh dung and compost manure have been documented to emit up to 14 and 12% more $CO_{2,}$ respectively compared with the control (Ma *et al*., 2006).

2.4 Effect of Organic Manure on Crop Yield and Quality

Organic manure sources hold a great potential as they are locally available, they contain various nutrient elements and their capacity to enhance soil physical appearance and crop productivity (Sathya & Maheswari, 2017). The benefit of adding organic manure into the soil is to improve soil physical, chemical and biological activities as well as increasing crop growth, development and quality (Adediran *et al*., 2003; Akanbi & Togun, 2002; Ghosh *et al*., 2004; Maharishnan *et al*., 2004; Manna *et al*., 2000; Srivastava *et al*., 2006). The use of organic amendments in the soil will be inadequate to overcome soil nutrient deficiency (Ilupeju *et al*., 2015). The combination of small quantities of chemical fertilizer with the organic materials present on the field offers a good approach in meeting the nutrient necessities of the crops. It reduces nutrient loss through leaching and contamination of groundwater (Manna *et al*., 2000). This capitalizes on usage of reachable organic resources and reduces usage of expensive inorganic fertilizers (Ghosh *et al*., 2004; Manral & Saxena, 2003). Studies have reported how addition of compost manure or in mixture of small quantities of inorganic fertilizer have improved plant performance and quality (Togun, 2003).

Slow release of nutrients by organic fertilizer reduces loss of nutrient through leaching thus improving nutrient use efficiency hence improving crop performance and this yields plants with higher harvest and nutritional values. According to Ilupeju *et al*. (2015) crops grown with higher amount of compost amendments registered higher yields and quality. This could be associated with the ability of compost amendments in improving soil cation exchange capacity (CEC) and soil fertility as they contain many active sites leading to efficient nutrient absorption and use by the crop (Ilupeju *et al*., 2015). To protection soil health, careful usage of organic manure and inorganic fertilizers is vital to increase crop yield and input use efficiency (Bandyopadhyay *et al.,* 2010). In future, use of organic manure to meet crop nutrient requirement will be an inevitable practice to boost sustainable agriculture by safeguarding soil health which in turn will improve crop productivity and maintains crop produce of high quality (Adekiya *et al*., 2020; Maheswarappa *et al*., 1999). Changes in soils properties by organic manures comprises of physical and chemical properties such as nutrient bioavailability, soil structure, water holding capacity, cation exchange capacity, soil pH, microbial community and activity (Agbede *et al*., 2008; Suge *et al*., 2011), moisture retention, bulk density and aeration (Frankenberger & Abdelmagid, 1985). Application of organic matter into the soil through application of organic amendments also influences soil pH.

Organic material amendments improve crop performance due to enhanced soil health through nutrient release by organic materials during decomposition and mineralization. In addition, they generally have better residual effect on successive crop as organic nutrient sources release their nutrients slow over time (Szott & Kass, 1993). Organic material amendments are crucial in maintaining good health soil as they provide essential nutrients, rebuild soil organic matter content, and reestablish microbial populations (Dauda *et al*., 2008; EPA, 2007; Suresh *et al.,* 2004). Present of organic matter content in the soil can be as result of application of plant residues, animal manure, microbial residues, and from decomposition of applied and present organic materials (Diacono & Montemurro, 2010). Organic materials in the soil originates from remains at several phases of decomposition (Diacono & Montemurro, 2010; Lal, 2007).

According to Prasanthrajan *et al*. (2011) organic manure comprises of large number of microorganisms associated with mineralization of organic nitrogen and this can largely affect the chemical properties of soil. According to Nahm (2005) soil characteristics such as texture, structure and organic matter, rainfall, temperature patterns and farming practices affect the amount of available nitrogen in the soils. Furthermore, variations in management practices in order to achieve better crop performance influences soil temperature and soil moisture content which control CO_2 production (Allaire *et al*., 2012; Dhadli *et al*., 2015; Peng *et al*., 2011; Zhang *et al*., 2013a). The primary environmental factors such as soil temperature and soil moisture content influence gas emission rates, as they influence the metabolic activities of microorganisms, organic manure gas diffusion, nutrient availability and nutrient redistribution (Luo *et al*., 2013). The amount of remaining nitrogen that is accessible to crops is influenced by the rate of added manure and how the manure was applied as well as residue characteristics. Study by Eghball *et al*. (2002) working with corn recorded 40% of available nitrogen to plants in the year of application, with residual nitrogen dropping to 15% in the second year after application. Similarly, Nahm (2005) established that 60% of the organic nitrogen present in poultry manure was released within 140 days after the poultry manure was applied.

Organic amendments are essential in provision of plant with required nutrients without having negative impact on the environment (Njoroge & Manu, 1999). Study by Rankov *et al*. (1979) comparing the same rate of inorganic fertilizer and organic amendments reported that tomato yield produced from organic amendments was higher than those produced by inorganic fertilizer. Application of organic amendments in higher quantities increase the accessibility and use efficiency of phosphorus by plants (Tisdale *et al*., 1985). In addition, greater availability of phosphorus can result from complexion of aluminum and iron with organic compounds after decomposition hence reducing aluminum toxicity (Suge *et al*., 2011).

Organic manures comprise of low amount of plant nutrient elements compared with chemical fertilizers. Use of inorganic fertilizer is effective in increasing crop yield but is short term solution whereas the demands require use which is a long-term basis. In addition, use of chemical fertilizers has hazardous effects on the environmental as well as high acquisition cost making it expensive for the small-scale farmers (Olowoake, 2014). Organic manures contain plant growth enhancing factors such as enzymes and hormones, in addition, plant nutrients make them crucial for enhancement of soil nutritional status and efficiency (Bhuma, 2001; Premsekhar & Rajashree, 2009). Studies by Beckman (1973) reported that organic manure improves soil productivity, enhances soil organic carbon content, soil microbial activities, improves soil structure, soil nutrition and subsequent crop produce. Use of poultry manure in eggplant production resulted in improved crop performance and high fruit yield (Dauda *et al*., 2005). In addition, Aliyu (2000) reported that application of farmyard manure (FYM) and poultry manure results in higher fruit yield of eggplant.

According to Tiamiyu *et al*. (2012), use of poultry manure in okra crop resulted in higher yield of fresh pod which was accredited to release of plant soluble nutrient by the poultry manure leading to enhanced soil nutrient status and water holding capacity. Studies by Sanwal *et al*. (2007) in turmeric (*Curcuma longa*) and Premsekhar and Rajashree (2009) in okra (*A. esculentus*) established that increased crop yield after use of organic manure amendments could be associated to enhanced physical and biological properties of the soil with subsequent increase in nutrient supply to the crops. Organic manures help in linking the present extensive gap among the nutrient depletion and supply and ensures balance in nutrient quantity through increasing response efficiency and capitalize on production of crops with favourable quality (Soni *et al*., 2018).

Tomato fruits produced from organic manure amendments comprise of high quantities of antioxidants, total phenolics and ascorbic acid (Toor *et al*., 2006), with more TSS (Chassy *et al*., 2006; Pieper & Barrett, 2009) in relation with those tomatoes grown with inorganic fertilizers, although a few investigations have reported contrast results (Bilalis *et al*., 2018). Studies by Barrett *et al*. (2007) on tomato grown with organic amendments found that tomato grown with organic amendments produced fruits with higher levels of titratable acidity while Hallmann (2012) reported lower concentration of organic acids from fruit of tomato produced by plant grown with organic amendments. Titratable acidity could decrease with increase in carbon distribution in the foliage and also increased fruit shading (Pieper & Barrett, 2009). According to Bilalis *et al*. (2018), higher values of TSS and total soluble solids to titratable acidity ratio (TSS/TA ratio) observed in tomato fruit grown with organic manure could be attributed to greater tomato plant biomass. The TSS/TA ratio is a better forecaster of the influence of an acid on fruit flavour than soluble solids or acidity alone, since acidity has the tendency to decrease with fruit maturity while sugar content tends to increase (Ilić *et al*., 2014).

Tomato lycopene content plays an important role in fruit appearance and attractiveness to consumer, besides its immense health benefits (Kirimi *et al*., 2011; Otieno *et al*., 2017) and its accountable for the red pigment of tomato fruits. Tomato lycopene content is the most prominent containing up to 90% of the total tomato fruit (Viskelis *et al*., 2015) with a high oxygen free radical scavenging and quenching capacity and thus providing protection against chronic diseases, such as several types of cancer, including cancer in the mouth, pharynx, esophagus, stomach and large intestine, and cardiovascular diseases (Perveen *et al*., 2015). Lycopene content in tomatoes is greatly affected by hereditary and ecological factors which includes the cultivar of tomato, growing season, cultivation conditions and stage of harvest of the tomato fruit (Pieper & Barrett, 2009; Toor *et al*., 2006). According to Agbede *et al*. (2019), increase in lycopene content in tomato fruits grown with green manures can be associated with increased nutrients availability in the soil. Study by Ghorbani *et al*. (2008) established that tomato grown with green organic manures had more lycopene content compared to those grown with inorganic fertilizer. The high lycopene content was attributed to enhanced soil moisture status and nutrient availability resulting in synthesis of carotenoids which are liable to tomato fruit color.

2.5 Effect of Carbon Dioxide Enrichment on Crop Productivity

Carbon allocation brings about varied variety of vegetation that occupy earth's biomes. Key importance of elevated carbon dioxide is enhanced photosynthetic rate leading to higher quantities of soluble and stored carbohydrates (Farrar & Gunn, 1996). Soil moisture combined with soil temperature and other soil activities together with application of nitrogen greatly affect soil carbon dioxide emissions and carbon dioxide increase (Dhadli *et al*., 2015; Mbonimpa *et al*., 2015). Increased CO_2 concentration levels results to increased water use efficiency of the plant, enhanced photosynthetic rate and light use efficiency hence higher source of photosynthates and enhanced crop development and yield (Ainsworth & Long 2005; Drake *et al*., 1997; Ji *et al*., 2015). Increases in soybean development and yield resulting from CO_2 enrichment have been documented in several studies (Baker *et al*., 1989; Sionit *et al*., 1987). According to Sionit *et al*. (1987) maintaining soybean plants in carbon dioxide concentrations of 350 µmol CO_2 mol^{-l} air, 675 µmol CO_2 mol^{-l} air and 1000 µmol CO_2 mol^{-l} air and established increased soybean performance and economic yield with increasing CO_2 concentration. Yield increases resulting from CO_2 enrichment could be associated to higher number of seeds other than higher seed weight (Sionit *et al*., 1987). Peet *et al.* (1991) proposed that CO_2 enrichment improves sink strength more than source strength in tomato, and during the fruit growth extra carbohydrates could be allocated to the fruits, hence more fruit yield. Studies by Yelle *et al*. (1990) reported enhanced early fruit yield and total fruit yield in tomato cv. Vedettos at raised carbon dioxide concentration levels. Similarly, Reinert *et al.* (1997) reported 22 to 41% rise in cumulative tomato yield when carbon dioxide concentration levels were increased from 10.23 µmole $mole^{-1}$ to 15.34 µmole $mole^{-1}$. Islam *et al*. (2006) reported that tomato cultivars grown at EC (19.32 µmole $mole^{-1}$) CO_2 concentration had significantly larger fruits compared to tomato cultivars grown at ambient (7.95 µmole $mole^{-1}$) CO_2 concentration. Slack (1986) reported that CO_2 enrichment increases total yield of greenhouse tomato by 30%.

Studies by Jin *et al*. (2009) working on elevated CO_2 concentration reported an increase in photosynthetic rate and relative growth of celery (*Apium graveolens* L.), leaf lettuce (*Lactuca virosa* L.), stem lettuce (*Lactuca saiva* L.), oily sow thistle (*Sonchus oleraceus* L.), and Chinese cabbage (*Brassica chinensis* L.). Raised carbon dioxide has been shown to induce an increase of fungal abundance in soils (Carney *et al*., 2007; Lipson *et al*., 2005) partly as a consequence of a higher carbon assimilation efficiency. In addition, high CO_2 concentration level could increase use efficiency of nitrogen and phosphorous (Conroy, 1992). Jin *et al*., 2009) reported that crop remains and animal manure composting produced CO_2 gradually which was sufficient for efficient photosynthesis to take place during the growth period of the plant. Studies by Hao *et al*. (2012) found that photosynthetic acclimation did not occur in soybean plant cultivar that developed new sinks after exposing to long-term elevated CO_2 even though it happened in soybean crop subjected to higher CO_2 for a long period of time and also differed among the cultivars.

The studies suggest that numerous crops, may respond positively to elevated carbon dioxide in situations where other harsh conditions are not present (Long *et al*., 2004). It's obvious that stable rise in atmospheric carbon dioxide affects the overall physiology, development and yields of crops (Mamatha *et al*., 2014). In general, elevated CO_2 concentration affect the quality of tomato fruit by affecting content of antioxidants, ascorbic acid, and sugars (Idso *et al*., 2002; Islam *et al*., 1996; Tajiri, 1985; Wang *et al*., 2003c). Consumption of flavonoids, ascorbic acid, and carotenoids reduces the dangers of various deteriorating diseases (Agarwal and Rao, 2000) hence, it's relevant to measure fruit quality under elevated CO_2 concentrations on tomato production (Mamatha *et al*., 2014). Study by Islam *et al*. (1996) recorded higher ascorbic acid and sugar contents in tomato fruits subjected to elevated CO_2 concentrations at different maturity stages. Nevertheless, investigations have reported contradictory report that antioxidant substance tended to be low in tomato grown in elevated carbon dioxide (CO_2) concentration levels (Barbale, 1970; Kimball & Michell, 1981; Madsen, 1971; 1975). According to Mamatha *et al*. (2014), fruit qualities such as ascorbic acid and lycopene content improved at elevated CO_2 concentrations up to 12.5 µmole mole^{-1} but reduced under elevated CO_2 concentrations of 15.91 µmole mole^{-1}. Similarly, Helyes *et al*. (2011) found that tomato (*Solanum lycopersicum* L.) fruits grown at 15.91 µmole mole^{-1} of carbon dioxide concentration levels had significantly lower lycopene content.

2.6 Effects of Agronet Covers on Pest Infestation, Crop Yield and Quality

Net technology has enormous benefits when used in crop production. Studies have reported some of benefits as protection of plants against extreme solar radiation, protection against insect pests attack and environmental fluctuations (Shahak *et al*., 2004). Filtering of diffuse sun radiation under net covers decreases the plant canopy and air temperature as well as the transpiration rate (Ilić *et al*., 2017). This improves crop performance and yield by decreasing water consumption and increasing water use efficiency (Ahemd *et al*., 2016). Agronet covers alter ecological factors such as temperatures, wind speed, or relative humidity (Arthurs *et al*., 2013) and light intensity and quality (Shahak, 2008; 2014) below the covering. Net technology reduces air mixing beneath them and this results to reduction in wind speeds and wind run, thus affecting air temperatures, relative humidity and gas concentration levels (Ilić *et al*., 2017). All these changes have effect on plant transpiration, photosynthesis, respiration among other key plant processes. Changes on the local microclimate under net covers can also modify CO_2 concentration level around the plant canopy thus improving plant development and yield (Kittas *et al*., 2012). According to Waterer *et al*. (2002), agronet cover affect the amount of air around the crop canopy thus influencing carbon dioxide concentration under the agronet cover. They also established that the level of the daytime variation in carbon dioxide concentration relied on the porosity of the agronet cover used where the variation was more conspicuous when non-perforated polyethylene material was used than when more permeable woven material was used. Hence, the effects of agronet cover on air movement relies on the porosity of the agronet cover.

Net technology is a common approach practiced by most vegetable growers in many developed countries to protect the plants against insect pest's attack. Nets enable regulation of flying winged insect by forming blockade amongst host plant with the insects (Vincent *et al*., 2003). The barrier created by nets prevents moving insect pests from finding the crop, therefore reducing the occurrence of direct effect of the pest on the crop (Teitel *et al*., 2008). Besides, physical barrier the agronet interrupts feeding and mating habits of the insect pests (Martin *et al*., 2006). Studies by Martin *et al*. (2006) using moveable net houses in control of diamondback moth (*Plutella xylostella* L.) established that cabbage plants were easily protected against the diamondback moth, cutworms and loopers leading to a reduction of between 66 to 97% in number of moths and caterpillars in relation to the control treatment.

Nets can modify crop environment for the pest (Mazzi & Dorn, 2012) by masking the plant, hence discouraging insect pests that distinguish their target (Weintraub & Berlinger, 2004). Studies by Sauphanor *et al*. (2012) using net technology in control of false codling moth (*Cydia pomonella* L) established that use of net technology reduced insect pest incidences of false codling moth on apple plants. Net technology against insect pest have been used in many parts of the world as dependable and resourceful technology to guard crops against numerous important insects (Castellano *et al.,* 2008; Harbi *et al.,* 2012).

Decrease in insect pest occurrence under net cover reduces the frequent application of insecticide by farmers and this reduces insecticide sprays thus protecting human health and elimination of hazardous effect of insecticide to the environment thus increasing efficiency of crop protection (Licciardi *et al*., 2007; Weintraub, 2009). According to Fajinmi and Fajinmi (2010), growing of lady's-finger with net covers after seedling appearance decreased the population of insect pests significantly compared to those grown without net covers. Study by Gogo *et al*. (2014) found that application of agronet was effective in managing tomato insect pests.

A study by Licciardi *et al*. (2007) on production of cabbage under protected environment to control diamondback moth and borer reported significantly lowered the population of the insect pests on plants grown under protected environment than those grown in plots applied with insecticides. Muleke *et al*. (2013) reported a significant lower number of leaf miner densities on cabbage seedlings grown under net covers and linked the result to blockade of the insect pests. Likewise, Palada and Ali (2007) working with net roofed tunnels established that net covers reduced insect pest population by 80% compared to open field production with significantly increase in marketable yields. Similarly, cabbage grown under net tunnels reduced insect pest incidence by 38 to 72% with a resulted increase in yield of head cabbage (Neave *et al*., 2011).

Net technology has other useful benefits, other than pest control. The modification of environmental factors can also be attributed to improved plant performance through increased biomass buildup and plant growth rate (Munywoki *et al*., 2017). In addition, use of screen nets in regulation of air temperature reduces crop stresses thus enhancing the performance of the crop (Kittas *et al*., 2012). Improved plant performance for crops grown with agronet can be associated with enhanced solar radiation reimbursement under agronet (Nangare *et al*., 2015). Light quality changes under agronet cover could possibly modify the crops physiological and biochemical processes, metabolite profiles and eventually crop performance and quality. Studies on photo selective nets have reported that these nets have effect on the biosynthesis of bioactive compounds in crops (Mashabela *et al*., 2015; Selahle *et al*., 2015). Studies on shading nets of red, pearl and yellow colour noticeably increase crop productivity (Fallik *et al*., 2009), improved crop quality (Kong *et al*., 2013) and reduced incidences of crop invasion by pests and diseases (Díaz-Pérez, 2014). According to Alkalai-Tuvia *et al*. (2014), tomato fruit maturation rate and fruit colour were influenced by light quality of dissimilar wave lengths.

Improvement of the crop environment by modification of the incident radiation and elevation of the relative content of scattered light by net covers has been done to enhance plant growth and yield (Nissim-Levi *et al*., 2008). Changes in light waveband affects physiological responses taking place inside the plants while light scattering on the other hand, enhances infiltration of light into the canopy of the plant (Shahak *et al*., 2004). In additional, scattered light increase radiation use efficiency, yields and affect time of flowering and number of flowers produced by the plant (Guenter *et al*., 2008; Sinclair *et al*., 1992).

Netting technology improves tomato plant yield and fruit quality (Ilić *et al*., 2012; 2015) and carotenoid content (Tinyane *et al*., 2013). Studies by Rylski and Spigelman (1986) established that *Capsicum annuum* fruit set was reduced under high temperatures (≥32 °C). Sweet pepper production increased when solar radiation was reduced by about 26% compared to when the crop was exposed to direct sunlight. Adams *et al*. (2001) found movable agronet covers used under strong sunlight resulted in a 10% rise in marketable yield in relation to when the crop was exposed to full sunlight. On the other hand, Gent (2007) reported linear decrease in total yield with increasing shade when nets of different shading intensities were used, although the difference on marketable yield was not significant among the different shading intensities. Studies by Caliman *et al*. (2010) revealed that tomato under shade net produced fruit with better quality. In addition, tomato planted in the open field had high TSS and significantly lesser lycopene contents than those tomato fruits produced in protected environment.

Lloyd *et al*. (2004) established that use of net covers improved environmental temperature. The higher temperatures under the net covers improved fruit expansion, enhanced total soluble solids together with fruit color. In a study by Milenkovic *et al*. (2012) established a decrease in tomato cracking by around 50%, increased number of marketable tomato fruits by 35% and reduced tomato fruits with sunscald when the crop was grown under different shade nets compared to those grown in non-shading condition. They attributed increased tomato yield and marketable fruits of shaded plants to reduced heat stress.

2.7 Effects of Intercropping on Pest Infestation and Crop Yield and Quality

Intercropping of crops is a practice carried out in the sub tropics and tropical regions in order to increase farmers income (Kizilsimsek & Erol, 2000). The mutual relationship between the varied plant species and biomass production exists under natural ecosystems (Tilman *et al*., 1996). The harmonized use of resources such as nutrients, water, and light by different diverse species is fundamental to increased productivity. The concept of complementarity is the crucial factor affecting productivity rather than species richness (Kahmen *et al*., 2005; Kahmen *et al*., 2006; Loreau, 2000). Plant species with different morphological and physiological strategies will complementarily explore resources better than any single strategy does.

The intercropping combination of legumes and cereal displays a complementary resource use. In this combination, legumes fix nitrogen and cereals absorb more nitrogen when planted together with legumes than when they are grown as sole crop hence their combination is considered as harmonize usage of nitrogen resources (Corre-Hellou *et al*., 2006; Fan *et al*., 2006; Hauggaard-Nielsen *et al*., 2001a; Jensen, 1996; Neumann *et al*., 2007). Advantage of intercropping includes improvement of ecosystem efficiency (Wiley, 1979), environmentally friendly strategy for insect control (Mitchell *et al*., 2002), greater nutrients accessibility by crops (Hauggaard-Nielsen *et al*., 2001b), weed control (Midmore, 1993), plant produce with higher quality (Anil *et al*., 1998) and assurance of farmers against crop failure (Ofori & Stern, 1987).

Many scenarios of intercropping have reported overyielding in which the yield obtained from intercropped crops was more than the predictable yield of the crops when grown as sole crop (Miyazawa *et al*., 2010). Even though higher yield is associated to greater functional group diversity in natural ecosystems, few studies have been done to determine the effects of mingling more than two crop on growth and yield in the agricultural field (Andersen *et al*., 2005, 2007). Planting several crops may not only improve productivity; but likewise play a greater role in nutrient use efficient by reducing nutrient loss and utilization of extra nutrients that would else be reserved in the soil (Kahmen *et al*., 2006). To maximize better nutrient uptake of nutrients by different crops, rooting patterns of those crops form are very important morphological feature for crops species being grown together.

Growing crop of different rooting depths allows use of more soil volume per unit area of land than when each crop species is grown as sole crop. According to Wilson (1988), use of crops that distributes roots at different depths in intercropping program forms an important mechanism of complementarity. Wilson and Newman (1987) reported very high yield when the crops were grown in deep boxes to allow root growth at different depths than when the plants grown in shallow boxes. In some circumstances plants change their rooting patterns to increase spatial complementarity. Study by Hauggaard-Nielsen *et al*. (2001a) reported that cereal crop like barley when intercropped with a legume crop like pea led to absorption of high amount of phosphorus by barley plant from deeper layers of soil than barley grown alone. They established that intercropped barley dispersed twice the amount of its roots at deeper layers of soil than when it was grown as a sole crop.

Intercropping is an insect control strategy where plants interfere with insect pests' ability to find host crop (Ratnadnass *et al*., 2011). Intercrop crops regulate insect pests by preventing their increase in population or by encouraging buildup of natural enemies to greater numbers that can outcompete and kill the insect pest. Tomato plant contains many protective approaches that control harmful insects which include glandular trichomes, toxic compounds and formation of protective enzymes (Carter *et al*., 1989; Howe *et al*., 1996; Simmons *et al*., 2005; Thaler, 1999).

Intercropping offers better land efficiency in terms of land equivalent ratio and also encourages build-up natural enemies' population (Songa *et al.,* 2007). Intercrop plants enhances crop variety and modify the pests' habitat causing interference with the pests' identification of the main crop (Tahvanainen & Root, 1972) resulting in decrease in pest prevalence and impairment in relation with sole crop production (Pitan *et al*., 2002). Finch *et al*. (2003) reported that cabbage root fly (*Delia radicum* L.) ability of finding host plant was disrupted by non- host plants resulting to reduction in eggs laid on cabbage plants when encircled by goosefoot (*Chenopodium album* L.) weed and by the weed fumaria (*Fumaria officinalis* L). Works done by Desaeger and Rao (2001) on intercropping *Crotalaria grahamiana* with leguminous cover crops such as *Sesbania sesban* and *Tephrosia vogelii* on *Meloidogyne spp* as these latter legumes are good hosts to *Meloidogyne spp*. They established that intercrop of *Crotalaria* with *S. sesban* and *T. vogelii* did not decrease the population density of *Meloidogyne spp*, nevertheless, they reduced root-knot nematode egg production as compared to growing of *S. sesban* and *T. vogelii* as a sole crop (Desaeger & Rao, 2001). Studies by Wang (2000) on intercropping *Crotalaria juncea* with pineapple found that *C. juncea* enhanced bacterivorous nematode population densities and nematode-trapping fungal propagules compared to uncultivated land or pineapple grown as sole crop, indicating that microbial activities against *Meloidogyne* could have been improved by *C. juncea*.

Studies have established that when plants are grown together, they grow better and display effective use of accessible resources giving rise to plants with high and steady yields (Feike *et al*., 2010). Sunn Hemp (*Crotalaria juncea* L.), African marigold (*Tagetes erecta* L.) and Radish *Brassica napus* L. are poor hosts to *Meloidogyne* species (Robinson *et al*., 1997) as they produce allelopathic compounds that are toxic to plant parasitic nematodes such as root-knot nematodes. Besides *Crotalaria* spp being a poor or non-host for a large group of pests and pathogens, they compete with weeds without becoming a weed as they grow very fast to provide good ground coverage, form symbiosis with rhizobium in the rhizosphere to fix nitrogen, and can also be used as green manure (Wang *et al*., 2002). Studies show that when *Crotalaria* spp used as green manure can fix nitrogen ranging between 150 to 165 kg Nha^{-1} if added before flowering (Rotar & Joy, 1983). Guvenc and Yildirim (2006) established intercropping of crops greatly improved development and yield of the crops. Study by Nyasani *et al*. (2011) reported that growing of legume crop as a monocrop resulted in higher proportion of unmarketable pods due to thrips damage than when legume plants were intercropped with cereals. In addition, they also reported reduced legume crop damage by thrips in those legume crop intercropped with other crops thus enhancing marketable yield of the pods.

Mixed growing of corn, squash and beans resulted in improved soil nutrients and conserved soil moisture leading to more crop yields (Jane, 2006). Agegnehu *et al*. (2006) working on teff (*Eragrostis tef*) and faba bean (*Vicia faba*) grown either as mixed intercrop and as a sole crop reported a substantial increase in yield when the two crop were grown together than when grown alone. Generally, intercropping resulted in enhanced land use efficiency leading to better plant performance in relation to sole cropping of the two crop species. However, some studies show that not all intercrops result to improved yield. Studies by Hauggaard-Nielsen *et al*. (2001a) working on cereal-legume intercropping established that cereal crop resulted in increase in yield but the yield of legume crop reduced. This was attributed to the fact that cereal crops usually have much more rooting densities than legume crops.

2.8 Integrated Crop and Pest Management

The using synthetic fertilizers in agriculture has resulted in increased crop yields. However, situations whereby the synthetic fertilizers are overused and/or used for a long period of time has led to negative effects on soil quality and environmental pollution (Ayilara *et al*., 2020; Ju *et al*., 2009; Mupambwa & Mnkeni, 2018; Zhang *et al*., 2013b). Use of organic amendments have widely been recommended as essential fertilizer source (Hasnain *et al*., 2020; Yang *et al*., 2020). Moreover, use organic and bioorganic amendments in crop production play a crucial role in waste utilization (Brunetti *et al*., 2019; Mupambwa & Mnkeni, 2018; Ravindran *et al*., 2019). Studies involving the type and dosage of organic amendments (Favoino & Hogg, 2008; Li *et al.*, 2018; Ravindran *et al*., 2019; Wang *et al*., 2019), the suitable ratio mixed with chemical fertilizer (Hernández *et al*., 2014; Li *et al.*, 2018; Paramesh *et al*., 2020), nitrogen application time (Choudhari & More, 2001; Shen *et al*., 2018), and combination of organic manure with soil organisms (Li *et al.*, 2018; Malusá *et al*., 2012) have been carried out for various crops and vegetables in different agroecological zones. Though, studies have established two or more factors simultaneously, the interactions between factors have however been mostly ignored (Bilalis *et al*., 2018; Ravindran *et al*., 2019; Zandvakili *et al*., 2019). However, use of organic soil amendments alone cannot supply enough nutrient required by the crops (Bedada *et al*., 2014). Integrated soil fertility management (ISFM) which involves use of both organic and synthetic fertilizer resources, is thus proposed for greater crop performance and better nutrient storage (Bedada *et al*., 2014; Ewusi-Mensah *et al*., 2015).

Integrated Pest Management (IPM) in which harm caused by pathogens on crops is controlled through the use of natural enemies which reduce population increase of microorganisms, if desirable complemented with suitable control strategies (Van Lenteren, 1993). Integrated pest management is built on the philosophy that natural pest management must be given first priority before use of chemical pesticides (Van Lenteren, 2008). Use of integrated pest management anchored on three aspect which includes biological control method, host plant resistance and cultural control method. In the case of biological control method, the population of insect pest is curbed by encouraging the abundance or activity of indigenous natural enemies present or by introducing new natural enemies to the crop to get rid of the insect (Van Lenteren, 2008). On the other hand, breeders select crop cultivars with the high resistance to insect pests using the capability of a crop to decrease its utilization as a host crop by a pest organism, although only few studies have been done on this section. Studies by Lucas (2011) reported that selection done by breeders on most cultivated varieties is based on yield improvement rather than on insect pest. Hence, more focus should be placed to precisely bred for insect pest and disease resistance traits or characteristics. Generally, when a hardy variety is used over a great area the insect pests and diseases display selection pressure to resistant traits (Pretty & Bharucha, 2015).

In case of cultural control method, modification of crop environment makes it less favorable for insect pest invasion (Dent, 1995). The main objective of this method is not to completely eliminate the insect pest, but to retain the insect pest below threshold level that cannot impose substantial harm to the crop. Use of chemical pesticides in integrated pest management is only carried out only when combination of biological control, host plant resistance and cultural control is inadequate (Dent, 1995; Koul *et al*., 2004; Romeis *et al*., 2008). In the situations where pests develop resistance against a given control method or requires repeated use of pesticide, methods to prevent resistance or combination of different pesticides can be applied to reduce the possibility of the insect pest to develop resistance. Successful integrated pest management programs have been developed for many crops over the world and have given rise to decreased pesticide usage and increased economic crop yields, as well as decreased economic risks for farm management due to lesser disparity in the harshness of insect pest problems (Dent, 1995; Koul *et al*., 2004). However, IPM strategies vary from one region to another (Barzman *et al*., 2015).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Site

Two trials were carried out at the Horticulture Research and Teaching Field (Field three) of Egerton University ($0^o23'$ S′ $35^o35'$ E), Njoro, Kenya. Located at 2238 m above sea level in the Lower Highland III Agro Ecological Zone (LH3). The soils are mainly vitric mollic andosols (Jaetzold *et al*., 2006). Weather conditions varied over the two trials (July to October 2019 for trial 1 and January to April 2020 for trial 2) as shown in Table 1.

3.2 Cultivar

Tomato seeds of cultivar Rio Grande were used. The determinate tomato produces a pear-shaped fruit weighing up to 150 g. Tomato and Slender leaf (*Crotalaria brevidens* var. *brevidens* Benth.) seeds used were obtained from Kenya Seed Company in Nakuru, Kenya.

3.3 Root-knot Nematode Inoculum Preparation

3.3.1 Nematode Collection and Augmentation

Root-knot nematodes were obtained from infested tomato plants and multiplied on 2 weeks old potted tomato seedlings using method described by Siddiqui and Akhtar (2007). Galls from infested tomato roots were punched to open up the gall and then mixed with the soil (Siddiqui & Akhtar, 2007). To augment the nematode inoculum, the mixture of punched galls and soil was added to the soil with 2 weeks old potted tomato seedlings. The nematode inoculum was left to infest, develop and multiply on the tomato plants for 8 weeks and then inoculated into the experimental unit.

3.3.2 Nematode Extraction and Inoculum Preparation

After eight weeks of multiplication, nematode eggs were removed from the galled tomato roots to prepare an inoculum as described by Kimenju *et al*. (2010). Galled root tissues were sliced to a length of 0.5 cm and macerated to release egg masses. The eggs were placed in 15 cm diameter sieves of 1 mm pore size, lined with cross–layered tissue paper and placed for hatching in glass petri-dishes containing distilled water and incubated at 27 ^oC. After hatching, the second instar juveniles (J2) were transferred into a 2 litre conical flask. Quantification of juveniles was done under light microscope with gridded petri dishes. Ten 1 ml replicate samples were drawn from the well mixed suspension to establish the number of juveniles per milliliter of sample. Treatment *Meloidogyne* species inoculum suspension was adjusted to contain approximately 250 juveniles.

Table 1: Average monthly air temperature (^oC) and total precipitation (mm) during Tomato production over the two trials (July to October 2019 and January to April 2020)

	Trial 1				Trial 2			
	July	August	September	October	January	February	March	April
Air temperature	19.1	19.2	20.5	19.3	19.6	20.5	21.0	20.4
Total Precipitation	146.7	76.4	89.7	161.6	83.9	40.0	62.8	303.8

Source: Egerton University Engineering Department (2020)

The field experiment was a 2 × 2 × 3 factorial arranged in a Randomized Complete Block Design (RCBD) with 3 replications. The 3 factors under study were cropping regime at 2 levels (tomato intercropped with slender leaf and monocrop tomato), agronet cover at 2 levels (net and no net cover) and fresh organic manure at 3 levels (cow dung, goat dung and no organic manure) giving a total of 12 treatment combinations. The resulting 12 treatment combinations were: (i) monocrop tomato grown under agronet cover with no fresh manure applied; (ii) monocrop tomato grown in the open with fresh cow dung; (iii) monocrop tomato grown in the open with fresh goat dung; (iv) intercrop tomato grown in the open with no fresh manure applied; (v) monocrop tomato grown under agronet cover with fresh cow dung; (vi) monocrop tomato grown under agronet cover with fresh goat dung; (vii) intercrop tomato grown under agronet cover with no fresh manure applied; (viii) intercrop tomato grown in the open with fresh cow dung; (ix) intercrop tomato grown in the open with fresh goat dung; (x) intercrop tomato grown under agronet cover with fresh cow dung; (xi) intercrop tomato grown under agronet cover with fresh goat dung; and (xii) control (monocrop tomato grown in the open with no fresh manure applied). Each experimental unit comprised of 5 troughs 2 m long, 0.4 m wide and 0.2 m high in a 2 m × 2 m plot separated from each other by 1 m path. Each block comprised of 12 such arrangements to accommodate treatment combinations. Individual blocks were separated from each other by 1.5 m path.

3.4 Soil Preparation

Soil for filling the trough was sterilized by covering with airtight clear polyethylene sheets for a period of 8 weeks. Soil was then sampled after sterilization before filling in the trough to ensure that it was free from plant parasitic nematodes. Troughs filled with sterilized soil were placed on a clear polyethylene sheet to prevent contaminating the field with nematodes.

3.5 Crop Establishment

In intercropped plots, 3-row slender leaf seedling were made across the trough at spacing of 60 cm apart in each trough and at 30cm from each tomato plant. Slender leaf seeds drilled in the main field and sowing of tomato seeds were done at the same time. This enabled slender leaf seedlings to establish well by the time tomato seedlings were transplanted. Slender leaf seedlings were thinned when they were around 5 to 8 cm high to attain interspacing of 10 cm, resulting in 12 plants per trough.

Tomato seeds were sown in rows spaced 20 cm apart in a raised nursery bed. After planting, the bed was watered to field capacity. Afterwards, other nursery management activities such as weeding and watering were carried out. Weeding of the nursery bed was done once in 2 weeks after emergence by uprooting the weeds using hands. On the other hand, watering was done during dry spells every morning using watering cans. When tomato seedlings were 5 weeks old, they were transplanted into troughs filled with soil in the field. Diammonium phosphate (DAP) fertilizer was applied at the rate of 240 kg ha^{-1} (HCDA, 2006). Tomato seedlings were planted at spacing of 60 cm apart in each trough giving a total of 4 plants per trough and 20 plants per experimental unit.

3.6 Nematode Inoculation and Treatment Applications

Two weeks after tomato transplanting second instar juvenile stage of *Meloidogyne* species inoculum suspension of approximately 250 juveniles per plant was added to each experimental unit. Thereafter, net covered plots where then covered with agronet cover and fresh organic manure at a rate of 15 tonnes ha^{-1} was also added in each furrows made adjacent to tomato plant to the designated treatments as per the field layout. Agronet cover was mounted on plots using 5 posts of 1.5 m to hold the agronet cover at each corner of the experimental unit and at the center of the plot. Once covered, the agronet cover was pegged at each corner to minimize effects of wind. Agronet covered plots were maintained permanently covered throughout the study period except during weeding and data collection period. The agronet cover used was of 0.4 mm pore diameter sourced from A to Z Textile Mills Ltd., Arusha Tanzania. Fresh cow and goat dung were obtained from Tatton Agriculture Park (TAP), Egerton University.

3.7 Crop Maintenance

Tomato plants were top dressed with Calcium Ammonium Nitrate at the rate of 240 Kg ha^{-1} (HCDA, 2006) applied in two splits; first split at three weeks after transplanting and the second split three week later. The first weeding was done three weeks after transplanting of tomato seedlings and the second weeding was done three weeks after the first weeding. Weeding was done carefully to avoid causing injury on tomato root. During flowering stage of the crop weeding was avoided and also when the troughs were wet to avoid soil compaction. During periods of extended dry spells supplemental irrigation was done with water provided manually with watering cans through the agronet cover.

3.8 Data Collection

Data collection commenced on the second week after transplanting until termination of the study. 4 plants were selected randomly from the inner rows in each experimental unit at the beginning of data collection and marked for data collection on plant growth and yield. The variables measured were:

3.8.1 Carbon Dioxide (CO_2) Determination

Carbon dioxide level was measured using a portable carbon dioxide gas analyzer (Model SKY2000-CO2, Shenzhen YuanTe Technology co., ltd. Shenzhen, China). Carbon dioxide concentration level was measured once weekly beginning, one week after application of treatments through to the first harvest. The readings were taken between 9:00-13:00 hours and recorded as parts per million (ppm) and reported as micromol mol^{-1}. It has been shown that sampling between 9:00 and 13:00 hours is suitable according to the diurnal gas flux variation measurement (Ma *et al*., 2006; Yanfen *et al*., 2003).

3.8.2 Nematode Infestation Assessment

Nematode infestation was determined by evaluating the root-knot nematode population in the soil and gall assessment on tomato roots at the end of the experiment. The populations of root-knot nematodes in the soil were determined by extracting second stage juveniles from 100 cm^3 of soil in every plot, using the method by Coyne *et al*. (2018). A double layered tissue paper was lined in a sieve where the soil samples was placed. 250 ml plastic beakers containing distilled water was used to immerse the sieves containing soil sample half way to allow root-knot nematode migration into the water beneath for 24 hours. Using light microscope with gridded petri dishes, the number of juveniles root-knot nematodes was done where 1 ml of well mixed suspension were drawn to determine the number of juveniles per millimeter to determine the number of nematodes per 100 cm^3 soil of each plot. This was later changed to average root-knot nematodes per treatment combination. In assessing root galls, plants were uprooted gently and their roots washed with tap water to remove the stick soil. Number of galls were established by counting the galls on tomato roots and the data was recorded as number of galls per plant.

3.8.3 Growth Parameters

Plant growth variables measured were plant height, stem collar diameter and internode numbers. The length of main stem of the marked plants in every plot were measured in centimeters (cm) after every two weeks starting from the second week after transplanting to first harvest. The stem diameter of each marked plant was also measured in millimeters (mm) at $\approx$ 2 cm above the ground level after every two weeks using a digital electronic gauge stainless steel vernier caliper (Compton, CA) starting from the second week after transplanting to first harvest. Data collected was used to calculate the average diameter of the stem. The internode numbers of the marked plants were also counted on a two weekly interval and recorded as number of internodes per plant starting from the second week after transplanting through first harvest.

3.8.4 Yield Components and Yield Variables

Yield components of tomato studied were branch numbers per plant, amount of flower trusses per tomato plant and flower quantity per truss. Yield parameters were total fruit numbers per plant, total fresh fruit weight per plant, total marketable and non-marketable fruit weight per plant. The branch numbers of the tagged plants in each plot were counted on a two weekly interval starting from the second week after transplanting to first harvest. Data obtained were recorded as number of branches per plant. The number of flower trusses were counted and recorded from the appearance of first flower truss per plot on a 2 weeks interval until the end of each trial as number of flower trusses per tomato plant. During each data collection day, individual flowers on each truss were also counted and recorded as number of flowers per truss.

Tomato fruits from each experimental unit were harvested twice every week at breaker stage. At each harvest, tomato fruits from each tagged plant were physically counted and later used to calculate the average fruit numbers per plant. At each harvest, tomato fruits from each tagged plant were weighed in kilograms (kg) using a weighing balance (ATZ; Shangai Precision and Scientific Instrument Co., Shangai, China) and later used to compute the average weight of fruits per plant. Afterwards, non-marketable fruits categorized. The marketable and non-marketable fruits from each experimental unit were weighed in kilograms and later used to compute the average weight of fruits per plant of marketable or non-marketable fruits.

3.9 Post-Harvest Quality Determination

Tomato fruits harvested from the various treatments during the field experiment comprised the plant materials for the laboratory experiment. Tomato fruits at breaker stage from each treatment were maintained separately, sorted to remove all materials which could affect the ripening process. Fruits of uniform size based on diameter from the harvest of the various treatments were selected for use in the laboratory experiment. They were then wiped to remove dust and any other dirt that may be on the fruit surfaces. The laboratory experiment for the tomato postharvest quality determination was also set up in a Randomized Complete Block Design (RCBD) with three replications. The experiment therefore comprised of 12 treatments similar to those of the field experiment with 3 replications giving a total of 36 experimental units each represented by a plastic tray. Each experimental unit comprised of 10 tomato fruits randomly selected from the harvest of the individual respective treatments in the field experiment. Tomato fruits from the individual treatments were stored at room temperature and allowed to ripen.

3.10 Data Collection

Data were collected on firmness, total soluble solids (TSS), titratable acidity (TA), fruit sugar: acid ratio and lycopene content. Destructive sampling was done for determination of firmness, total soluble solids, and titratable acidity where four fruits were selected from ripened red tomato drawn from each treatment lot. Lycopene content was on the other hand determined on harvested red ripe tomato fruits.

Fruit firmness was determined using a hand-held penetrometer with 8mm plunger size (Model 62/DR UK) according to procedure by Ritenour *et al*. (2002) and results recorded in kilogram force (KgF). Total soluble solids (TSS) and Titratable acidity (TA) were determined from the similar fruits used for determination of fruit firmness where TSS was determined using a hand-held refractometer (0-30 ºBrix) (RHW Refractometer, Optoelectronic Technology Company Limited, UK) according to Majidi *et al*. (2011) and the results recorded as °Brix. Titratable acidity (TA) of fruits was determined by titrating 5 ml of tomato juice diluted with 50 ml of distilled water against 0.1M NaOH solution, using phenolphthalein as an indicator. The volume of NaOH titre required to change the indicator from colorless to pink were recorded and multiplied by a correction factor of 0.064, the acid factor for the predominant acid in tomato (citric acid), to estimate the TA levels as percentage of citric acid (Anonymous, 1968; Otieno *et al*., 2017; Turhan & Seniz, 2009). Sugar acid ratio was computed from total soluble solids (TSS) and titratable acidity (TA) values using the formula by Ranganna (1986) where:

Sugar: Acid Ratio = ºBrix value /% Citric Acid

Lycopene content was calculated using procedures formulated by Goodwin and Britton (1988). An extractant, acetone-hexane (4:5) mixture was prepared. Samples of fresh ripe fruits were weighed (0.5g) and crashed put in centrifuge tubes. A sample of 15 ml of extractant was added in each centrifuge tubes and put in centrifuge (Kubota HSC-700, Tokyo Japan) for 10 minutes at 4000 revolutions per minute. The supernatant was then put into 25 ml volumetric flasks and topped up with acetone-hexane extractant to 25 ml. Glass cuvettes were used to measure extinction of samples using a spectrophotometer (U-2000, Hitachi, Tokyo, Japan) at a wavelength of 505 nanometer (nm). Lycopene content was formulated using the equation below described by Fish *et al*. (2002):

$$\mathbf{LFW = (E_x \times V)/FW}$$

where LFW is lycopene fresh weight; E_x is Extinction (absorbance at 505 nm); V is volume of the supernatant (25ml); and FW is the sample fresh weight (0.5g)

3.11 Data Analysis

The *Proc univariate* procedure of statistical analysis system (SAS) software version 9.2 (SAS Institute NC., 2010) was used to determine normality and equal variances assumptions of analysis of variance (ANOVA) of the data before analysis. Where assumptions were not met appropriate transformation was done. Data were subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedure in SAS software using below equation:

$$\mathbf{Y_{ijkl} = \mu + \alpha_i + \beta_j + \tau_k + \gamma_l + \beta\tau_{jk} + \beta\gamma_{jl} + \tau\gamma_{kl} + \beta\tau\gamma_{jkl} + \varepsilon_{ijkl}}$$

i = 1, 2, 3; j = 1, 2; k = 1, 2; l = 1, 2, 3

where Y_{ijkl} – Tomato response, μ – Overall mean, α_i -effect of the i^{th} block, β_j – effect of the j^{th} agronet cover level, τ_k – effect of the k^{th} cropping regime, γ_l – effect of the l^{th} organic manure level, $\beta\tau_{jk}$- interaction effect of the j^{th} agronet cover level and k^{th} cropping regime, $\beta\gamma_{jl}$- interaction effect of the j^{th} agronet cover level and l^{th} organic manure level, $\tau\gamma_{kl}$ - interaction effect of the k^{th} cropping regime and l^{th} organic manure level, $\beta\tau\gamma_{jkl}$- interaction effect of the j^{th} agronet cover level, k^{th} cropping regime and l^{th} organic manure level, ε_{ijkl} - random error component which is assumed to be normally and independently distributed about zero mean with a common variance σ^2.

Mean separation test was performed using Tukey's honestly significant difference (Tukey HSD) procedure at a $p \leq 0.05$ level of significance for each evaluated trait whenever the effects were significant (Tukey, 1949). Data on count were subjected to square root transformation but values presented are original means before analysis. Pearson correlation analysis was conducted using the *PROC CORR* procedure in SAS software version 9.2 (SAS Institute NC., 2010) to establish the relationship among CO_2 concentration and tomato plant growth, and yield variables.

The standard error of the mean (Livingston, 2004) was estimated by equation below:

$$\mathrm{SE}_{\bar{x}} = \frac{s}{\sqrt{n}}$$

where, s is the sample standard deviation, and n is the size of the sample.

CHAPTER FOUR

RESULTS

In this chapter, results were presented in the following the order; carbon dioxide (CO_2) concentration, nematode infestation, growth variables, yield components and yield variables and post-harvest fruit quality.

4.1 Effects of Agronet Cover, Cropping Regime and Fresh Organic Manure on Carbon Dioxide (CO_2) Concentration

Carbon dioxide (CO_2) concentration within the proximity of tomato plants was significantly enhanced by use of agronet cover and fresh organic manures (Table 2). The effect of cropping regime on CO_2 concentration was however, not significant. Interaction between agronet cover and cropping regime (Figure 1a), agronet cover and fresh organic manure (Figure 1b) and cropping regime and fresh manure (Figure 1c) were not significant. The three-way interaction between agronet cover, cropping regime and fresh organic manure was also not significant (Table 2). Over the study period, the highest CO_2 concentration was recorded in monocrop tomato plots applied with fresh goat dung and covered with agronet cover while the lowest CO_2 concentration level was in monocrop tomato plots with no fresh manure applied nor agronet cover (Table 2). Averaged across all net cover and fresh manure levels, there was no significant difference in the concentration of CO_2 within the vicinity of monocrop (6.97 micromol mol^{-1}) and intercrop (6.98 micromol mol^{-1}) tomato. Growing tomato under agronet cover however resulted in a significantly higher mean CO_2 concentration of 7.06 micromol mol^{-1} within the crop vicinity compared to a mean concentration of 6.90 micromol mol^{-1} obtained when no agronet cover was used (Table 2). Averaged across all net cover levels and cropping regimes, the mean CO_2 concentration was highest in plots applied with fresh goat manure. The CO_2 concentration obtained for this treatment was however, not statistically different from the amount recorded for the fresh cow dung manure treatment but significantly higher than where fresh manure was not applied at all (Table 2).

Although the interaction between net cover and cropping regime, net cover and fresh organic manure and fresh organic manure and cropping regime were not significant, some trend could be established whereby CO_2 levels tended to be higher in monocrop than in intercropped tomato under agronet cover while in the open, CO_2 levels tended to be higher in intercropped tomato than in monocrop tomato (Figure 1a). The concentration of CO_2 also tended to be higher in monocrop tomato grown with fresh organic manure compared to intercropped tomato

Table 2: Effects of agronet cover and fresh organic manure on carbon dioxide (CO_2) concentration levels (micromol mol^{-1}) under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
Net	Intercrop	7.05*	7.11	6.98	
	Monocrop	7.07	7.14	7.03	**7.06a****
No Net	Intercrop	6.94	6.93	6.87	
	Monocrop	6.91	6.94	6.80	**6.90b**
Organic Manure Means		**6.99e**	**7.03e**	**6.92f**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

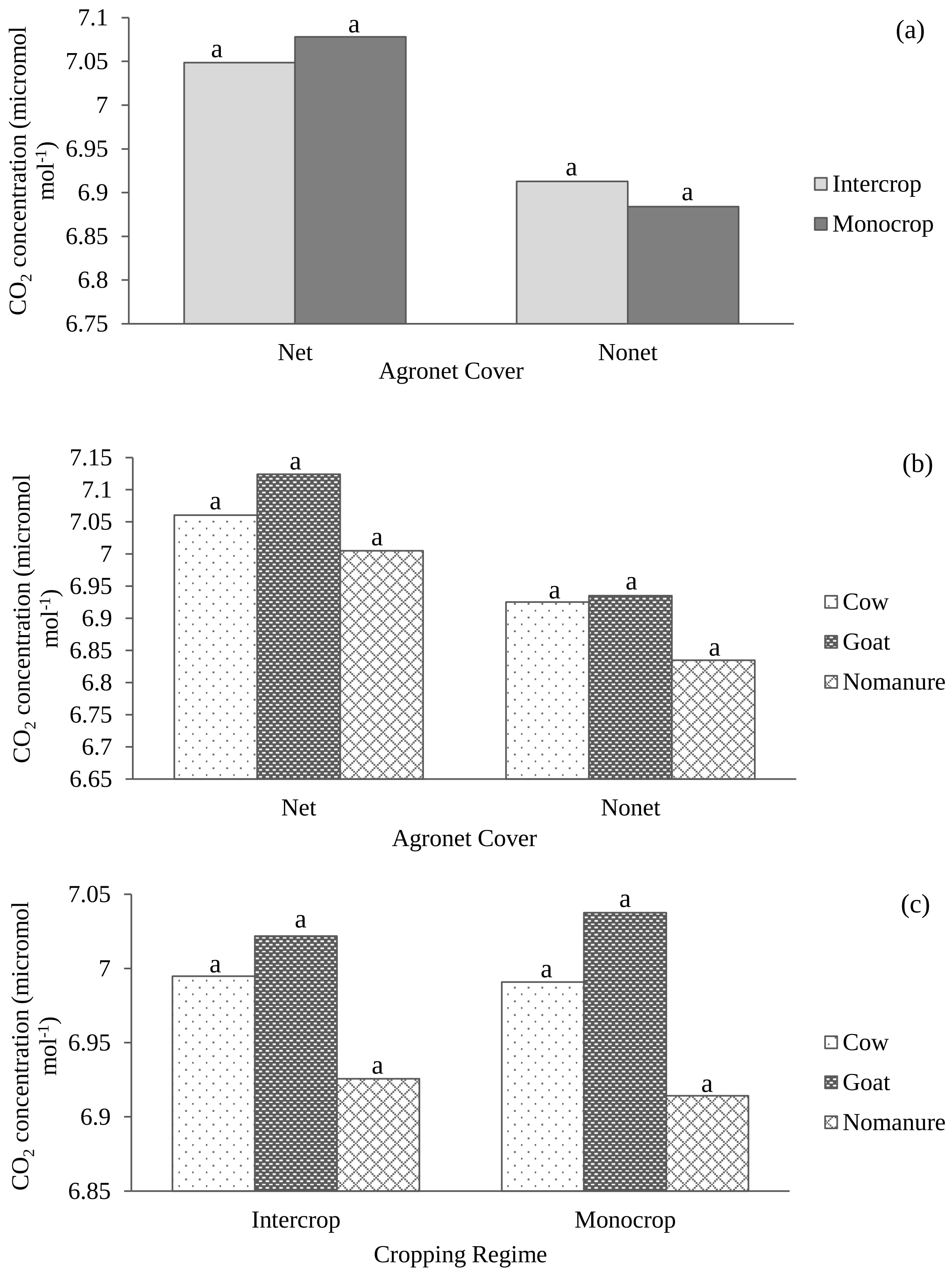


Figure 1: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on carbon dioxide (CO_2) concentration levels (micromol mol^{-1}) during tomato production. Means with the same letter are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$ within a trial.

grown with fresh organic manure (Figure 1c). On the other hand, CO_2 levels within the tomato crop vicinity tended to be highest in plots where fresh goat dung followed by those with fresh cow dung and were lowest in plots with no fresh organic manure applied regardless of the cropping regime. Similarly, CO_2 concentration was higher for all manure levels under agronet cover in relation to when no agronet cover was used (Figure 1b).

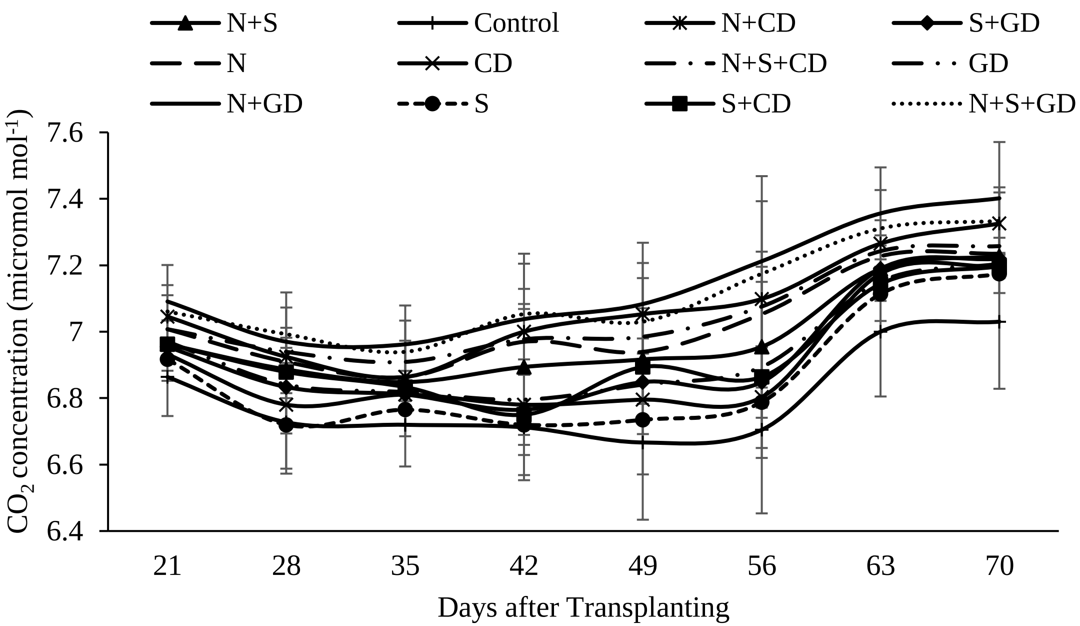
Comparing the trend of CO_2 concentration under the different treatments over the growing period, CO_2 concentration levels tended to be highest in monocrop tomato plots applied with fresh goat dung and covered with agronet while the control treatment (monocrop tomato grown in the open with no fresh manure applied) had the lowest CO_2 concentration levels in most data collection dates (Figure 2). Generally, CO_2 concentration levels under the different treatments tended to be higher as the crop approached maturity.

4.2 Effects of Agronet Cover, Cropping Regime and Fresh Organic Manure on Infestation of Tomato by Root-Knot Nematode

The level of infestation of tomato plants by root-knot nematodes was determined by evaluating the nematode population in the soil and gall assessment on tomato roots.

4.2.1 Effects of Agronet Cover, Cropping Regime and Fresh Organic Manure on the Population of Root-knot Nematodes on Tomato

Use of agronet cover, cropping regime and fresh organic manure significantly influenced juvenile root-knot nematode population in the soil during tomato production in both trials (Table 3). The interaction between agronet cover and cropping regime (Figure 3a), agronet cover and fresh organic manure (Figure 3b) and cropping regime and fresh manure (Figure 3c) on the number of juvenile root knot nematodes were however, not significant in both trials. The three-way interaction between agronet cover, cropping regime and fresh organic manure was also not significant (Table 3). Averaged across all cropping regimes and fresh organic manure levels, there was a significant difference in the number of juvenile root knot nematodes in the soil under agronet cover and when no agronet cover was used in both trials with more juveniles recorded in no net cover than under net cover (Table 3). Intercrop tomato had significantly lower number of juvenile root knot nematodes in the soil of 30.06 in trial 1 and 18.94 in trial 2 averaged across all net covers and fresh manure levels compared to the number of juvenile root knot nematodes in the soil of 42.53 in trial 1 and 28.69 in trial 2 recorded in monocrop tomato. In both trials, the mean number of juvenile root knot



N - $y = 0.0151x^2 - 0.0916x + 7.0528$

CD - $y = 0.0246x^2 - 0.1762x + 7.0739$

Control - $y = 0.0227x^2 - 0.1755x + 7.0133$

N+S - $y = 0.0175x^2 - 0.1133x + 7.0484$

N+CD - $y = 0.0157x^2 - 0.0886x + 7.0704$

GD - $y = 0.0232x^2 - 0.1673x + 7.1013$

S+GD - $y = 0.025x^2 - 0.1792x + 7.1032$

N+S+CD - $y = 0.0135x^2 - 0.0768x + 7.05$

N+S+GD - $y = 0.0137x^2 - 0.0737x + 7.0935$

S+CD - $y = 0.0228x^2 - 0.1668x + 7.1103$

S - $y = 0.027x^2 - 0.1972x + 7.065$

N+GD - $y = 0.0157x^2 - 0.0833x + 7.1127$

Figure 2: Effects of agronet cover, cropping regime and fresh organic manure on carbon dioxide (CO_2) concentration levels (micromol mol^{-1}) overtime during tomato production.

Means with error bars that overlap within a sampling date are not significantly different.

Key: N+S is intercrop tomato grown under agronet cover with no fresh manure applied; N+CD is monocrop tomato grown under agronet cover with fresh cow dung; S+GD is intercrop tomato grown in the open with fresh goat dung; N is monocrop tomato grown under agronet cover with no fresh manure applied; CD is monocrop tomato grown in the open with fresh cow dung; N+S+CD is intercrop tomato grown under agronet cover with fresh cow dung; GD is monocrop tomato grown in the open with fresh goat dung; N+GD is monocrop tomato grown under agronet cover with fresh goat dung; S is intercrop tomato grown in the open with no fresh manure applied; S+CD is intercrop tomato grown in the open with fresh cow dung; N+S+GD is intercrop tomato grown under agronet cover with fresh goat dung; and control is monocrop tomato grown in the open with no fresh manure applied.

Table 3: Effects of agronet cover and fresh organic manure on root-knot nematode population per 100 g of soil under different cropping regimes

	Cropping Regime	Fresh Organic Manure			
		Cow	Goat	No Manure	**Net Cover Means**
		Trial 1			
Net	Intercrop	13.83*	9.83	27.33	
	Monocrop	24.50	21.00	42.67	**23.19b****
No Net	Intercrop	39.17	35.33	54.83	
	Monocrop	48.50	46.83	71.67	**49.39a**
Organic Manure Means		**31.50f**	**28.25f**	**49.13e**	
		Trial 2			
Net	Intercrop	6.50	5.50	22.17	
	Monocrop	18.83	15.33	28.67	**16.17b**
No Net	Intercrop	23.83	21.83	33.83	
	Monocrop	30.33	27.83	51.17	**31.47a**
Organic Manure Means		**19.88f**	**17.63f**	**33.96e**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

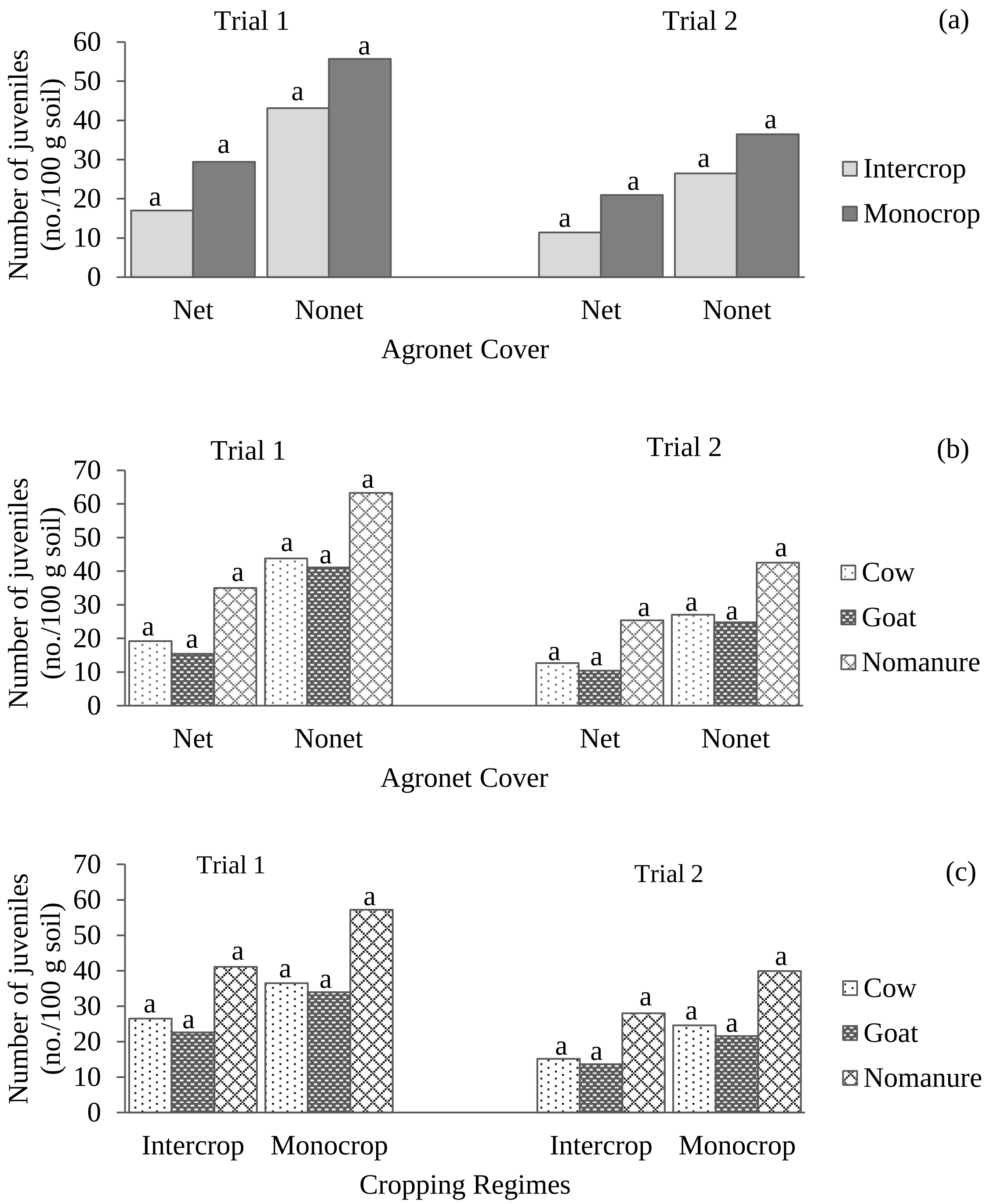


Figure 3: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on number of root-knot nematodes population per 100 g of soil during tomato production. Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

nematodes in the soil averaged across all net cover levels and cropping regimes was lowest in plots applied with fresh goat manure. The number of juvenile root knot nematodes in this treatment was however, not statistically different from that obtained in the soil of tomato grown in plots applied with fresh cow dung manure but significantly lower than that obtained in plants grown without any fresh organic manure applied (Table 3).

The interactions between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime were not significant (Figure 3). However, higher reduction in number of juvenile root knot nematode in the soil was registered in plots with monocrop or intercropped tomato under agronet cover than in the open in both trials. Although agronet cover reduced the number of juvenile root knot nematode in soil in both monocrop and in tomato intercropped with slender leaf the reduction was higher in the intercropped than in the monocrop tomato. Similarly, the number of juvenile root knot nematodes was lower for all manure levels under agronet cover compared to when no agronet cover was used. On the other hand, the number of juvenile root knot nematode in the soil tended to be higher in plots with monocrop tomato grown with fresh organic manure compared to plots with intercrop tomato grown with fresh organic manure in both trials. The highest number of juvenile root knot nematode in the soil was registered in plots with no fresh organic manure applied followed by those applied with fresh cow dung with the number of juvenile root knot nematodes being lowest in plots applied with fresh goat dung regardless of the cropping regime in both trials.

Use of agronet cover, cropping regimes and fresh organic either alone or in combinations reduced number of juvenile root knot nematodes in the soil by between 23.5 - 86.3% in trial 1 and between 33.9 - 89.3% in trial 2, in comparison with the control treatment (monocrop tomato grown in the open with no fresh manure applied) (Table 4). Overall, the lowest number of juvenile root knot nematodes in the soil was recorded in intercrop tomato grown in plots applied with fresh goat dung and covered with agronet while the highest number of juvenile root knot nematodes was registered under control treatment in both trials (Table 4). Intermediate numbers of juvenile root knot nematodes were obtained for the other treatments in both trials.

Table 4: Effects of agronet cover, cropping regime and fresh organic manure on root-knot nematode population per 100 g of soil during tomato production

Agronet cover	Cropping Regime	Fresh organic manure	Nematode juveniles/100 g soil	Reduction (%)	Nematode juveniles/100 g soil	Reduction (%)
			TRIAL 1		**TRIAL 2**	
Net	Intercrop	Cow	13.83	**80.70***	6.50	**87.30**
		Goat	9.83	**86.28**	5.50	**89.25**
		No Manure	27.33	**61.87**	22.67	**55.70**
	Monocrop	Cow	24.50	**65.82**	18.83	**63.20**
		Goat	21.00	**70.70**	15.33	**70.04**
		No Manure	42.67	**40.46**	28.67	**43.97**
No Net	Intercrop	Cow	39.17	**45.35**	23.83	**53.43**
		Goat	35.33	**50.70**	21.83	**57.34**
		No Manure	54.83	**23.50**	33.83	**33.89**
	Monocrop	Cow	48.50	**32.33**	30.33	**40.73**
		Goat	46.83	**34.66**	27.83	**45.61**
		No Manure	71.67		51.17	

*Reduction computed in reference to number of root-knot nematode population per 100 g of soil in the control treatment (monocrop tomato grown in the open with no fresh manure applied).

4.2.2 Effects of Agronet Cover, Cropping Regime and Fresh Organic Manure on Number of Root Galls during Tomato Production

Agronet cover, cropping regime and fresh organic manure significantly reduced the root gall numbers on tomato plants in both trials (Table 5). The interaction between agronet cover and cropping regime, agronet cover and fresh organic manure, and cropping regime and fresh manure were also significant in both trials, (Figure 4). The three-way interaction between agronet cover, cropping regime and fresh organic manure was also significant in both trials (Table 5). Averaged across all cropping regimes and fresh manure levels in both trials, the number of root galls on tomato roots was significantly lower on tomato grown under agronet cover than when tomato was grown without agronet cover (Table 5). Tomato intercropped with slender leaf also had significantly lower root gall numbers per plant of 110.89 in trial 1 and 101.02 in trial 2 averaged across all net covers and fresh manure levels compared to root gall numbers per plant of 160.65 in trial 1 and 139.89 in trial 2 obtained on monocrop tomato. In both trials, the mean number of galls per plant averaged across all net cover levels and cropping regimes was lowest on tomato plants grown in plots applied with fresh goat manure although the number of galls under this treatment was not statistically different from that recorded in tomato plants grown in plots applied with fresh cow dung but was significantly lower than the number of galls recorded in plants grown without any fresh organic manure applied (Table 5).

The interactions between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime were significant (Figure 4). Combining agronet cover and the different cropping regimes resulted in significantly lower number of root galls per plant in intercropped tomato than monocrop tomato under both agronet cover levels in trial 1. In trial 2, intercropped tomato still registered significantly lower number of root galls per plant than monocrop tomato in plots where no agronet cover was used, but the difference was not significant among the cropping regimes under agronet cover (Figure 4a). In both trials, the variation in gall numbers per plant amongst intercrop and monocrop tomato was higher under no net cover than under the agronet cover. Additionally, significantly lower number of root galls was obtained in intercrop or monocrop tomato under agronet cover than when no agronet cover was used. Although use of agronet cover reduced the number of root galls per tomato plant, the reduction of root galls per plant was however, higher under interaction of agronet cover and slender leaf intercrop.

Table 5: Effects of agronet cover and fresh organic manure on the number of root galls per tomato plant grown under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	92.78cd*	86.89d	108.22bcd	
	Monocrop	112.11bcd	105.44bcd	131.67bcd	**106.19b****
No Net	Intercrop	123.22bcd	116.33bcd	137.89bc	
	Monocrop	141.67b	127.00bcd	346.00a	**165.35a**
Organic Manure Means		**117.44f**	**108.92f**	**180.94e**	
		Trial 2			
Net	Intercrop	84.33cd	67.33d	97.78bcd	
	Monocrop	96.00bcd	90.44bcd	106.22bcd	**90.35b**
No Net	Intercrop	117.00bc	107.67bcd	132.00b	
	Monocrop	125.11bc	119.56bc	302.00a	**150.56a**
Organic Manure Means		**105.61f**	**96.25f**	**159.50e**	

*Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

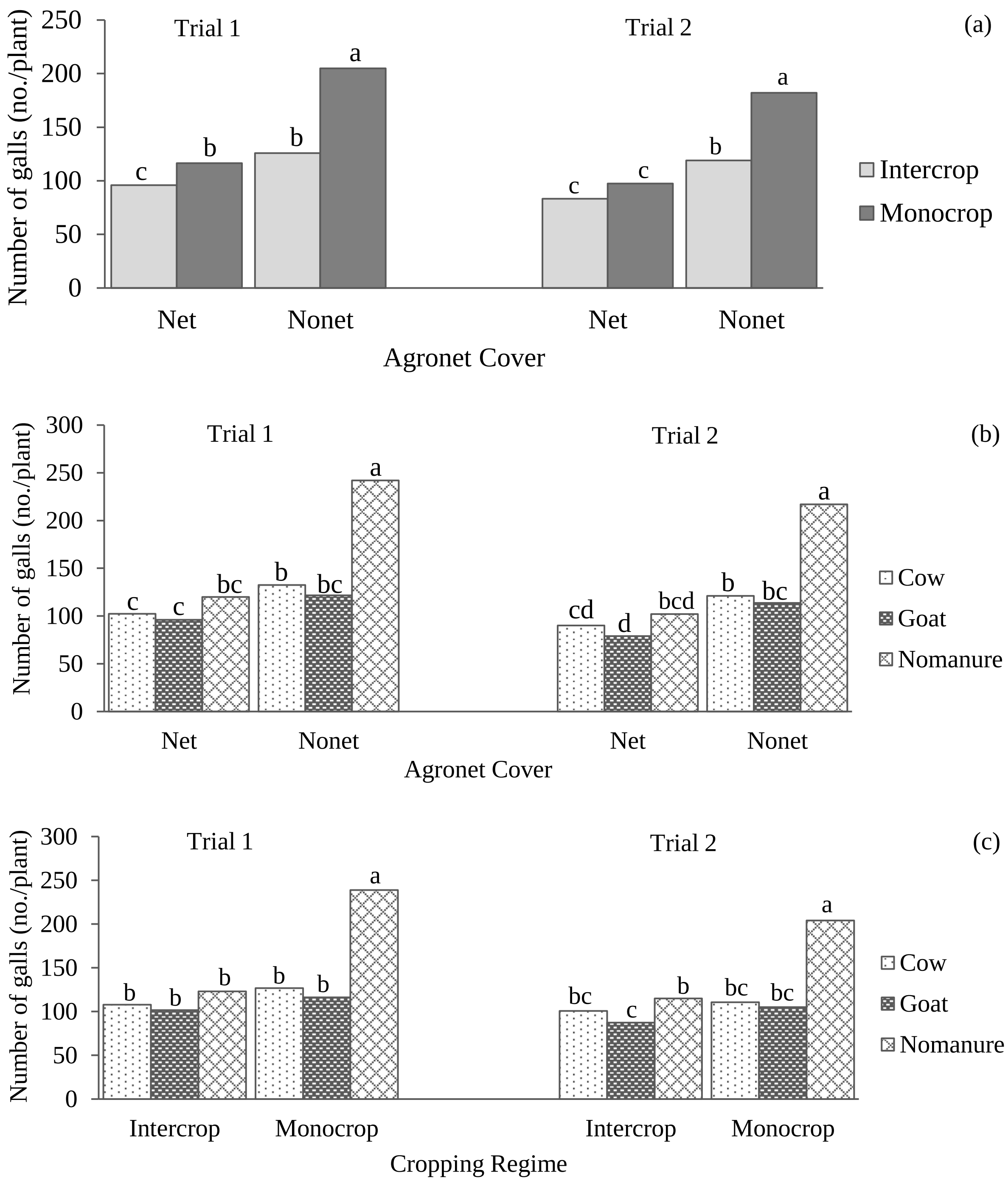


Figure 4: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on number of root galls per plant during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

The number of root galls per plant was significantly lower in tomato grown in the open with fresh organic manure compared to the number on tomato grown under agronet cover without any of the fresh organic manure treatments in both trials (Figure 4b). On the other hand, a lower number of root galls was registered in agronet covered tomato grown in plots with fresh organic manure compared to agronet covered tomato grown without any fresh organic manure, even though the difference was not statistically significant. In both trials, the root gall numbers per plant were significantly lower in agronet covered tomato and tomato grown in the open with fresh cow or goat dung than tomato grown with no fresh organic manure applied and no agronet cover in both trials. In trial 2, significantly lower number of root galls per plant was obtained in plots applied with fresh goat dung and covered with agronet compared to tomato grown in the open with fresh cow or goat dung or with no fresh organic manure applied.

Monocrop tomato resulted in significantly higher number of root galls than intercrop tomato when no fresh organic manure was applied in both trials (Figure 4c). The number of root galls per plant recorded in plots applied with fresh goat dung or fresh cow dung was not significantly different regardless of the cropping regimes. In both trials, the difference in the number of galls per plant in plots applied with fresh organic manure (cow or goat dung) and those without any fresh organic manure was higher under monocrop tomato than in tomato intercropped with slender leaf. Generally, the number of root galls per plant was highest in plots with no fresh organic manure followed by those applied with fresh cow dung and the lowest in plots applied with fresh goat dung regardless of the agronet cover levels or cropping regimes.

Comparing the different treatments during tomato production, use of agronet cover, cropping regime and fresh organic manure significantly decreased number of galls per plant on roots of tomato plants by between 59.1 - 74.9% in trial 1 and between 56.3 - 77.7% in trial 2, in comparison with the control treatment (monocrop tomato grown in the open with no fresh manure applied). Overall, the lowest number of root gall was recorded in tomato intercropped with slender leaf grown in plots applied with fresh goat dung and covered with agronet while the highest number was under control treatment in both trials (Table 6). Intermediate number of root galls were obtained for the other treatments but the differences in gall numbers per plant recorded in plots with agronet cover as one of the combinations were not statistically significant in both trials.

Table 6: Effects of agronet cover, cropping regime and fresh organic manure on number of root galls per plant (no./plant) during tomato production

Agronet Cover	Cropping Regime	Fresh Organic Manure	Gall number (no./plant)	Reduction (%)	Gall number (no./ plant)	Reduction (%)
			TRIAL 1		**TRIAL 2**	
Net	Intercrop	Cow	92.78cd	**73.18***	84.44cd	**72.04**
		Goat	86.89d	**74.89**	67.33d	**77.71**
		No Manure	108.22bcd	**68.72**	97.78bcd	**67.62**
	Monocrop	Cow	112.11bcd	**67.60**	96.00bcd	**68.21**
		Goat	105.44bcd	**69.53**	90.44bcd	**70.05**
		No Manure	131.67bc	**61.95**	106.22bcd	**64.83**
No Net	Intercrop	Cow	123.22bcd	**64.39**	117.00bc	**61.26**
		Goat	116.33bcd	**66.38**	107.67bcd	**64.35**
		No Manure	137.89b	**60.15**	132.00b	**56.29**
	Monocrop	Cow	141.67b	**59.05**	125.11bc	**58.57**
		Goat	127.00bcd	**63.29**	119.56bc	**60.41**
		No Manure	346.00a		302.00a	

*Reduction computed in reference to number of root galls in the control treatment (monocrop tomato grown in the open with no fresh manure applied).

4.3 Effects of Agronet Cover, Cropping Regime and Fresh Organic Manure on Tomato Plant Growth

Tomato plant growth variables considered in this study were plant height, plant collar diameter, number of internodes and number of branches.

4.3.1 Effects of Agronet Cover, Cropping Regime and Fresh Organic Manure on Tomato Plant Height

In both trials, tomato plant height was significantly improved by use of agronet cover (Table 7). The effect of cropping regime and fresh organic manures on tomato plant height was however, not significant (Table 7). Interaction between agronet cover and cropping regime (Figure 5a), agronet cover and fresh organic manure (Figure 5b) and cropping regime and fresh manure (Figure 5c) on tomato plant height were not significant in both trials. The three-way interaction between agronet cover, cropping regime and fresh organic manure was also not significant in both trials (Table 7). Agronet covered tomato plants had significantly taller plants averaged across all cropping regimes and fresh organic manure levels related to those planted without net cover in both trials (Table 7). When plant height was averaged across all net covers and fresh manure levels, tomato plants intercropped with slender leaf were taller (39.18 cm in trial 1 and 59.00 cm in trial 2) compared to those grown as a monocrop (38.58 cm in trial 1 and 57.41 cm in trial 2), although the difference was not statistically In both trials, tomato plant height averaged across all net cover levels and cropping regimes was slightly higher in plots applied with fresh organic manure although not statistically different from the height of plants grown in plots without any fresh organic manure applied (Table 7).

Although the interaction between net cover and cropping regime, net cover and fresh organic manure and fresh organic manure and cropping regime were not significant, plants tended to be slightly taller for all manure levels and cropping regimes under agronet cover compared to when no agronet cover was used. Though net cover resulted in taller plants in both monocrop and intercropped tomato plants, the increase in tomato plant height was higher in intercropped tomato than monocrop tomato in both trials (Figure 5a). Tomato plants also tended to be taller in plots not applied with any fresh organic manure than in plots applied with fresh goat dung under agronet cover unlike in the open where tomato plants were taller in plots applied with fresh goat dung than in plots without any fresh organic manure applied (Figure 5b).

Table 7: Effects of agronet cover and fresh organic manure on plant height (cm) of tomato plants grown under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	42.88*	42.78	43.24	
	Monocrop	45.82	39.65	40.67	**42.51a****
No Net	Intercrop	38.05	35.59	32.57	
	Monocrop	35.20	36.84	33.32	**35.26b**
Organic Manure Means		**40.49****	**38.71**	**37.45**	
		Trial 2			
Net	Intercrop	63.37	61.79	63.97	
	Monocrop	61.41	59.32	60.36	**61.70a**
No Net	Intercrop	55.2	54.67	54.98	
	Monocrop	55.38	57.52	50.49	**54.71b**
Organic Manure Means		**58.84***	**58.32**	**57.45**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

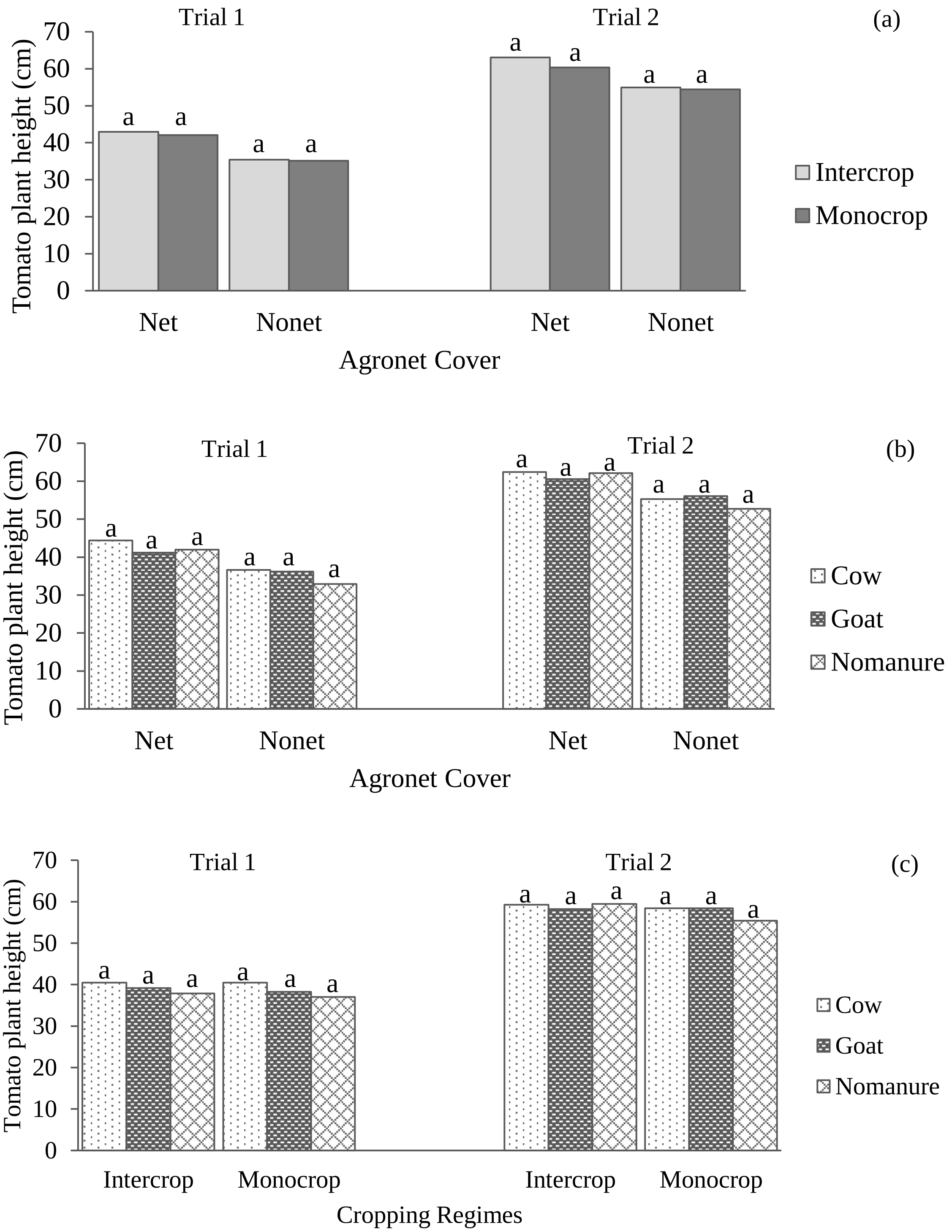


Figure 5: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on plant height (cm) during tomato production.

Means with the same letter in a trial are not significantly different according to Tukey's honestly significant difference test at $p \leq 0.05$.

Comparing the plant height under the different treatment combinations over the growing period, monocrop tomato grown in plots applied with fresh cow dung and covered with agronet in trial 1 and intercropped tomato grown in plots applied with fresh cow dung and covered with agronet in trial 2 registered tallest plant in most data collection dates. The control treatment (monocrop tomato grown in the open with no fresh manure applied) plots had the shortest plants in most dates when the data was collection in both trials (Table 8). Significant differences in plant heights due to treatments effects were recorded between 42 DAT and 70 DAT in trial 1 and between 28 DAT and 70 DAT in trial 2. However, lower heights were observed in monocrop or intercrop tomato grown in the open without agronet cover but with fresh cow or fresh goat dung. Tomato plant grown without agronet cover as monocrop or intercropped with slender leaf but with fresh cow or fresh goat dung resulted in slightly taller plants compared to the control treatment, although no statistically significant difference was observed amongst these treatments and the control in most sampling dates in both trials. In the final data collection date (70 DAT), intercropped tomato grown in plots applied with fresh cow or goat dung and covered with agronet cover had significantly (*p=0.0001*) bigger plants than plants in the control in both trials (Table 8).

4.3.2 Effects of Agronet Cover, Cropping Regime and Fresh Organic Manure on Plant Collar Diameter during Tomato Production

Tomato stem collar diameter was enhanced by use of agronet cover, cropping regime and fresh organic manure in both trials (Table 9). Collar diameter for tomato plants grown under agronet cover was slightly thicker than those for plants grown without the agronet cover in both trials, even though the difference was statistically significant only in in trial 1. The effect of cropping regime and fresh organic manures on tomato collar diameter was however, not significant in both trials (Table 9). Interaction between agronet cover and cropping regime (Figure 6a), agronet cover and fresh organic manure (Figure 6b) and cropping regime and fresh manure (Figure 6c) on collar diameter were not significant in both trials. Three-way interaction between agronet cover, cropping regime and fresh organic manure was also not significant in both trials. Averaged across all net covers and fresh manure levels, tomato intercropped with slender leaf had thicker collar diameter (7.98 mm in trial 1 and 9.99 mm in trial 2) compared to collar diameter of monocrop tomato (7.84 mm in trial 1 and 9.67 mm in trial 2). In both trials, mean collar diameter averaged across all net cover levels and cropping regimes was slightly larger in tomato grown with fresh organic

Table 8: Effects of agronet cover, cropping regime and fresh organic manure on plant height (cm) overtime during tomato production

Agronet cover	Cropping regime	Fresh manure	Days after Transplanting									
			14	28	42	56	70	14	28	42	56	70
			TRIAL 1					TRIAL 2				
Net	Intercrop	Cow	13.33**	22.43	45.09ab*	62.57ab	70.98ab	20.79	48.33ab	66.41a	87.03a	94.28a
		Goat	11.21	19.83	40.07abc	65.72ab	77.00a	18.98	45.59abc	67.33a	84.82a	92.21ab
		No manure	15.67	24.91	47.13a	61.32abc	67.15abc	23.35	51.06a	68.66a	84.88a	91.88ab
	Monocrop	Cow	14.79	26.96	46.43a	66.23a	74.70ab	20.78	47.80ab	66.95a	81.76ab	89.78abc
		Goat	13.00	20.41	37.39abc	58.25abcd	69.19ab	19.99	43.56abc	62.60ab	82.43ab	88.00abc
		No manure	13.83	22.96	40.43abc	60.02abcd	66.11abc	22.80	48.68ab	64.40ab	79.22abc	86.71abcd
No net	Intercrop	Cow	11.79	19.23	38.04abc	54.39abcd	66.81abc	22.00	42.81bc	56.68bc	74.28abc	80.25bcd
		Goat	14.25	20.05	34.90abc	49.14bcd	59.59bc	18.63	44.24abc	56.10bc	72.92abc	81.44abcd
		No manure	12.46	19.22	28.49c	45.97cd	56.69c	22.11	45.61abc	60.77ab	69.44bc	76.99cd
	Monocrop	Cow	13.42	19.58	35.05abc	49.27bcd	58.67bc	18.58	38.88c	57.05bc	77.99abc	84.37abcd
		Goat	13.25	20.62	35.74abc	50.53abcd	64.07abc	20.73	43.24abc	60.11abc	78.13abc	85.36abcd
		No manure	15.21	19.79	31.86bc	44.76d	55.00c	19.34	41.29bc	51.52c	66.22c	74.09d

*Means with the same letter in a trial sampling date are not significantly different, Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

**Means in a trial sampling date with no letter are not significantly different, Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

Table 9: Effects of agronet cover and fresh organic manure on collar diameter (mm) of tomato plants grown under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	8.47*	8.43	8.39	
	Monocrop	8.63	8.45	8.16	**8.42a****
No Net	Intercrop	7.63	7.91	7.05	
	Monocrop	7.64	7.66	6.48	**7.39b**
Organic Manure Means		**8.09***	**8.11**	**7.52**	
		Trial 2			
Net	Intercrop	10.37	10.23	9.92	
	Monocrop	10.12	9.92	10.03	**10.10a**
No Net	Intercrop	9.82	10.07	9.54	
	Monocrop	9.61	9.67	8.69	**9.57a**
Organic Manure Means		**9.98**	**9.97**	**9.55**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

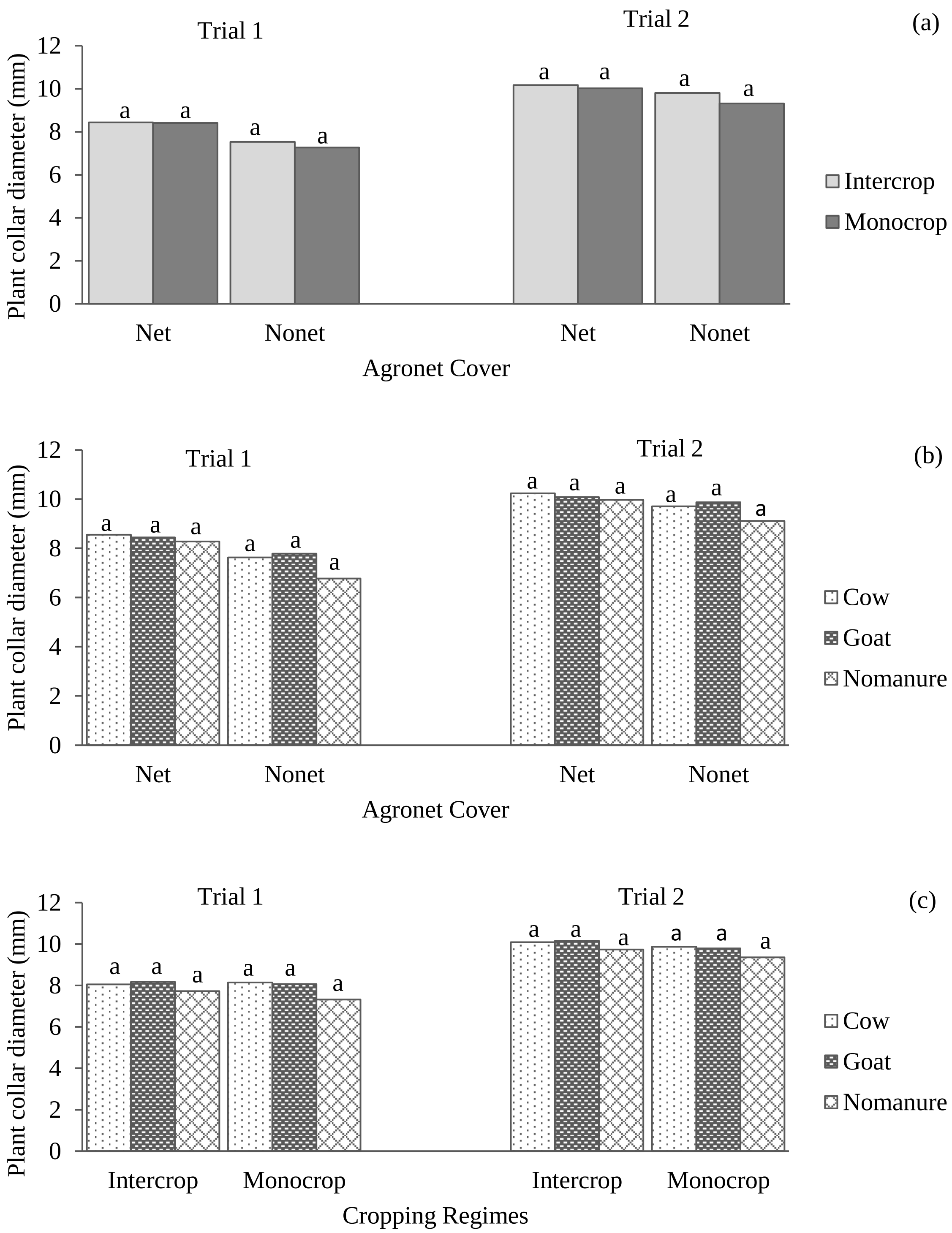


Figure 6: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on plant collar diameter (mm) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

manure than for tomato grown without fresh organic manure, even though the difference was not statistically significant (Table 9).

The interactions between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime were not significant (Figure 6). However, monocrop tomato tended to have slightly thicker stems than intercropped tomato with the difference in stems collar diameter of tomato plants under the two cropping regimes being higher under agronet cover than in the open in both trials (Figure 6a). Tomato stems were thicker in plots applied with fresh cow dung than in plots applied with fresh goat dung under agronet cover while in the open, tomato plants tended to be thicker in plots applied with fresh goat dung than in plots applied with fresh cow dung in both trials (Figure 6b). On the other hand, stem collar diameter tended to be slightly thicker in plots applied with fresh organic manure than in plots with no fresh organic manure applied regardless of the cropping regime in both trials (Figure 6c).

Over the study period, intercropped tomato covered with agronet and grown in plots applied with fresh organic manure produced plants with the thickest stems in both trials (Table 10). In both trials, collar diameter for tomato plants grown as monocrop or intercrop in plots with or without agronet cover and applied with fresh organic manure were not statistically significant. During the final data collection date (70 DAT) in trial 1, intercropped tomato grown with fresh goat dung had the thickest stems followed by intercropped tomato grown with fresh cow dung, followed by monocrop tomato grown with fresh goat dung, then monocrop tomato grown without fresh organic manure applied, then followed by monocrop tomato grown with fresh cow dung and the thinnest plants were in intercropped tomato plots grown without fresh organic manure applied. Similarly in trial 2, intercropped tomato grown with fresh cow dung had the thickest stems followed by intercropped tomato grown with fresh goat dung, followed by monocrop tomato grown fresh goat dung and the thinnest plants were in monocrop tomato grown without application of fresh organic manure (Table 10). The stems of tomato plants also tended to be thinner in monocrop or intercrop tomato grown in the open without agronet cover but with fresh cow or fresh goat dung but the stem collar diameter recorded for tomato grown under these treatments was slightly thicker than for plants grown in control treatment, in both trials.

Table 10: Effects of agronet cover, cropping regime and fresh organic manure on plant collar diameter (mm) overtime during tomato production

Agronet cover	Cropping regime	Fresh manure	Days after Transplanting									
			14	28	42	56	70	14	28	42	56	70
			TRIAL 1					**TRIAL 2**				
Net	Intercrop	Cow	4.00**	5.95	8.74	10.60	12.03	4.62	7.88	11.66	13.13a*	14.55a
		Goat	3.75	6.02	8.93	10.99	12.49	4.41	8.93	11.12	12.55ab	14.14a
		No manure	4.27	6.41	8.79	10.48	11.00	4.82	7.96	10.52	12.78ab	13.81a
	Monocrop	Cow	4.10	6.67	9.14	10.80	11.43	4.45	8.04	11.65	12.59ab	13.86a
		Goat	3.83	6.00	8.72	10.35	12.03	4.11	7.61	11.10	12.77ab	14.03a
		No manure	4.03	6.44	8.28	10.32	11.73	4.52	8.90	10.78	12.24ab	13.72a
No net	Intercrop	Cow	3.19	5.38	8.09	10.41	11.40	4.44	8.14	10.80	12.29ab	13.40ab
		Goat	3.68	6.08	8.06	10.11	11.61	4.56	8.93	10.88	12.34ab	13.65ab
		No manure	3.59	5.22	7.54	8.90	9.98	4.78	7.83	10.55	11.54ab	13.02ab
	Monocrop	Cow	3.60	5.56	8.49	10.40	12.19	4.18	7.31	10.76	12.41ab	13.38ab
		Goat	3.71	5.72	7.89	9.62	11.68	4.56	7.57	10.51	12.35ab	13.35ab
		No manure	3.63	5.26	7.67	9.82	10.57	4.39	7.41	9.28	10.56b	11.83b

*Means with the same letter in a trial sampling date are not significantly different, Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

**Means in a trial sampling date with no letter are not significantly different, Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

4.3.3 Effects of Agronet Cover, Cropping Regime and Fresh Organic Manure on the Number of Internodes during Tomato Production

The internode numbers per plant was not enhanced by use of agronet cover, cropping regime and fresh organic manure in both trials (Table 11). The interaction between agronet cover and cropping regime (Figure 7a), agronet cover and fresh organic manure (Figure 7b) and cropping regime and fresh organic manure (Figure 7c) and the three-way interaction between agronet cover, cropping regime and fresh organic manure were also not significant (Table 11). Although the effect of the factors under study were not significant, a tendency could be established over the study period. The number of internodes per plant tended to be highest in intercrop tomato plots applied with fresh cow dung and covered with agronet cover while the lowest number of internodes per plant was obtained in monocrop tomato plots with no fresh manure applied nor agronet cover (Table 11). Averaged across all net covers and fresh manure levels, no significant difference in internode numbers per plant of intercrop and monocrop tomato in both trials. However, intercrop tomato plants tended to have slightly higher internodes numbers (9.81 in trial 1 and 11.03 in trial 2) compared to the number of internodes per plant (9.52 in trial 1 and 10.64 in trial 2) obtained on monocrop tomato. Growing tomato under agronet cover produced plants with slightly higher number of internodes compared to when no agronet cover was used. Averaged across all net cover levels and cropping regimes, plants grown with fresh cow manure tended to have more internodes followed by those grown in plots applied with fresh goat dung and the least number of internodes per plant was recorded in plots where no fresh manure was applied in both trials (Table 11).

Although the interaction between agronet cover and cropping regime, agronet cover and fresh organic manure and fresh organic manure and cropping regime were not significant, the number of internodes per plant from plots applied with different levels of fresh organic manure or different cropping regimes under agronet cover tended to be slightly higher compared to when no agronet cover was used (Figure 7a and 7b). Though agronet covered plants tended to have more internodes, internode numbers tended to be higher in intercropped tomato than in monocrop tomato in both trials. Similarly, the number of internodes per plant tended to be higher in intercropped tomato grown with fresh organic manure compared to monocrop tomato grown with fresh organic manure applied (Figure 7c).

Table 11: Effects of agronet cover and fresh organic manure on the number of internodes (no./plant) of tomato plants grown under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	10.55*	10.35	9.98	
	Monocrop	10.23	10.08	9.77	**10.16a****
No Net	Intercrop	9.52	9.48	8.96	
	Monocrop	9.15	9.28	8.58	**9.16a**
Organic Manure Means		**9.86***	**9.80**	**9.32**	
		Trial 2			
Net	Intercrop	11.30	10.93	11.18	
	Monocrop	10.95	10.83	10.92	**11.02a**
No Net	Intercrop	10.88	11.05	10.82	
	Monocrop	10.63	10.73	9.77	**10.65a**
Organic Manure Means		**10.94**	**10.89**	**10.67**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

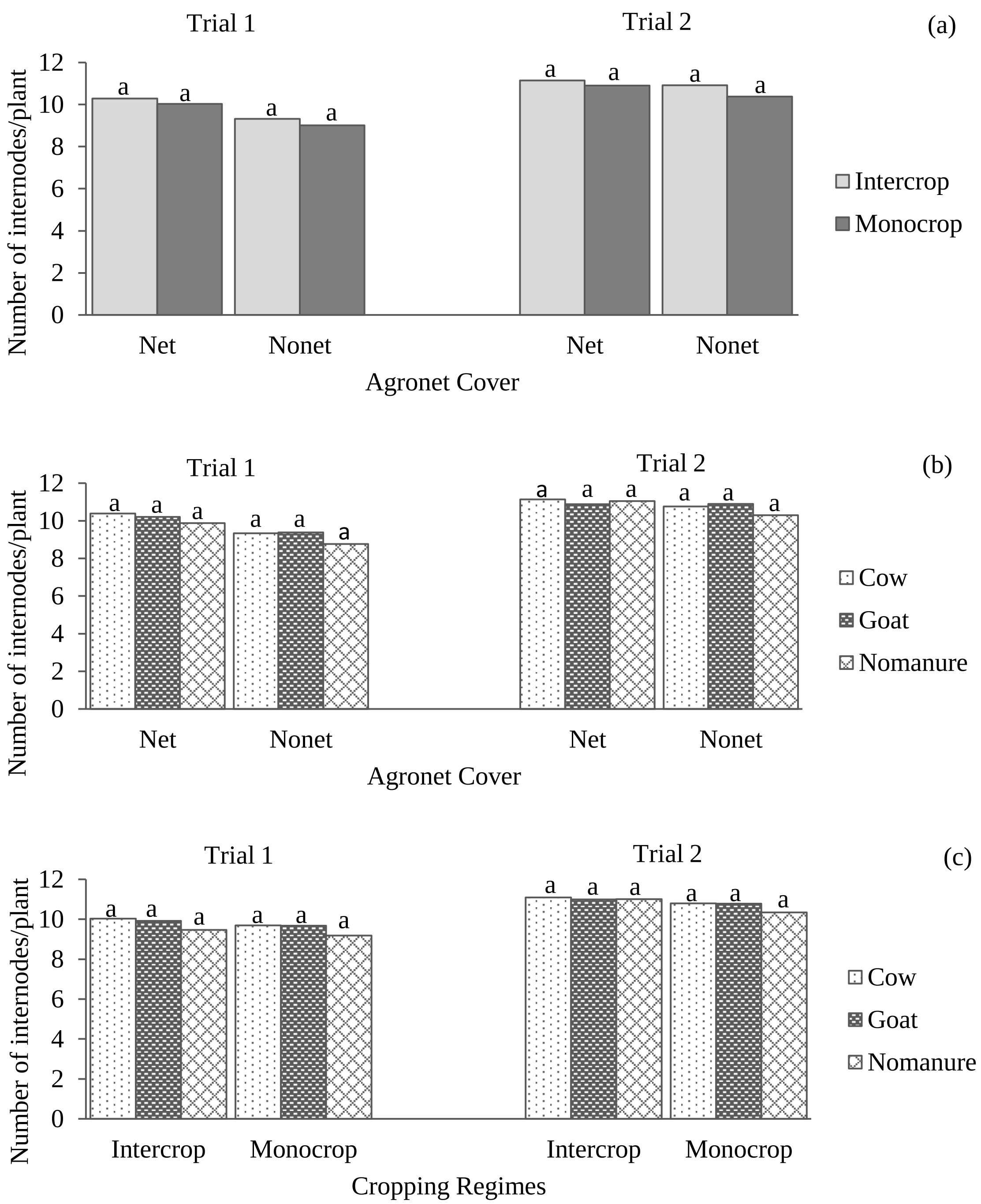


Figure 7: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on number of internodes (no./plant) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

Over the study period, intercropped tomato grown with fresh organic manure and covered with agronet produced plants with more internodes in the two trials (Table 12). In most dates of data collection, internode numbers tended to be higher on intercropped tomato grown with fresh cow dung and covered with agronet while those plants grown under the control treatment (monocrop tomato grown in the open with no fresh manure applied) tended to have fewer internodes in both trials. The number of internodes recorded in monocrop or intercrop tomato grown in the open without agronet cover but with fresh cow or goat dung tended to be slightly higher than those recorded on the control plants, during most data collection dates except at 42, 56 and 70 DAT in trial 1 and at 56 and 70 DAT in trial 2 when the differences in the number of internodes amongst the different treatments were significantly different (Table 12).

4.4 Effects of Agronet Cover, Cropping Regime and Fresh Organic Manure on Yield Components and Yield of Tomato

Tomato yield components studied were: i) number of branches per plant (no./plant); ii) number of flower trusses per tomato plant (no./plant); and ii) flower numbers per truss (no./truss) while yield variables were: i) total fruit numbers per plant (no./plant); ii) total fresh fruit weight per plant (kg/plant); iii) total marketable fruit weight per plant (kg/plant); and iv) non-marketable fruit weight per plant (kg/plant).

4.4.1 Effects of Agronet Cover, Cropping Regime and Fresh Organic Manure on Yield Components of Tomato

i) **Number of Branches per Plant**

Tomato grown under agronet cover significantly influenced the branching ability of tomato plants resulting in plants with more branches under this treatment than in open filed grown tomato in both trials (Table 13). The effect of cropping regime and fresh organic manures on the number of branches per plant was however, not significant in both trials (Table 13). Interaction effect between agronet cover and cropping regime (Figure 8a), agronet cover and fresh organic manure (Figure 8b) and cropping regime and fresh manure (Figure 8c) on the number of branches per plant were not significant in both trials. The three-way interaction between agronet cover, cropping regime and fresh organic manure was however not significant in both trials (Table 13).

Table 12: Effects of agronet cover, cropping regime and fresh organic manure on number of plant internodes (no./plant) overtime during tomato production.

Agronet cover	Cropping regime	Fresh manure	Days after Transplanting									
			14	28	42	56	70	14	28	42	56	70
			TRIAL 1					**TRIAL 2**				
Net	Intercrop	Cow	4.50**	8.00	10.75a*	13.92a	15.58ab	6.08	10.08	12.50	13.42a	14.42a
		Goat	4.25	7.50	10.58a	13.75a	15.67a	5.92	9.50	11.67	13.50a	14.08a
		No manure	4.33	7.67	10.58a	13.00ab	14.33abcd	6.42	9.75	12.42	13.33a	14.00a
	Monocrop	Cow	4.50	7.58	10.42ab	13.58ab	15.08abc	6.08	9.50	11.83	13.42a	13.92ab
		Goat	3.83	7.00	10.75a	13.44ab	15.36ab	5.83	9.33	11.67	13.33a	14.00a
		No manure	4.17	7.50	10.25ab	12.75ab	14.17abcd	6.25	9.58	11.92	13.00a	13.83ab
No net	Intercrop	Cow	4.67	6.92	10.03ab	12.29abc	13.69bcde	6.25	9.17	12.00	13.25a	13.75ab
		Goat	4.42	7.08	9.50ab	12.40abc	14.08abcd	6.50	9.50	12.33	13.08a	13.83ab
		No manure	4.08	6.67	9.33ab	11.58bc	13.13de	6.17	9.75	12.08	12.83ab	13.25ab
	Monocrop	Cow	4.08	6.83	9.42ab	12.17abc	13.26cde	5.92	9.25	11.42	13.00a	13.58ab
		Goat	4.33	6.92	9.75ab	12.08abc	13.33cde	6.17	9.25	11.58	13.00a	13.67ab
		No manure	4.42	6.67	8.83b	10.75c	12.25e	5.83	8.58	10.25	11.67b	12.50b

*Means with the same letter in a trial sampling date are not significantly different, Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

**Means in a trial sampling date with no letter are not significantly different, Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

Table 13: Effects of agronet cover and fresh organic manure on number of branches (no./plant) of tomato plants grown under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	7.44*	7.10	7.00	
	Monocrop	7.10	7.17	6.35	**7.03a******
No Net	Intercrop	6.34	6.19	5.25	
	Monocrop	6.41	5.81	5.06	**5.84b**
Organic Manure Means		**6.82****	**6.57**	**5.92**	
		Trial 2			
Net	Intercrop	7.29	8.33	7.50	
	Monocrop	7.35	7.54	7.23	**7.54a**
No Net	Intercrop	6.98	7.27	6.40	
	Monocrop	7.00	6.83	5.75	**6.70b**
Organic Manure Means		**7.16**	**7.49**	**6.72**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

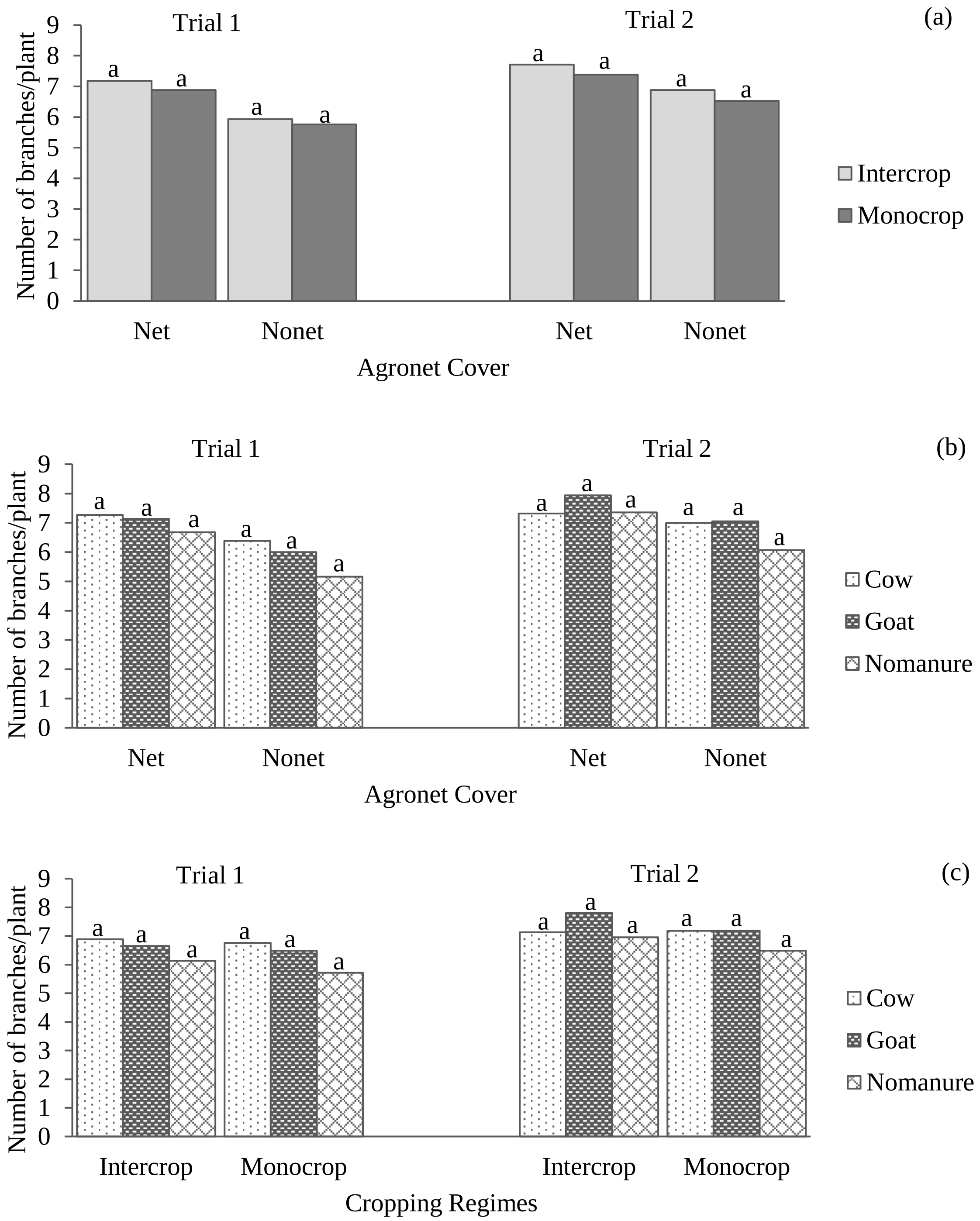


Figure 8: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on number of branches (no./plant) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

Agronet covered tomato plants had significantly more branches per plant averaged across cropping regimes and fresh manure levels related to those grown without the net cover in the two trials (Table 13). Comparing the cropping regime, intercropped tomato plants had slightly higher number of branches per plant compared to monocrop tomato, although the difference in the number of branches amongst the two cropping regimes was not statistically significant during both trials. Intercropped tomato had slightly higher number of branches per plant of 6.55 in trial 1 and 7.30 in trial 2 averaged across all net covers and fresh manure levels compared to the number of branches per plant of 6.32 in trial 1 and 6.95 in trial 2 obtained on monocrop tomato. In both trials, the mean number of branches per plant averaged across all agronet cover levels and cropping regimes tended to be slightly higher for plants grown in plots applied with fresh goat or cow dung although not statistically different from the number of branches from tomato plant grown in plots not applied with fresh organic manure applied (Table 13).

The interactions between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime were not significant in both trials (Figure 8). However, the number of branches per plant tended to be slightly higher in plots with monocrop or intercropped tomato grown under agronet cover than for tomato plants grown in the open in both trials. The number of branches per plant also tended to be slightly higher in intercropped tomato than in monocrop tomato regardless of the agronet cover level (Figure 8a). In both trials, the number of branches per plant also tended to be slightly higher for all manure levels under agronet cover compared to when no agronet cover was used in both trials (Figure 8b). Moreover, the number of branches per plant was also slightly higher in intercropped tomato grown with fresh organic manure compared to monocrop tomato grown with fresh organic manure applied (Figure 8c).

The branch numbers per plant was significantly affected by the three-way interaction (different treatment combinations) except at 28 DAT in both trials (Table 14). In both trials, the number of branches per plant was higher in intercropped tomato grown with fresh goat dung and covered with agronet while the lowest branch numbers per plant was registered on plants in the control during most data collection dates. In most sampling dates in the two trials, agronet covered monocrop or intercropped tomato grown with fresh organic manure had slightly higher number of branches compared to monocrop or intercropped tomato grown in the open with fresh organic manure. By the final data collection date (70 DAT), intercropped tomato grown with agronet cover and fresh goat dung had greater branch numbers with the lowest branch numbers recorded in the control treatment in both trials.

Table 14: Effects of agronet cover, cropping regime and fresh organic manure on number of branches (no./plant) overtime during tomato production

Agronet cover	Cropping regime	Fresh manure	Days after Transplanting							
			28	42	56	70	28	42	56	70
			TRIAL 1				**TRIAL 2**			
Net	Intercrop	Cow	4.83**	6.92a*	8.33a	9.67ab	4.58	6.58ab	7.92ab	10.08a
		Goat	3.50	6.50ab	8.42a	10.00a	5.17	8.00a	9.17a	11.00a
		No manure	4.17	6.58ab	7.83ab	9.42ab	4.50	7.17a	8.17ab	10.17a
	Monocrop	Cow	4.83	6.42ab	7.75ab	9.42ab	4.58	7.00ab	7.83ab	10.00a
		Goat	3.67	6.67ab	8.50a	9.86ab	4.33	7.08a	8.08ab	10.67a
		No manure	3.08	5.75ab	7.42abc	9.17abc	4.00	6.83ab	7.92ab	10.17a
No net	Intercrop	Cow	2.75	6.11ab	7.17abc	9.33abc	4.17	6.42ab	7.42ab	9.92a
		Goat	4.17	5.42ab	6.83abcd	8.33abc	5.25	6.58ab	7.75ab	9.50ab
		No manure	2.75	4.33ab	5.75cd	8.17bc	3.50	5.92ab	6.92b	9.25ab
	Monocrop	Cow	3.75	6.00ab	6.92abcd	8.97abc	4.25	6.50ab	7.50ab	9.75ab
		Goat	2.92	5.42ab	6.42bcd	8.50abc	4.17	6.58ab	7.25ab	9.33ab
		No manure	3.00	4.25b	5.33d	7.67c	3.42	5.08b	6.42b	8.08b

*Means with the same letter in a trial sampling date are not significantly different, Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

**Means in a trial sampling date with no letter are not significantly different, Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

Among the other treatment combinations, the lowest branch numbers per plant was registered on intercrop tomato grown with no fresh manure applied and no agronet during this samplings date in both trials. Similarly, monocrop or intercrop tomato grown in the open without agronet cover but with fresh cow or goat dung had slightly greater number of branches than those grown in the control treatment, even though the difference in branch numbers amongst these treatment combinations and the control were not statistically significant except for intercrop tomato grown with fresh cow dung in trial 2.

ii) Number of Flower Trusses per Plant

The flower trusses per plant was significantly enhanced by use of agronet cover in both trials. The effect of cropping regime and fresh organic manure on number of flower trusses per plant was however, not significant (Table 15). Interaction effects between agronet cover and cropping regime (Figure 9a), agronet cover and fresh organic manure (Figure 9b) and cropping regime and fresh organic manure (Figure 9c) were not significant in both trials. The three-way interaction between agronet cover, cropping regime and fresh organic manure was also not significant (Table 15). Averaged across all net covers and fresh manure levels, flower trusses per plant of intercropped and monocrop tomato were not significantly different in both trials. However, intercropped tomato tended to have slightly more flower trusses per plant of 13.32 in trial 1 and 18.18 in trial 2 compared to the number of flower trusses per plant of 13.06 in trial 1 and 16.89 in trial 2 obtained in monocrop tomato. Growing tomato under agronet cover resulted in a significantly more flower trusses per plant in relation to growing tomato without net cover. Averaged across all net cover levels and cropping regimes, plots applied with fresh goat manure gave the highest number of flower trusses per plant followed by plots applied with fresh cow dung with the least number of flower trusses per plant recorded in plots where no fresh manure was applied in both trials, although the difference in the number of flower trusses obtained from plots treated with the different organic manure levels were not statistically significant (Table 15).

Although the interaction between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime were not significant, the number of flower trusses per plant for all manure levels and cropping regimes under agronet cover was slightly higher compared to when no agronet cover was used. Although both monocrop and intercropped tomato grown under agronet cover had more flower trusses, the

Table 15: Effects of agronet cover and fresh organic manure on the number of flower trusses (no./plant) of tomato grown under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	16.65*	17.13	15.04	
	Monocrop	16.63	16.05	13.81	**15.88a****
No Net	Intercrop	10.42	11.99	8.69	
	Monocrop	13.28	11.63	6.95	**10.49b**
Organic Manure Means		**14.24***	**14.20**	**11.12**	
		Trial 2			
Net	Intercrop	21.27	22.58	17.10	
	Monocrop	18.77	19.31	18.06	**19.52a**
No Net	Intercrop	16.79	17.31	14.04	
	Monocrop	16.08	15.88	13.25	**15.56b**
Organic Manure Means		**18.23**	**18.77**	**15.62**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

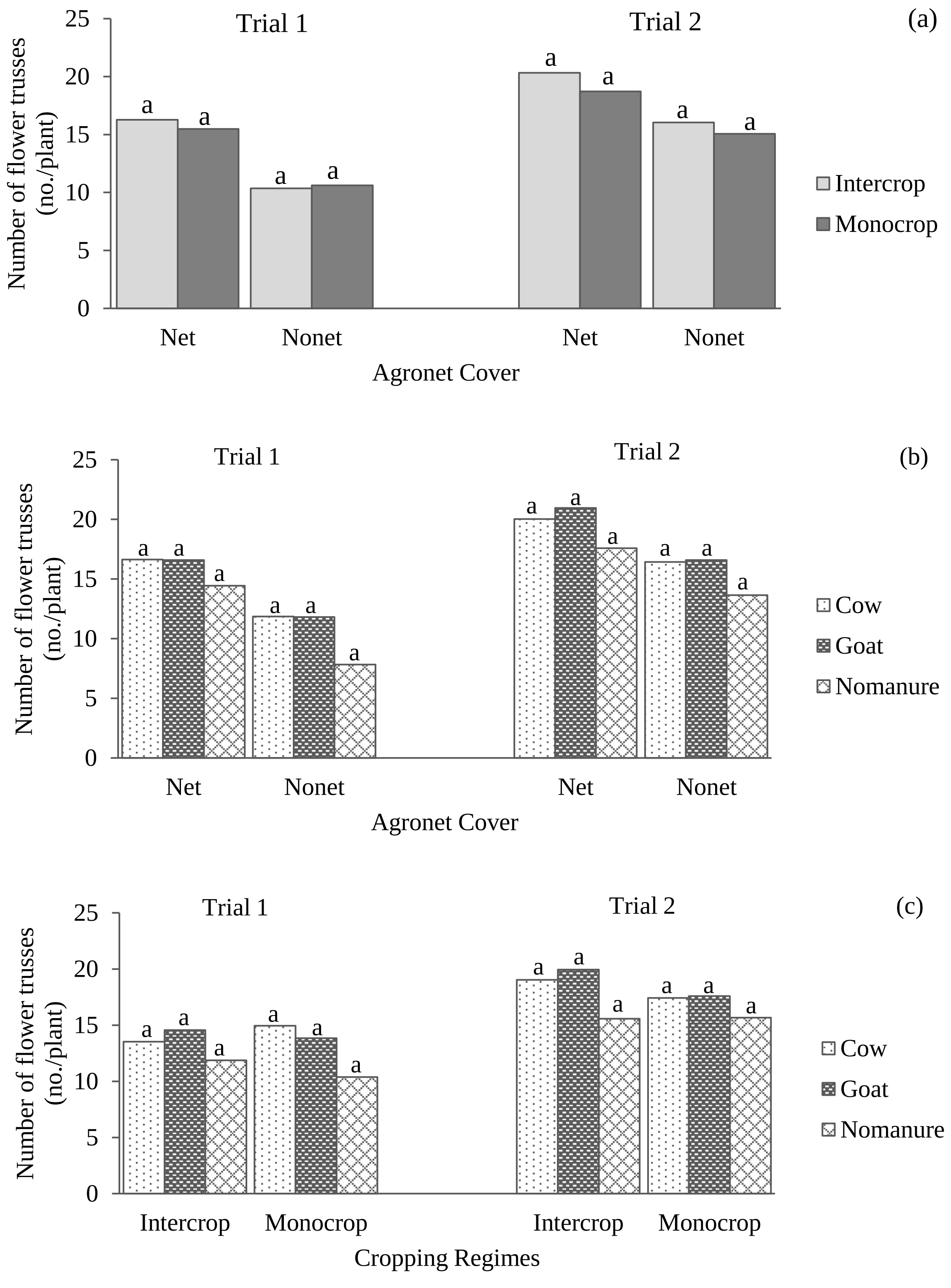


Figure 9: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on number of flower trusses per plant (no./plant) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

increase in the number of trusses was be higher in intercropped tomato than monocrop tomato in both trials (Figure 9a). The number of flower trusses per plant also tended to be higher for all manure levels under agronet cover in relation to when no agronet cover was used in both trials (Figure 9b). Similarly, flower trusses per plant was highest in plots applied with fresh goat dung followed by those applied with fresh cow dung and the least in plots with no fresh organic manure applied regardless of the cropping regime in both trials (Figure 9c). The flower trusses per plant was also higher in intercropped tomato grown with fresh organic manure compared to monocrop tomato grown with fresh organic manure applied.

Although the three way interaction between agronet cover levels, cropping regimes and fresh organic manure levels was not significant, a trend could be established with a slightly higher total number of flower trusses per plant recorded on intercropped tomato grown in plots applied with fresh goat dung and covered with agronet and the lest flower trusses per plant registered under the control treatment (monocrop tomato grown in the open with no fresh manure applied) in both trials (Table 15). Tomato grown as either a monocrop or intercropped with slender leaf in the open without agronet cover but with fresh cow or goat dung registered slightly higher number of flower trusses per plant than those grown in the control in both trials. Amongst the other treatment combination, the number of flower trusses per plant tended to be lower for tomato plants grown under intercropping in the open without application of fresh organic manure in both trials.

Comparing the number of flower trusses per plant under the different treatment combinations over the growing period, intercropped tomato grown in plots applied with fresh goat dung and covered with agronet registered highest number of flower trusses per plant in most data collection dates in both trials (Table 16). The control treatment (monocrop tomato grown in the open with no fresh manure applied) plots had the lowest number of flower trusses per plant in most data collection dates in both trials. Significant differences in number of flower trusses per plant due to treatments effects were recorded between 49 DAT and 77 DAT in both trials. However, lower number of flower trusses per plant were registered in monocrop or intercropped tomato grown in the open without agronet cover but with fresh cow or fresh goat dung. Tomato grown without agronet cover as monocrop or intercropped with slender leaf but with fresh cow or fresh goat dung resulted in slightly higher number of flower trusses per plant compared to the control treatment, although no statistically significant difference was observed amongst these treatments and the control treatment in most sampling dates in both trials (Table 16).

Table 16: Effects of agronet cover, cropping regime and fresh organic manure on number of flower trusses (no./plant) overtime during tomato production

Agronet cover	Cropping regime	Fresh manure	Days after Transplanting							
			35	49	63	77	35	49	63	77
			TRIAL 1				**TRIAL 2**			
Net	Intercrop	Cow	1.92**	9.92ab*	21.08a	33.67ab	2.83	16.58a	27.42ab	38.25a
		Goat	2.00	10.25ab	21.67a	36.97a	2.75	17.08a	29.67a	40.83a
		No manure	2.25	8.83ab	15.92ab	31.75abc	3.00	12.42ab	21.83abc	31.17ab
	Monocrop	Cow	2.33	11.17a	21.00a	31.33abc	3.00	13.83ab	23.17abc	35.08ab
		Goat	2.44	9.17ab	19.25ab	33.32ab	2.33	14.50ab	24.67abc	35.75ab
		No manure	1.72	9.58ab	16.00ab	27.67abc	2.83	12.58ab	22.08abc	34.75ab
No net	Intercrop	Cow	1.61	6.58ab	12.92ab	20.57abc	2.75	12.25ab	21.42abc	30.75ab
		Goat	2.06	7.64ab	13.58ab	24.68abc	3.00	13.00ab	20.83abc	32.42ab
		No manure	1.44	5.92ab	10.44ab	16.94bc	2.58	10.75ab	17.83bc	25.00b
	Monocrop	Cow	1.50	6.75ab	18.25ab	26.63abc	2.08	12.33ab	20.75abc	29.17ab
		Goat	1.61	6.75ab	14.25ab	23.90abc	2.42	12.25ab	20.33abc	28.50ab
		No manure	1.50	4.42b	8.25b	13.63c	2.33	10.08b	16.25c	24.33b

*Means with the same letter in a trial sampling date are not significantly different, Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

**Means in a trial sampling date with no letter are not significantly different, Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

iii) Number of Flowers per Truss

Use of agronet cover influenced the flower numbers per truss of tomato plant in both trials (Table 17). The effect of cropping regime and fresh organic manure on the number of flowers per truss was however, not significant in both trials. Interactive effect between agronet cover and cropping regime (Figure 10a), agronet cover and fresh organic manure (Figure 10b) and cropping regime and fresh organic manure (Figure 10c) as well as the three-way interaction between agronet cover, cropping regime and fresh organic manure (Table 17) were also not significant in both trials. Averaged across all cropping regimes and fresh manure levels in both trials, the number of flowers per truss of tomato plants grown under agronet cover were significantly higher compared to when no agronet cover was used (Table 17). Intercropped tomato had slightly higher number of flowers per truss (4.21 in trial 1 and 4.10 in trial 2) averaged across all net covers and fresh manure levels compared to the number of flowers per truss (4.11 in trial 1 and 3.90 in trial 2) obtained on monocrop tomato. Averaged across all net cover levels and cropping regimes, the highest number of flowers per truss was obtained in plots applied with fresh goat manure followed by those grown in plots applied with fresh cow dung with the least number of flowers per truss recorded in plots where no fresh manure was applied in both trials, but the differences were not statistically significant (Table 17).

The interactions between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime were not significant (Figure 10). However, slightly higher number of flowers per truss was obtained in plots with monocrop or intercropped tomato grown under agronet cover than in tomato grown in the open in both trials. The number of flowers per truss tended to be higher in intercropped tomato than in monocrop tomato under both agronet cover levels (Figure 10a). In both trials, the number of flowers per truss was also greater in all manure levels under agronet cover compared to when no agronet cover was used (Figure 10b). Moreover, flower numbers per truss was also higher in intercropped tomato grown with fresh organic manure in associated with monocrop tomato grown with fresh organic manure applied (Figure 10c).

Although the three-way interaction between agronet cover levels, cropping regimes and fresh organic manure levels was not significant, a trend could be established with a slightly higher total number of flowers per truss recorded on intercropped tomato grown in plots applied with fresh goat dung and covered with agronet and the least flower numbers per truss was registered in the control (monocrop tomato grown in the open with no fresh manure applied) in both trials (Table 17). Monocrop or intercropped tomato grown in the open without agronet cover but with fresh cow or goat dung had a higher number of flowers per truss compared

Table 17: Effects of agronet cover and fresh organic manure on the number of flowers per truss (no./truss) of tomato grown under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	4.53*	4.39	4.49	
	Monocrop	4.29	4.23	4.33	**4.38a****
No Net	Intercrop	4.04	4.14	3.67	
	Monocrop	4.17	4.16	3.46	**3.94b**
Organic Manure Means		**4.26***	**4.23**	**3.99**	
		Trial 2			
Net	Intercrop	4.14	4.26	4.31	
	Monocrop	4.11	4.13	4.01	**4.16a**
No Net	Intercrop	3.93	4.14	3.80	
	Monocrop	3.87	3.94	3.31	**3.83b**
Organic Manure Means		**4.01**	**4.12**	**3.86**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

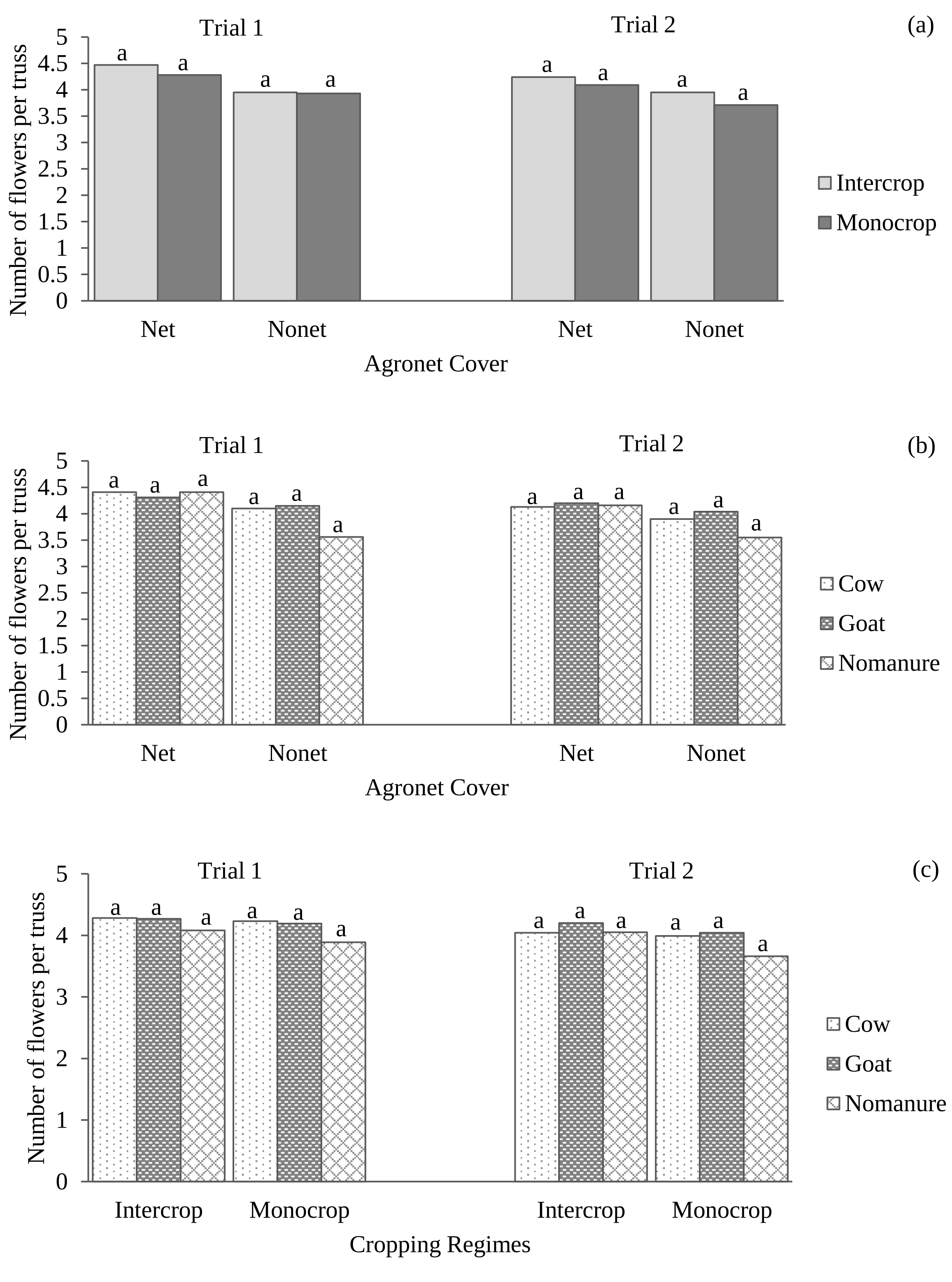


Figure 10: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on flower numbers per truss (no./truss) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

to monocrop tomato grown in plots with no fresh manure nor agronet cover in both trials.

Over the study period, intercropped tomato grown with fresh goat dung manure and covered with agronet produced plants with more flowers per truss while monocrop tomato grown in the open with no fresh manure applied produced plants least number of flower trusses per plant in most dates of data collection in the two trials (Table 18). Significant differences in number of flowers per truss due to treatments effects were recorded between 49 DAT and 77 DAT in trial 1 and between 63 DAT and 77 DAT in trial 2. However, slightly higher number of flowers per truss was obtained in plots with monocrop or intercropped tomato grown in the open without agronet cover but with fresh cow or fresh goat dung than the control treatment plants, although no statistically significant difference was recorded in all data collection dates in both trials.

4.4.2 Effects of Agronet Cover, Cropping Regime and Fresh Organic Manure on Yield of Tomato

i) Number of Fruits per Plant

The fruit numbers per plant was significantly improved by the use of agronet cover and fresh organic manure (Table 19). The effect of cropping regime on number of fruits per plant was however, not significant. Interaction between agronet cover and cropping regime (Figure 11a), agronet cover and fresh organic manure (Figure 11b) and cropping regime and fresh manure (Figure 11c) were not significant in both trials. The three-way interaction between agronet cover, cropping regime and fresh organic manure was also not significant (Table 19). Averaged across all net cover and fresh manure levels, difference in fruit numbers per plant of intercropped and monocrop tomato was not significant in both trials. However, intercropped tomato tended to have slightly higher number of fruits per plant (32.44 in trial 1 and 47.56 in trial 2) compared to fruit numbers per plant (31.06 in trial 1 and 43.39 in trial 2) obtained on monocrop tomato. Tomato grown under agronet cover resulted in a significantly higher of fruit numbers per plant compared to when no agronet cover was used. Averaged across all net cover levels and cropping regimes, the fruits number per plant were highest in plots applied with fresh goat manure although not statistically different from fruit numbers obtained in plots applied with fresh cow dung but significantly higher than those recorded in plots where no fresh manure was applied in both trials.

Table 18: Effects of agronet cover, cropping regime and fresh organic manure on number of flowers per truss (no./truss) overtime during tomato production

Agronet cover	Cropping regime	Fresh manure	Days after Transplanting							
			35	49	63	77	35	49	63	77
			TRIAL 1				**TRIAL 2**			
Net	Intercrop	Cow	3.39**	4.09ab*	5.01a	5.12a	2.78	3.86	4.38a	5.56a
		Goat	3.22	4.16ab	5.08a	5.20a	2.89	4.19	4.45a	5.67a
		No manure	3.70	4.22a	4.99a	5.02ab	3.32	4.02	4.38a	5.35a
	Monocrop	Cow	3.26	4.08ab	4.82ab	5.00ab	3.08	3.90	4.27a	5.20ab
		Goat	2.78	4.10ab	4.94a	5.10a	2.61	3.91	4.46a	5.56a
		No manure	3.26	4.11ab	4.95a	4.98ab	2.74	3.85	4.34a	5.12ab
No net	Intercrop	Cow	3.31	3.61ab	4.51ab	4.72ab	2.58	3.81	4.19ab	5.12ab
		Goat	2.97	3.81ab	4.77ab	5.01ab	3.14	4.03	4.28a	5.08ab
		No manure	2.36	3.49ab	4.22ab	4.59ab	2.44	3.68	4.06ab	4.99ab
	Monocrop	Cow	3.04	4.06ab	4.65ab	4.93ab	2.56	3.64	4.19ab	5.09ab
		Goat	3.04	4.09ab	4.63ab	4.86ab	2.67	3.92	4.15ab	5.05ab
		No manure	2.22	3.31b	3.99b	4.32b	2.17	3.08	3.55b	4.42b

*Means with the same letter in a trial sampling date are not significantly different, Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

**Means in a trial sampling date with no letter are not significantly different, Tukey's Honestly Significant Difference Test at $p \leq 0.05$.

Table 19: Effects of agronet cover and fresh organic manure on the number of fruits per plant (no./plant) of tomato grown under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	41.00*	43.58	35.92	
	Monocrop	37.42	39.58	33.5	**38.50a****
No Net	Intercrop	24.25	28.67	21.25	
	Monocrop	30.33	27.75	17.75	**25.00b**
Organic Manure Means		**33.25e**	**34.90e**	**27.10f**	
		Trial 2			
Net	Intercrop	56.33	59.00	45.33	
	Monocrop	48.67	52.00	46.33	**51.28a**
No Net	Intercrop	41.33	45.00	38.33	
	Monocrop	39.67	42.67	31.00	**39.67b**
Organic Manure Means		**46.50e**	**49.67e**	**40.25f**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

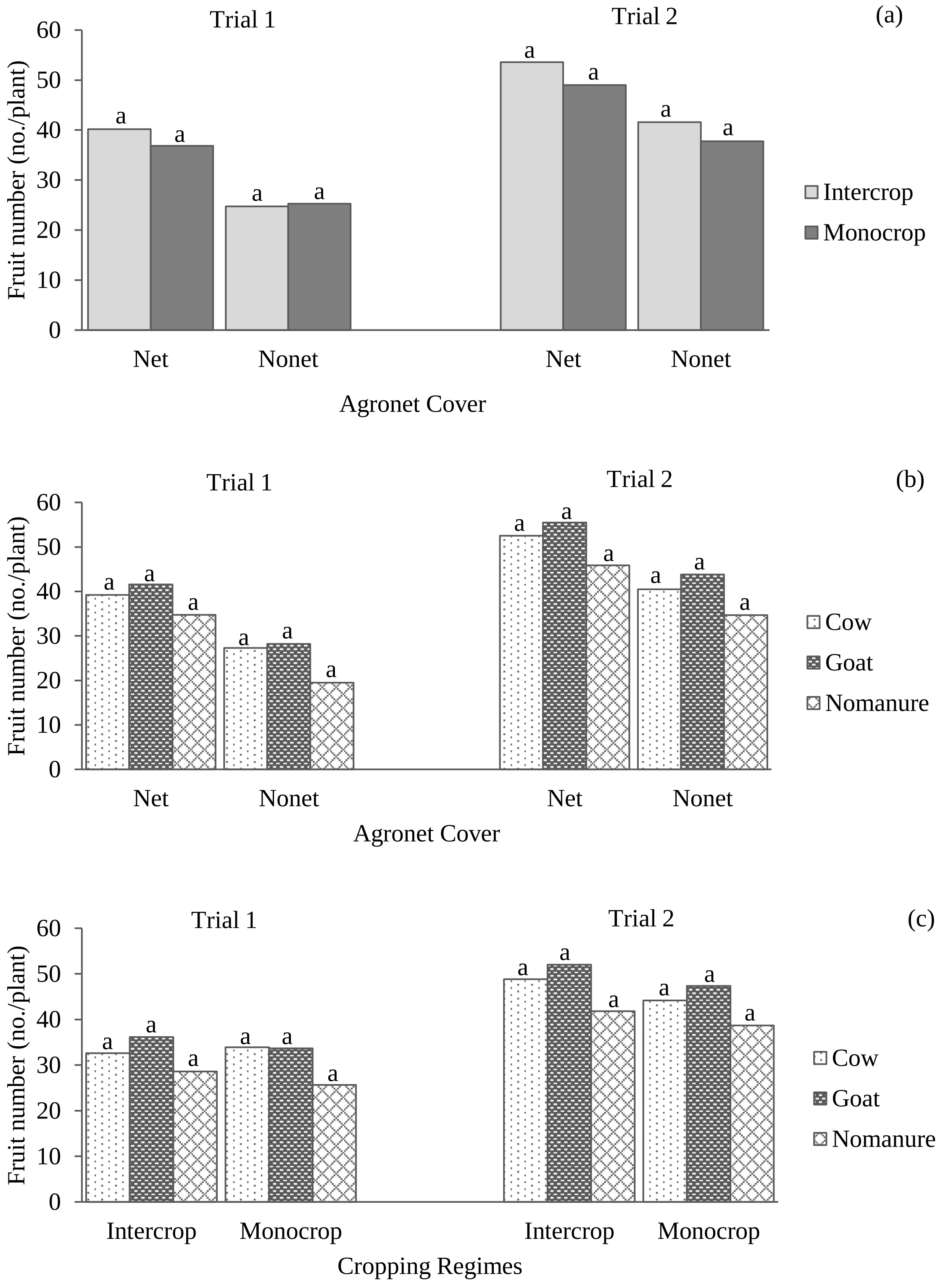


Figure 11: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on number of fruits per plant (no./plant) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

Although the effect of the three-way combination of levels of agronet cover, cropping regimes and fresh organic manure was not significant, the fruit numbers per tomato plant tended to be highest in intercropped tomato grown in plots applied with fresh goat dung and covered with agronet while the lowest number of fruits per tomato plant was found in monocrop tomato plots grown with no agronet cover or fresh manure applied in both trials (Table 19). A higher number of fruits per tomato plant was also obtained when tomato was grown under agronet cover with fresh cow or goat dung compared to when the crop was grown in the open and without the application of fresh organic manure regardless of the cropping regime.

The interactions between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime were not significant (Figure 11). However, fruit numbers per tomato plant was greater in monocrop or intercropped tomato grown under agronet cover than in the open in both trials. Intercropped tomato had more fruits per plant than monocrop tomato regardless of the agronet cover level. In both trials, fruit number per plant also tended to be higher in intercropped tomato grown with fresh organic manure compared to monocrop tomato grown with fresh organic manure applied (Figure 11c). On the other hand, the highest number of fruits per plant was obtained in plots applied with fresh goat dung followed by those applied with fresh cow dung with the lowest number of fruits per tomato plant recorded in plots with where no fresh organic manure was applied regardless of the cropping regime in both trials. Similarly, the number of fruits per plant was slightly higher for all manure levels under agronet cover compared to when no agronet cover was used in both trials (Figure 11b).

ii) Fresh Fruit Weight per Plant

Total fresh fruit weight per plant (kg/plant) was significantly influenced by the use of agronet cover and fresh organic manure (Table 20) in both trials. The effect of cropping regime on total tomato fresh fruit weight per plant was not significant. The interaction effect between agronet cover and cropping regime (Figure 12a), agronet cover and fresh organic manure (Figure 12b) and cropping regime and fresh manure (Figure 12c) on fruit weight per plant were not significant in both trials. The three-way interaction between agronet cover, cropping regime and fresh organic manure was also not significant in both trials (Table 20).

Averaged across all net covers and fresh manure levels, intercrop tomato had slightly higher fresh fruit weight per plant (1.49 kg in trial 1 and 2.43 kg in trial 2) compared to fresh fruit weight per plant (1.37 kg in trial 1 and 2.27 kg in trial 2) obtained on monocrop tomato.

Table 20: Effects of agronet cover and fresh organic manure on fresh fruit weight per plant (kg/plant) of tomato grown under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	2.00*	2.23	1.62	
	Monocrop	1.85	1.80	1.57	**1.84a****
No Net	Intercrop	1.06	1.23	0.83	
	Monocrop	1.14	1.19	0.68	**1.02b**
Organic Manure Means		**1.51e**	**1.61e**	**1.18f**	
		Trial 2			
Net	Intercrop	2.97	3.53	2.49	
	Monocrop	2.88	2.99	2.66	**2.92a**
No Net	Intercrop	1.85	2.05	1.72	
	Monocrop	1.92	1.94	1.23	**1.78b**
Organic Manure Means		**2.40e**	**2.63e**	**2.02f**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

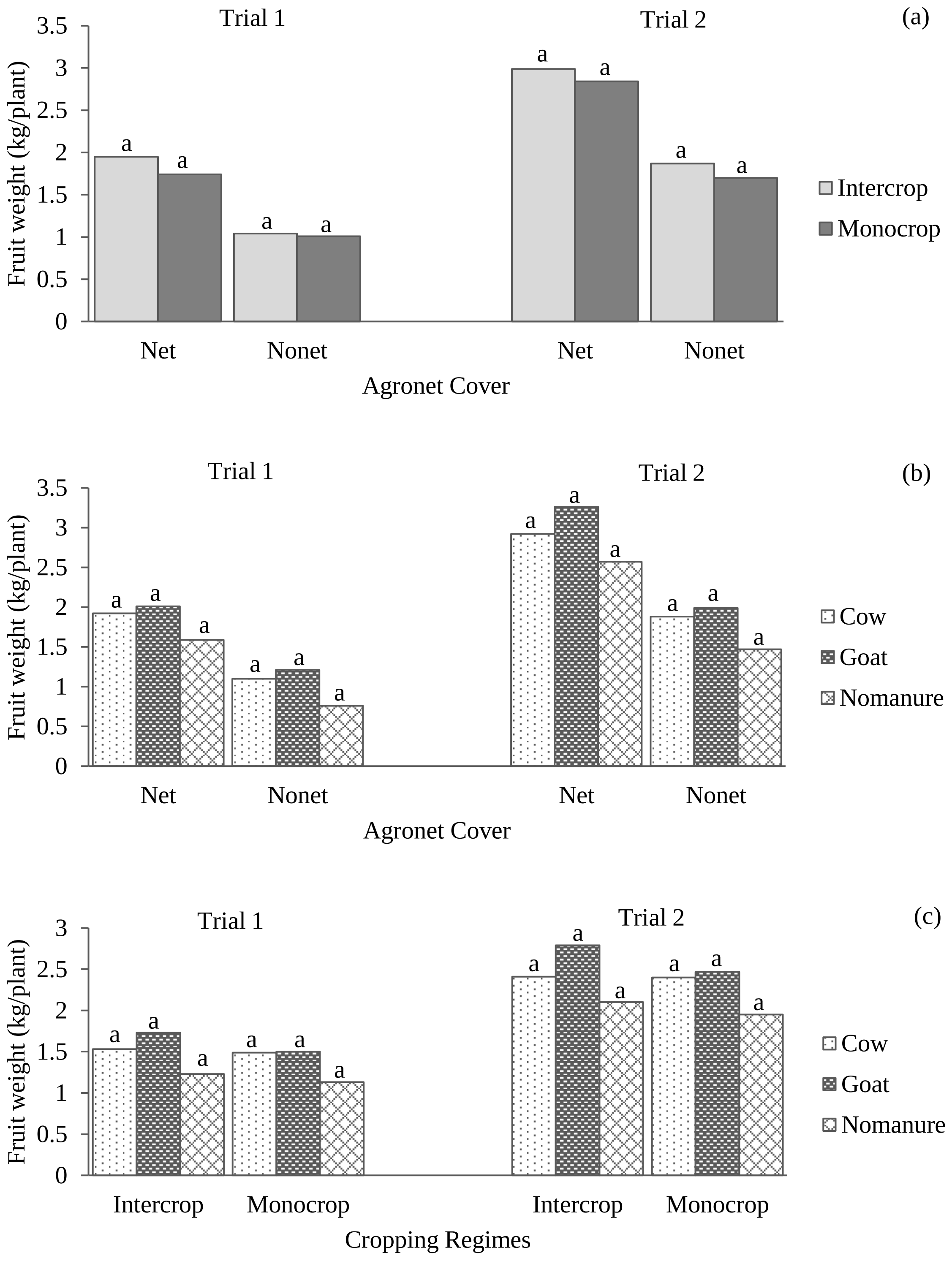


Figure 12: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on fresh fruit weight per plant (kg/plant) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

Agronet covered tomato plants on the other hand produced a higher fresh fruit weight per plant averaged across all cropping regimes and fresh manure levels compared to those grown without agronet cover in both trials. In both trials, total fruit weight per plant averaged across agronet cover levels and cropping regimes was higher in plots applied with fresh goat manure although not statistically different from those obtained in plots applied with fresh cow dung but significantly higher than those recorded in plots where no fresh manure was applied (Table 20).

Although the interactions between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime on total fresh fruit weight per plant were not significant, some trend could be picked whereby the difference in total fresh fruit weight per tomato plant from plots applied with fresh goat dung among the two cropping regimes was greater compared to the total fresh fruit weight per tomato plant in plots applied with fresh cow dung and when no fresh organic manure was applied. In both trials, higher total fresh fruit weight per plant was obtained in plots with monocrop or intercropped tomato under agronet cover than in the open (Figure 12a). Similarly, total fresh fruit weight per plant was also higher for tomato grown all fresh organic manure levels under agronet cover compared to when no agronet cover was used (Figure 12b). On the other hand, total fresh fruit weight per plant was slightly lower in plots with monocrop tomato grown with fresh organic manure compared to plots with intercrop tomato grown with fresh organic manure in both trials (Figure 12c). Plots with no fresh organic manure applied had the lowest total fresh fruit weight per plant followed by those applied with fresh cow dung with the highest total fresh fruit weight per plant recorded in plots applied with fresh goat dung regardless of the cropping regime or agronet cover level in both trials.

Although the three-way interaction between agronet cover levels, cropping regimes and fresh organic manure levels was not significantly different, some trend could be established whereby intercropped tomato grown in plots applied with fresh goat dung and covered with agronet produced highest fresh fruit weight per plant while the lowest fresh fruit weight per plant was recorded in the control in both trials. Other treatments yielded intermediate values of fresh fruit weight in both trials (Table 20).

iii) Total Marketable Fresh Fruit Weight per Plant

Total marketable fresh fruit weight per plant was enhanced by the use of agronet cover and fresh organic manures in both trials (Table 21). The effect of cropping regime on total fresh weight per plant of marketable tomato fruit was however, not significant

Table 21: Effects of agronet cover and fresh organic manure on total marketable fresh fruit weight per plant (kg/plant) of tomato grown under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure: Cow	Goat	No Manure	**Net Cover Means**
		Trial 1			
Net	Intercrop	1.78*	2.04	1.36	
	Monocrop	1.60	1.56	1.30	**1.61a****
No Net	Intercrop	0.78	0.98	0.51	
	Monocrop	0.84	0.90	0.30	**0.72b**
Organic Manure Means		**1.25e**	**1.37e**	**0.87f**	
		Trial 2			
Net	Intercrop	2.68	3.31	2.10	
	Monocrop	2.54	2.66	2.27	**2.59a**
No Net	Intercrop	1.45	1.68	1.25	
	Monocrop	1.49	1.53	0.65	**1.34b**
Organic Manure Means		**2.04e**	**2.29e**	**1.57f**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

in both trials. The interaction between agronet cover and cropping regime (Figure 13a), agronet cover and fresh organic manure (Figure 13b) and cropping regime and fresh manure (Figure 13c) on total fresh weight per plant of marketable tomato fruits were not significant. The three-way interaction between agronet cover, cropping regime and fresh organic manure was also not significant (Table 21). Averaged across all cropping regimes and fresh organic manure levels, the total fresh weight per plant of marketable tomato fruits under agronet cover was significantly higher compared to when no agronet cover was used in both trials (Table 21). Intercropped tomato had slightly higher total fresh weight per plant of marketable tomato fruits of 1.24 kg in trial 1 and 2.08 kg in trial 2 averaged across all net covers and fresh manure levels compared to total fresh weight per plant of marketable tomato fruits of 1.08 kg in trial 1 and 1.86 kg in trial 2 obtained on monocrop tomato. In both trials, the mean total fresh weight per plant of marketable tomato fruits averaged across all net cover levels and cropping regimes was highest in tomato grown in plots applied with fresh goat manure although not statistically different from those grown in plots applied with fresh cow dung but significantly higher than when the plants were grown without any fresh organic manure applied (Table 21).

The interactive effect between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime on total fresh weight per plant of marketable tomato fruits were also not significant (Figure 13). However, total fresh weight per plant of marketable tomato fruit was more in monocrop or intercropped tomato plots under agronet cover than in tomato grown in the open in both trials (Figure 13a). Similarly, total fresh weight per plant of marketable tomato fruits was greater for all manure levels under agronet cover in relation to when no agronet cover was used (Figure 13b). On the other hand, total fresh weight per plant of marketable tomato fruits tended to be lower in monocrop tomato grown with fresh organic manure compared to intercropped tomato grown with fresh organic manure in both trials (Figure 13c). Plots with no fresh organic manure applied had the lowest total fresh weight per plant of marketable tomato fruits followed by those applied with fresh cow dung with the highest total fresh weight per plant of marketable tomato fruit was recorded in plots applied with fresh goat dung regardless of the cropping regime or agronet cover level in both trials.

Although the three-way interaction between agronet cover, cropping regime and fresh organic manure was not significant, total fresh weight per plant of marketable tomato fruits tended to be highest in intercropped tomato grown in plots applied with fresh goat dung and covered with agronet total fresh weight per plant of marketable tomato fruit was lowest under

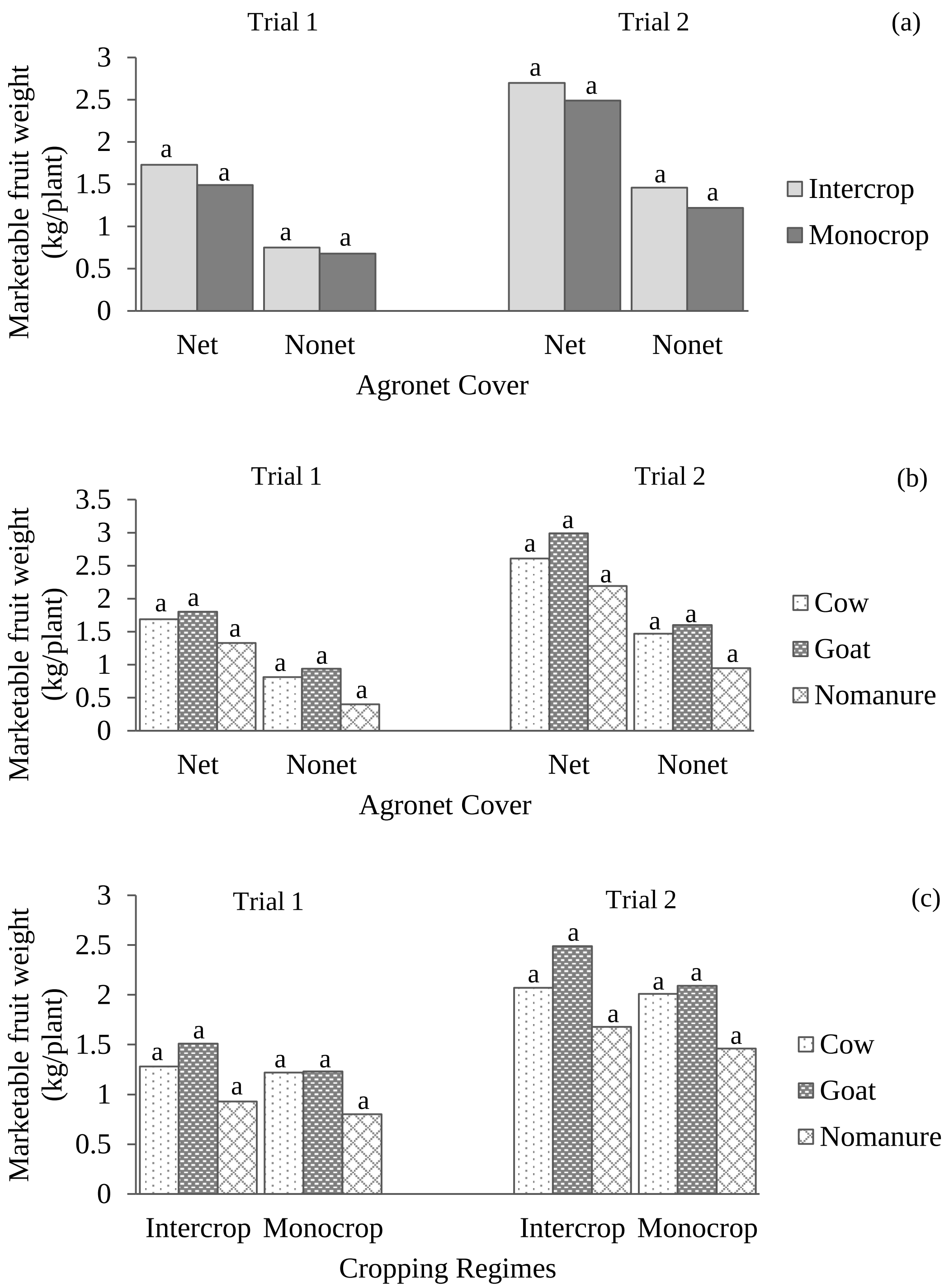


Figure 13: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on total marketable fresh fruit weight per plant (kg/plant) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

the control treatment (monocrop tomato grown in the open with no fresh manure applied) in both trials. Intermediate values of total fresh weight per plant of marketable tomato fruits per plant were obtained in plots with other treatments in both trials (Table 21).

iv) Non-Marketable Fresh Fruit Weight per Plant

Agronet cover, cropping regime and fresh organic manure significantly reduced non-marketable tomato fruits per plant (Table 22). In both trials, the interaction between agronet cover and cropping regime (Figure 14a), agronet cover and fresh organic manure (Figure 14b) and cropping regime and fresh manure (Figure 14c) on non-marketable tomato fruits per plant were however, not significant in both trials. The three-way interaction between agronet cover, cropping regime and fresh organic manure was also not significant (Table 22). Averaged across all cropping regimes and fresh manure levels in both trials, the fresh weight per plant of non-marketable tomato fruit under agronet cover was significantly lower compared to when no agronet cover was used (Table 22). Intercropped tomato had significantly lower fresh weight per plant of non-marketable tomato fruit (0.25 kg in trial 1 and 0.35 kg in trial 2) averaged across all net cover and fresh manure levels compared to fresh weight per plant of non-marketable tomato fruits (0.29 kg in trial 1 and 0.42 kg in trial 2) obtained for monocrop tomato. In both trials, the mean fresh weight per plant of non-marketable tomato fruits averaged across all net cover levels and cropping regimes was lowest in tomato plants grown in plots applied with fresh goat manure although not statistically different from those obtained for tomato plants grown in plots applied with fresh cow dung but significantly lower than for tomato grown in plots with no fresh organic manure applied (Table 22).

The interactive effect between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime on fresh weight per plant of non-marketable tomato fruit were not significant in both trials (Figure 14). However, some trend could be picked where fresh weight per plant of non-marketable tomato fruits tended to be lower monocrop or intercropped tomato plots under agronet cover than in plots in the open in both trials (Figure 14a). Similarly, fresh weight per plant of non-marketable tomato fruits was lower for tomato grown in plots applied with any manure level but under agronet cover compared to when no agronet cover was used (Figure 14b). On the other hand, fresh weight per plant of non-marketable tomato fruits tended to be higher in monocrop tomato grown with fresh organic manure compared to intercropped tomato grown with fresh organic manure in both trials (Figure 14c). The highest fresh weight per plant of non-marketable tomato fruits was

Table 22: Effects of agronet cover and fresh organic manure on non-marketable fresh fruit weight per plant (kg/plant) of tomato grown under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	0.22*	0.19	0.26	
	Monocrop	0.25	0.24	0.27	**0.24b****
No Net	Intercrop	0.28	0.25	0.33	
	Monocrop	0.30	0.29	0.38	**0.31a**
Organic Manure Means		**0.26f**	**0.24f**	**0.31e**	
		Trial 2			
Net	Intercrop	0.28	0.23	0.38	
	Monocrop	0.34	0.33	0.39	**0.33b**
No Net	Intercrop	0.40	0.37	0.47	
	Monocrop	0.43	0.41	0.58	**0.44a**
Organic Manure Means		**0.36f**	**0.33f**	**0.46e**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

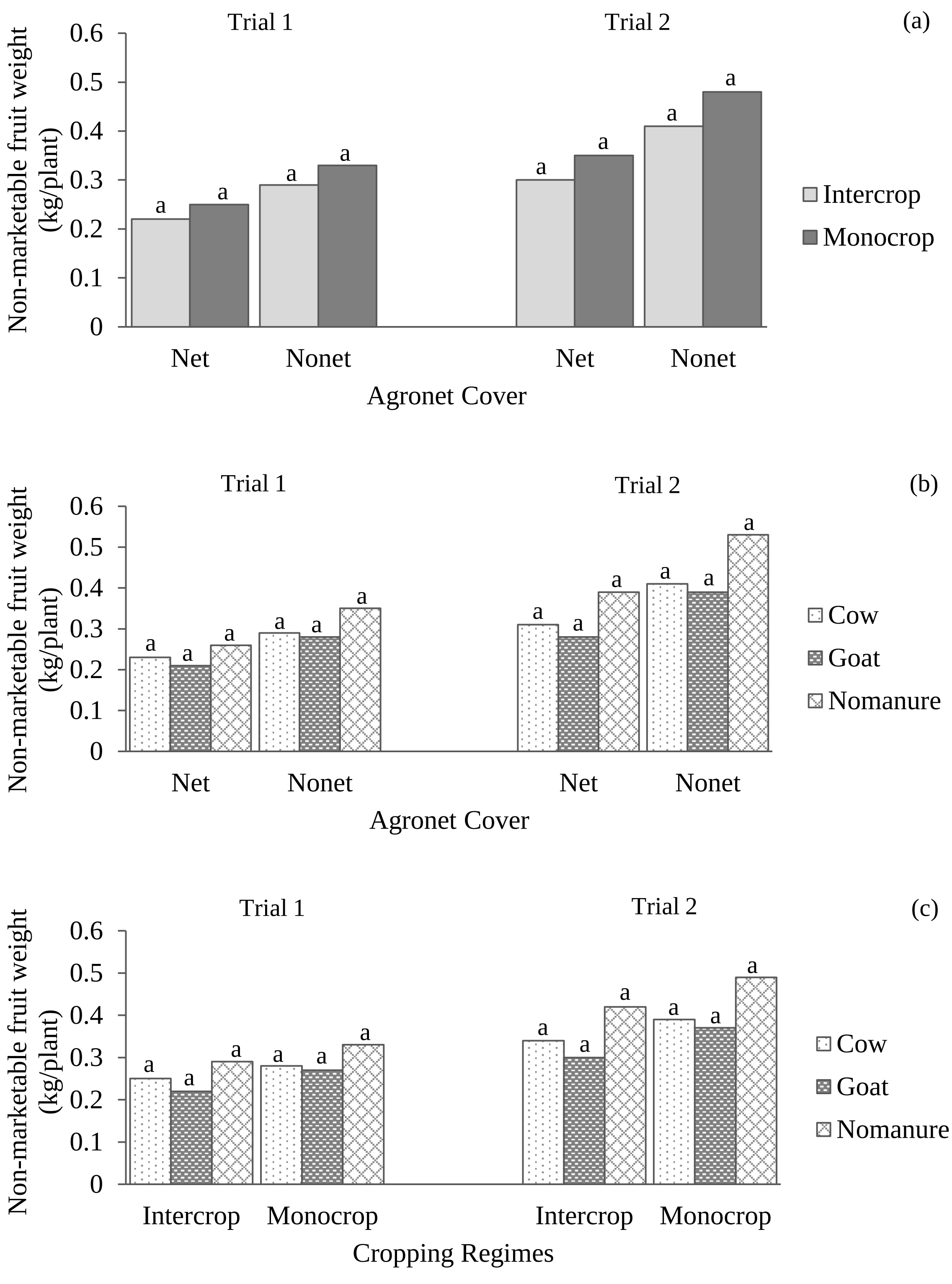


Figure 14: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on non-marketable fresh fruit weight per plant (kg/plant) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

registered in plots with no fresh organic manure applied followed by those applied with fresh cow dung while the lowest fresh weight per plant of non-marketable tomato fruits was registered in plots applied with fresh goat dung regardless of the cropping regime or agronet cover level in both trials.

Although the three-way interaction between agronet cover, cropping regimes and fresh organic manure was not statistically significant, fresh weight per plant of non-marketable tomato fruits tended to be lowest in intercropped tomato grown in plots applied with fresh goat dung and covered with agronet while the highest fresh weight per plant of non-marketable tomato fruit was registered in the control treatment (monocrop tomato grown in the open with no fresh manure applied) in both trials. Other treatments gave intermediate values of fresh weight per plant of non-marketable tomato fruits, although the differences in fresh weight per plant of non-marketable tomato fruits amongst the different treatment combinations were not statistically significant in both trials (Table 22).

4.5 Relationship between Carbon Dioxide (CO_2) Concentration and Tomato Plant Growth and Yield Variables

Correlation analysis exhibited a significant positive correlation between CO_2 concentration within the crop vicinity with tomato plant height, stem diameter, number of internodes and numbers of branches. The CO_2 concentration did not affect numbers of fruit and fruit weight (Table 23).

4.6 Effects of Agronet Cover, Cropping Regime and Fresh Organic Manure on Postharvest Quality of Tomato Fruit

Postharvest fruit quality traits studied were fruit firmness, total soluble solids (TSS), titratable acidity (TA), sugar acid ratio (TSS/TA) and lycopene content.

i) Fruit Firmness

Tomato fruit firmness was enhanced by the use of agronet cover and fresh organic manure in both trials (Table 24). The effect of cropping regime on fruit firmness was however, not significant in both trials. The interaction between agronet cover and cropping regime, agronet cover and fresh organic manure, and cropping regime and fresh manure were on the other hand all significant in both trials (Figure 15). The three-way interaction between agronet cover, cropping regime and fresh organic manure was however, not significant in both trials (Table 24). Averaged across all cropping regime and fresh manure levels in both trials tomato fruits produced under agronet cover were significantly firmer in associated with those produced in the open field with no agronet cover used (Table 24).

Table 23: Pearson correlation coefficients for carbon dioxide (CO_2) concentration and tomato plant growth and yield variables at p≤0.05.

	Plant growth and yield variables					
	Plant height (cm)	Stem diameter (mm)	Number of internodes	Number of branches	Number of fruit	Fruit weight (kg)
Carbon dioxide	0.4360	0.3262	0.4294	0.4351	0.1191	0.2930
p-value	0.0001	0.0052	0.0002	0.0001	0.6380	0.2380

Table 24: Effects of agronet cover and fresh organic manure on fruit firmness (KgF) of tomato grown under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	2.95*	2.93	2.68	
	Monocrop	2.87	2.85	2.75	**2.84a****
No Net	Intercrop	2.64	2.71	2.55	
	Monocrop	2.51	2.63	2.25	**2.55b**
Organic Manure Means		**2.74e**	**2.78e**	**2.56f**	
		Trial 2			
Net	Intercrop	3.33	3.41	3.18	
	Monocrop	3.24	3.28	3.14	**3.26a**
No Net	Intercrop	3.03	3.11	2.91	
	Monocrop	3.08	3.07	2.73	**2.98b**
Organic Manure Means		**3.17e**	**3.21e**	**2.99f**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

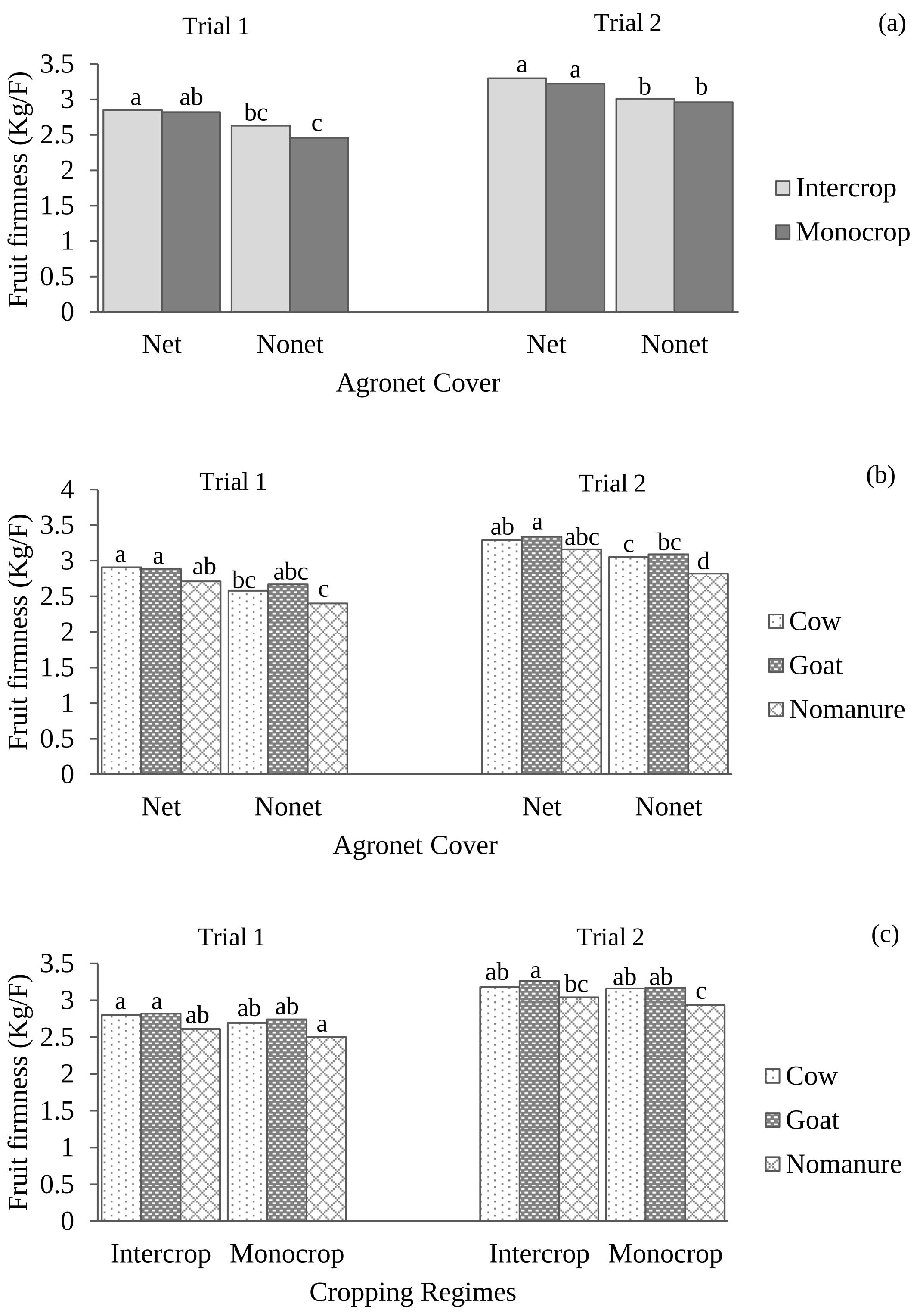


Figure 15: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on tomato fruit firmness (KgF) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

Intercropped tomato produced tomato fruit that were slightly firmer (firmness of 2.74 KgF in trial 1 and 3.16 KgF in trial 2) averaged across all net cover and fresh manure levels compared to tomato fruit firmness of 2.64 KgF in trial 1 and 3.09 KgF in trial 2 obtained for monocrop tomato. In both trials, mean tomato fruit firmness averaged across all net cover levels and cropping regimes was higher in plots applied with fresh goat manure although not statistically different from the firmness recorded for fruits produced by plants in plots applied with fresh cow dung but significantly higher than the firmness recorded for tomato fruits produced in plots where no fresh manure was applied (Table 24).

The interactions between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime on tomato fruit firmness were also significant (Figure 15). Interactive effects of agronet cover and cropping regimes showed that intercropped tomato had slightly firmer tomato fruit than monocrop tomato in under agronet cover levels in both trials (Figure 15a). However, significantly firmer tomato fruits were obtained in intercropped or monocrop tomato under agronet cover than when no agronet cover was used in trial 2. Firmer tomato fruits were obtained in agronet covered tomato grown in plots applied with fresh organic manure compared to agronet covered tomato grown without any fresh organic manure, even though the difference was not statistically significant (Figure 15b). On the other hand, tomato fruit tended to be slightly firmer for intercropped tomato grown in plots applied with fresh organic manure compared to monocrop tomato grown in plots applied with fresh organic manure in both trials (Figure 15c). In trial 2, tomato fruits were significantly firmer in tomato grown with no agronet cover but with fresh organic manure applied compared to tomato grown in open field plots without any fresh organic manure applied. Generally, firmer fruits were obtained in plots applied with fresh goat dung followed by those applied with fresh cow dung and the least firmness was registered in tomato fruits grown in plots without any fresh organic manure applied regardless of the cropping regime or agronet cover level in both trials.

Although the three-way interaction between agronet cover, cropping regimes and fresh organic manure was not statistically significant, firmer fruits were obtained in intercropped tomato grown in plots applied with fresh goat dung and covered with agronet while the control treatment plants produced fruits with the least firmness in both trials (Table 24). More firm tomato fruits were obtained from monocrop or intercropped tomato grown in plots applied with fresh cow dung or without fresh organic manure but covered with agronet in both trials compared to fruits produced by tomato plants grown with no agronet cover. On the other hand, monocrop or intercropped tomato plants grown in the open without agronet cover but with fresh organic manure tended to produce fruits that were slightly firmer than fruits produced under the control treatment.

ii) Total Soluble Solids (TSS)

Total soluble solids of tomato fruits were improved by the use of agronet cover, cropping regime and fresh organic manure during tomato production in both trials (Table 25). The interactive effects of agronet cover and cropping regime (Figure 16a), agronet cover and fresh organic manure (Figure 16b) and cropping regime and fresh manure (Figure 16c) on tomato fruit total soluble solids were also significant in both trials except the interaction between cropping regime and fresh manure in trial 1. The three-way interaction between agronet cover, cropping regime and fresh organic manure was however, not significant in both trials (Table 25). Averaged across all cropping regime and fresh manure levels in both trials, the mean total soluble solids of tomato fruits were significantly higher for fruits produced under agronet cover compared to when no agronet cover was used (Table 25). Intercropped tomato produced fruits with significantly higher total soluble solids (5.12% in trial 1 and 5.34% in trial 2) averaged across all net cover and fresh manure levels compared to fruit total soluble solids (4.99% in trial 1 and 4.97% in trial 2) obtained for monocrop tomato. In both trials, mean fruit total soluble solids averaged across all net cover levels and cropping regimes was higher for fruits produced in plots applied with fresh goat manure although not statistically different from those obtained for fruits produced in plots applied with fresh cow dung but significantly higher than those recorded for fruits produced in plots where no fresh manure was applied (Table 25).

The interaction between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime significantly influenced tomato fruit total soluble solids (Figure 16). Interactive effects of agronet cover and cropping regime showed that intercropped tomato produced fruits with higher total soluble solids compared to monocrop tomato regardless of the agronet cover level in both trials (Figure 16a). Moreover, significantly higher fruit total soluble solids were recorded for fruits from intercropped or monocrop tomato produced under agronet cover than for fruits produced with no agronet cover in trial 1. In both trials, tomato fruit total soluble solids were higher in tomato produced under agronet cover with fresh organic manure than in fruits produced with no agronet cover but with fresh organic manure, although the difference was not statistically significant (Figure 16b). However, significantly higher fruit total soluble solids were realized for tomato fruits produced under agronet cover with fresh cow or goat dung applied compared to fruit total soluble solids obtained for tomato fruits produced in the open with no agronet cover nor fresh organic

Table 25: Effects of agronet cover and fresh organic manure on total soluble solids (%) of tomato fruits produced under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	5.38*	5.75	5.35	
	Monocrop	5.20	5.45	5.17	**5.38a****
No Net	Intercrop	4.75	4.87	4.63	
	Monocrop	4.67	5.15	4.30	**4.73b**
Organic Manure Means		**5.00ef**	**5.30e**	**4.86f**	
		Trial 2			
Net	Intercrop	5.75	6.00	5.22	
	Monocrop	5.50	5.50	4.92	**5.48a**
No Net	Intercrop	5.00	5.25	4.83	
	Monocrop	4.75	4.83	4.33	**4.83b**
Organic Manure Means		**5.25e**	**5.40e**	**4.83f**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

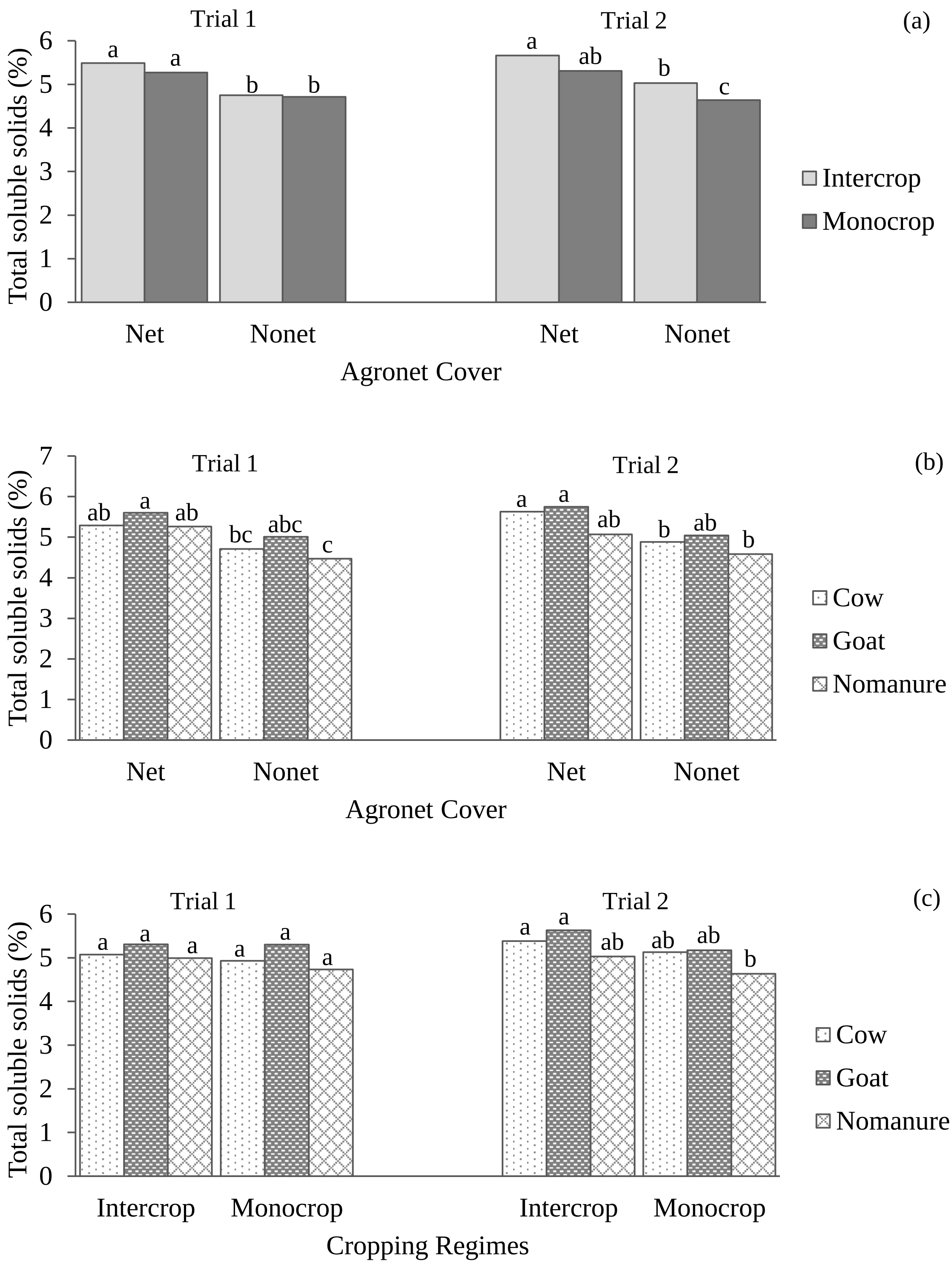


Figure 16: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on total soluble solids (%) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

manure applied. Tomato fruit total soluble solids obtained for intercropped tomato grown in plots applied with fresh organic manure was higher compared to that of monocrop tomato grown in plots applied with fresh organic manure in both trials (Figure 16c). In trial 1, the interactions between fresh organic manure and cropping regime were not significant. Fruit total soluble solids tended to be higher for fruits from intercropped tomato applied with fresh goat dung during production than in monocrop tomato. In trial 2 however, fruit total soluble solids were significantly higher in intercropped tomato grown with fresh organic manure compared to monocrop tomato grown in plots without any fresh organic manure.

Although the three-way interaction between agronet cover, cropping regime and fresh organic manure was not significant, fruits obtained from intercropped tomato grown in plots applied with fresh goat dung and covered with agronet tended to have the highest total soluble solids levels of 5.75% and 6.00% in trial 1 and 2, respectively while the lowest sugar levels of 4.30% in trial 1 and 4.33% in trial 2 was recorded in fruits from the control treatment (Table 25). Monocrop or intercropped tomato grown in the open without agronet cover but with fresh cow or goat dung produced tomato fruits with slightly more total soluble solids in relation to the control treatment tomato in both trials.

iii) Titratable Acidity (TA)

The titratable acidity content of tomato fruits was significantly influenced by the use of agronet cover, cropping regime and fresh organic manure during tomato production in both trials (Table 26). The interaction between agronet cover and cropping regime (Figure 17a), agronet cover and fresh organic manure (Figure 17b) and cropping regime and fresh manure (Figure 17c) on fruit titratable acidity were also significant in both trials. The three-way interaction between agronet cover, cropping regime and fresh organic manure was not however not statistically significant in both trials (Table 26). Averaged across all cropping regime and fresh manure levels in both trials, the mean fruit titratable acidity for tomato produced under agronet cover was lower in relation to that of tomato fruits produced in the open with no agronet cover used (Table 26). Intercropped tomato had significantly lower fruit titratable acidity (0.39% in trial 1 and 0.33% in trial 2) averaged across all net cover and fresh manure levels compared to fruit titratable acidity (0.41% in trial 1 and 0.36% in trial 2) recorded for monocrop tomato. The mean fruit titratable acidity averaged across all net cover levels and cropping regimes was lowest in tomato fruits produced from plots applied with fresh goat manure,

Table 26: Effects of agronet cover and fresh organic manure on titratable acidity (%) content of tomato fruits produced under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	0.35*	0.33	0.37	
	Monocrop	0.36	0.35	0.40	**0.36b****
No Net	Intercrop	0.44	0.42	0.45	
	Monocrop	0.43	0.44	0.49	**0.45a**
Organic Manure Means		**0.40f**	**0.39f**	**0.43e**	
		Trial 2			
Net	Intercrop	0.29	0.26	0.30	
	Monocrop	0.31	0.27	0.35	**0.30b**
No Net	Intercrop	0.36	0.35	0.39	
	Monocrop	0.40	0.38	0.42	**0.38a**
Organic Manure Means		**0.34f**	**0.32g**	**0.37e**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

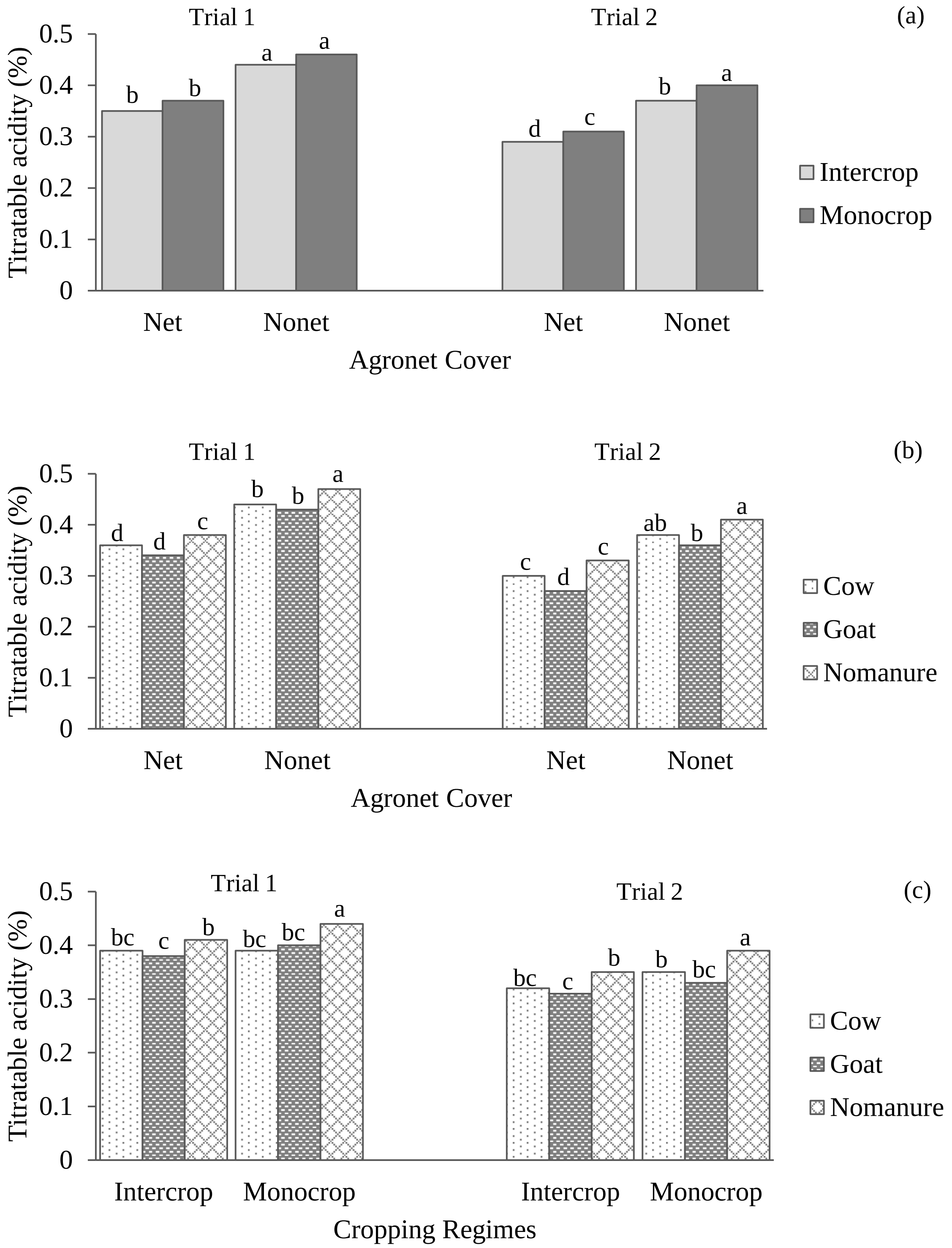


Figure 17: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on tomato fruit titratable acidity (%) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

although not statistically different from those produced in plots applied with fresh cow dung in trial 1 but significantly different in trial 2. Moreover, fruit titratable acidity was significantly lower in tomato fruits produced from plots applied with fresh goat manure than when the plants were grown without any fresh organic manure applied in both trials (Table 26).

The interactive effects of between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime on tomato fruit titratable acidity were significant (Figure 17). Interactive effects of agronet cover and cropping regimes resulted in slightly lower fruit titratable acidity in tomato fruits produced under intercropped than for those produced under monocrop with or without agronet cover, although the difference was not significant in trial 1. In trial 2, fruit titratable acidity was significantly lower for fruits produced under intercrop than those produced under monocrop regime regardless of the agronet cover level (Figure 17a). In both trials, tomato fruit titratable acidity was lower for fruits produced agronet cover with fresh organic manure than for fruits produced with no agronet cover but with fresh organic manure, although the difference was not statistically significant (Figure 17b).

Fruit titratable acidity was significantly lower in tomato produced in plots applied with fresh cow or goat dung than tomato produced in plots where no fresh organic manure was applied regardless of the agronet cover level in trial 1. In trial 2, fruit titratable acidity was significantly lower in tomato produced in plots applied with fresh goat dung and under agronet compared to those produced in plots applied with fresh cow dung under agronet while in the open, fruit titratable acidity was lower in fruits from tomato grown with fresh goat manure although not statistically different from titratable acidity obtained in fruits from tomato grown in plots applied with fresh cow dung but significantly lower than those recorded in plots where no fresh manure was applied. Although the fresh organic manure reduced fruit titratable acidity in tomato, the reduction was however, higher under interaction of agronet cover and fresh goat dung. Fruit titratable acidity tended to be higher in fruits from monocrop tomato produced in plots applied with fresh organic manure compared to that of fruits from intercropped tomato produced in plots with fresh organic manure in both trials (Figure 17c). Additionally, fruit titratable acidity was lowest for fruits produced in plots applied with fresh goat dung followed by those applied with fresh cow dung while the highest fruit titratable acidity was registered in tomato fruits grown in plots not applied with any fresh organic manure during production regardless of the cropping regime in both trials.

Although the three way interaction of agronet cover, cropping regimes and fresh organic manure did not significantly influence, titratable acidity content of tomato fruits, fruits obtained from the control treatment tended to have the highest titratable acidity of 0.49% and 0.42% in trial 1 and trial 2, respectively while the lowest titratable acidity of 0.33% in trial 1 and 0.26% in trial 2 was recorded in fruits from intercropped tomato produced in plots applied with fresh goat dung and covered with agronet (Table 26). Monocrop or intercropped tomato grown in the open without agronet cover but with fresh cow or goat dung produced tomato fruits with slightly lower titratable acidity percentage in relation to the control in both trials.

iv) Sugar Acid Ratio

The sugar acid ratio of tomato fruits was improved by the use of agronet cover, cropping regime and fresh organic manure during tomato production in both trials (Table 27). The interaction between agronet cover and cropping regime, agronet cover and fresh organic manure, and cropping regime and fresh manure on tomato fruit sugar acid ratio were also significant in both trials (Figure 18). Three-way interaction between agronet cover, cropping regime and fresh organic manure was however, not significant in both trials (Table 27). Averaged across all cropping regime and fresh manure levels in both trials, the mean tomato fruit sugar acid ratio was significantly higher for fruits grown under agronet cover than for fruits produced in the open field with no agronet cover used (Table 27). Intercropped tomato also produced fruits with significantly higher fruit sugar acid ratio of 13.35 in trial 1 and 16.94 in trial 2 averaged across all net cover and fresh manure levels compared to sugar acid ratio of 12.33 in trial 1 and 14.52 in trial 2 obtained for fruits from monocrop tomato also averaged across all net cover and fresh manure levels. In both trials, tomato fruit sugar acid ratio averaged across all net cover levels and cropping regimes was significantly higher for fruits produced in plots applied with fresh organic manure than for fruits produced in plots without any fresh organic manure applied (Table 27). Tomato plants grown in plots applied with fresh goat manure yielded fruits with significantly higher sugar acid ratio than those produced in plots applied with fresh cow dung in both trials.

The interactive effects of between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime on tomato fruit sugar acid ratio were significant (Figure 18). Interactive effects of agronet cover and cropping regimes resulted in slightly higher fruit sugar acid ratio in tomato fruits produced under

Table 27: Effects of agronet cover and fresh organic manure on sugar acid ratio of tomato fruit produced under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	15.53*	17.31	14.39	
	Monocrop	14.37	15.36	13.08	**15.01a****
No Net	Intercrop	10.93	11.63	10.30	
	Monocrop	10.72	11.68	8.79	**10.67b**
Organic Manure Means		**12.89f**	**14.00e**	**11.64g**	
		Trial 2			
Net	Intercrop	19.64	23.31	17.17	
	Monocrop	17.91	20.23	14.07	**18.72a**
No Net	Intercrop	14.07	14.87	12.55	
	Monocrop	11.90	12.64	10.36	**12.73b**
Organic Manure Means		**15.88f**	**17.76e**	**13.54g**	

*Means with no letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

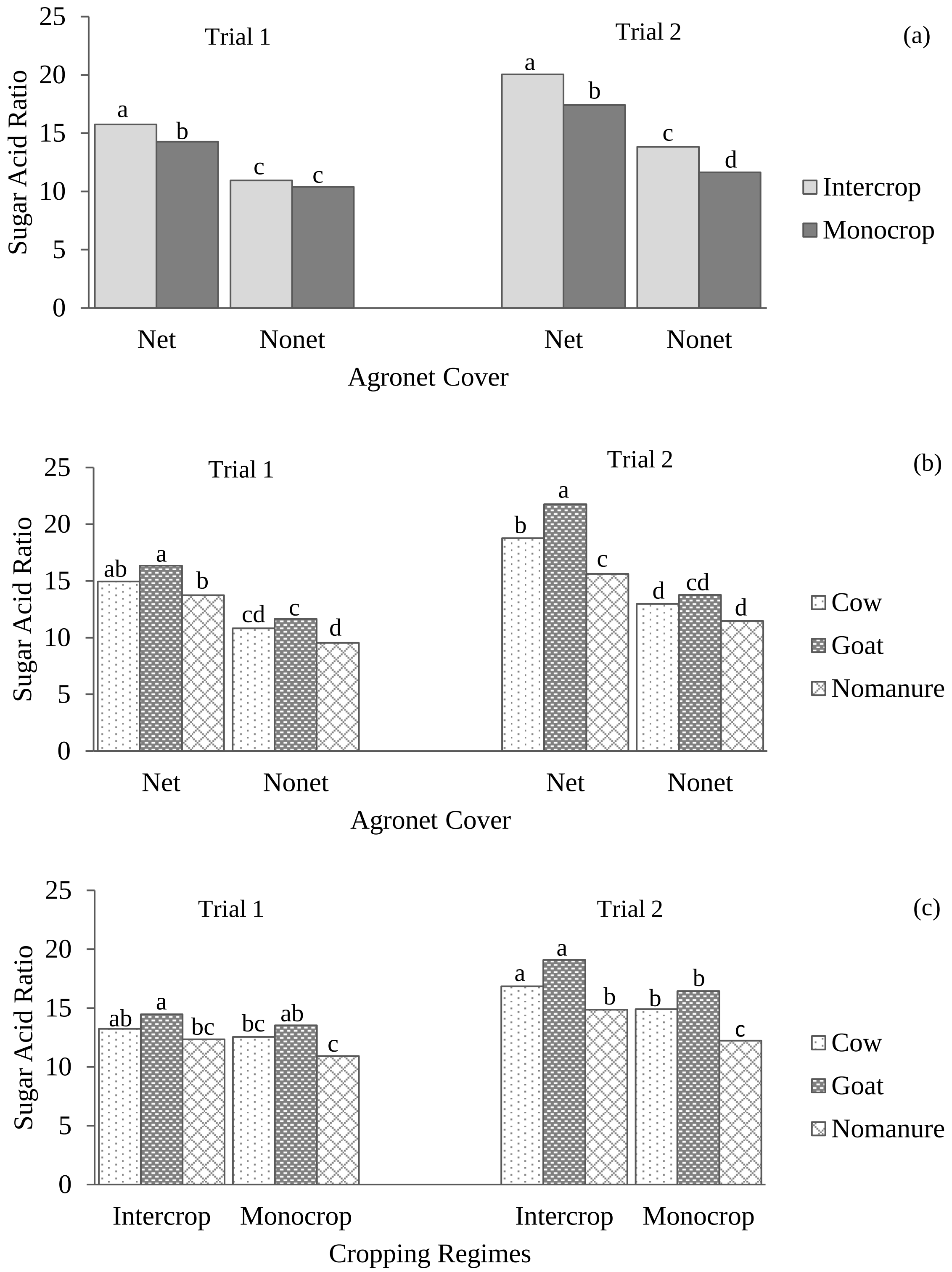


Figure 18: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on tomato fruit sugar acid ratio during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

intercropped than for those produced under monocrop with or without agronet cover, although the difference was not significant among the cropping regimes when no agronet cover was used in trial 1. In trial 2, fruit sugar acid ratio was significantly higher for fruits grown under intercrop than those produced under monocrop regime regardless of the agronet cover level (Figure 18a). In both trials, the difference in fruit sugar acid ratio between intercrop and monocrop tomato fruits was higher under the agronet cover than when no agronet cover was used. In both trials, sugar acid ratio tended to be higher tomato fruits produced in agronet covered plots with fresh organic manure applied compared the sugar acid content recorded for fruits produced with no agronet cover but with fresh organic manure applied (Figure 18b).

In trial 1, significantly higher fruit sugar acid ratio was obtained in tomato fruits produced in plots applied with fresh goat dung than in plots where no fresh organic manure was applied regardless of the agronet cover level. On the other hand, fruit sugar acid ratio for tomato fruits produced in plots applied with fresh cow dung was slightly higher than for fruits produced in the open without any fresh organic manure applied under both agronet cover levels even though the difference was not significantly different. In trial 2, significantly higher fruit sugar acid ratio was recorded for tomato fruits produced in plots applied with fresh goat dung than for fruits produced in plots applied with fresh cow dung and under agronet compared to that of fruits produced in the open field with no agronet cover tomato although the difference was not statistically significant. The fruit sugar acid ratio was higher in fruits from intercropped plots applied with fresh organic manure compared to that of fruits from monocrop plots applied with fresh organic manure, although the difference was not statistically significant in both trials (Figure 18c). In both trials, fruit sugar acid ratio was significantly high in tomato fruits produced from plots applied with fresh goat dung than for fruits grown in plots where no fresh organic manure was applied in both cropping regimes.

Although the three-way interaction of agronet cover, cropping regime and fresh organic manure was not significant, monocrop or intercropped tomato grown with or without fresh organic manure under agronet cover tended to produce fruits with slightly higher sugar acid ratio than when tomato was produced in the open without agronet cover in both trials (Table 27). On the other hand, tomato fruits produced by monocrop or intercropped tomato without agronet cover but with fresh cow or goat dung tended to record slightly higher sugar acid ratio compared to fruits produced under the control treatment in both trials.

iv) Lycopene Content

Lycopene content was improved by the use of agronet cover, cropping regime and fresh organic manure during tomato production in both trials (Table 28). The interactive effects of agronet cover and cropping regime (Figure 19a), agronet cover and fresh organic manure (Figure 19b) and cropping regime and fresh manure (Figure 19c) on lycopene content were significant. The three-way interaction between agronet cover, cropping regime and fresh organic manure was also significant in both trials (Table 28). Averaged across all cropping regime and fresh manure levels in both trials, the lycopene content of tomato fruits was significantly more for fruits grown under agronet cover compared to when no agronet cover was used (Table 28). Intercropped tomato produced fruits with significantly higher fruit lycopene content of (15.83 mg in trial 1 and 16.73 mg in trial 2) averaged across all net cover and fresh manure levels compared to fruit lycopene content (15.79 mg in trial 1 and 14.11 mg in trial 2) obtained for monocrop tomato. In both trials, mean fruit lycopene content averaged across all net cover levels and cropping regimes was significantly higher for fruits produced in plots applied with fresh goat manure than those grown in plots applied with fresh cow dung and also significantly higher than those recorded for fruits produced in plots where no fresh manure was applied (Table 28).

The interaction between agronet cover and cropping regimes, agronet cover and fresh organic manure and fresh organic manure and cropping regime significantly influenced tomato fruit lycopene content (Figure 19). Interactive effects of agronet cover and cropping regime showed that intercropped tomato produced fruits with significantly higher lycopene content compared to monocrop tomato regardless of the agronet cover level in trial 2 (Figure 19a). In trial 1, fruits produced by intercropped tomato had significantly higher lycopene content than those produced by monocrop tomato when no agronet cover was used while under the agronet cover, fruits produced by monocrop tomato had significantly higher lycopene content than those produced by intercropped tomato. Additionally, significantly higher fruit lycopene content was recorded for fruits from intercropped or monocrop tomato produced under agronet cover than for fruits produced in the open with no agronet cover in both trials (Figure 19a). In both trials, tomato fruit lycopene content was more in tomato produced in agronet cover with fresh organic manure than in fruits produced with no agronet cover but with fresh organic manure (Figure 19b). However, significantly higher fruit lycopene content was obtained for tomato fruits grown under agronet cover with fresh cow or goat dung applied compared to

Table 28: Effects of agronet cover and fresh organic manure on lycopene content (mg/100g fresh weight) of tomato fruits produced under different cropping regimes

Agronet Cover	Cropping Regime	Fresh Organic Manure			**Net Cover Means**
		Cow	Goat	No Manure	
		Trial 1			
Net	Intercrop	18.98d*	19.35c	15.25e	
	Monocrop	14.68f	24.60a	21.83b	**19.11a****
No Net	Intercrop	14.33g	14.65f	12.45i	
	Monocrop	11.80j	13.48h	8.35k	**12.51b**
Organic Manure Means		**14.95f**	**18.02e**	**14.47g**	
		Trial 2			
Net	Intercrop	22.28b	23.33a	15.75d	
	Monocrop	14.58e	19.63c	13.90f	**18.24a**
No Net	Intercrop	13.25g	14.40e	11.40i	
	Monocrop	12.55h	13.60fg	10.43j	**12.60b**
Organic Manure Means		**15.66f**	**17.74e**	**12.87g**	

*Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

**Means with the same letter in a letter series and in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

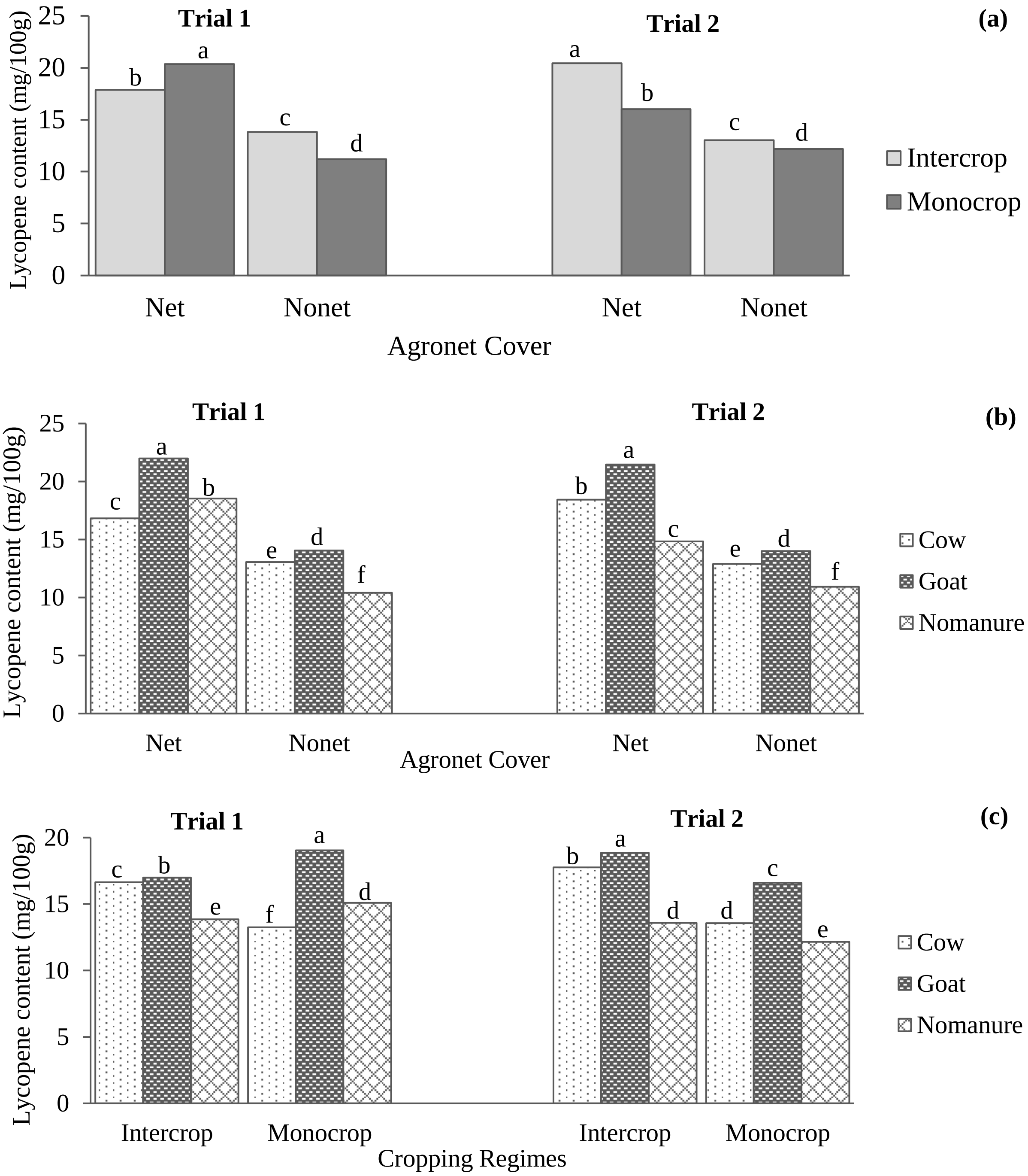


Figure 19: Interactive effects of (a) agronet cover and cropping regime, (b) agronet cover and fresh organic manure and (c) cropping regime and fresh organic manure on tomato fruit lycopene content (mg/100g fresh weight) during tomato production.

Means with the same letter in a trial are not significantly different, Tukey's honestly significant difference test at $p \leq 0.05$.

fruit lycopene content obtained for tomato fruits produced in the open with no agronet cover nor fresh organic manure applied. In both trials, lycopene content for fruits produced in the open with fresh organic manure was significantly higher compared to that of fruits produced in the open without fresh organic manure. On the other hand, under the agronet cover, fruits produced with application of fresh cow or goat dung manure had significantly higher lycopene content compared to those produced without fresh organic manure. Lycopene content was significantly different among the organic manure levels regardless of the agronet cover levels in both trials.

Tomato fruit lycopene content obtained for intercropped tomato grown in plots applied with fresh organic manure was higher compared to that of monocrop tomato grown in plots applied with fresh organic manure in both trials (Figure 19c). Lycopene content for fruits produced by monocrop or intercropped tomato grown with fresh goat dung was significantly higher compared to that of monocrop or intercropped tomato grown in plots applied with fresh cow dung or without fresh manure in trial 1 (Figure 19c). In both trials, lycopene content obtained in fruits produced by tomato grown with fresh goat and cow dung was significantly different in both cropping regimes. Generally, lycopene content was lowest in fruits produced by tomato grown in plots without fresh organic manure followed by those of tomato grown with fresh cow dung and the highest lycopene content was obtained in fruits produced by tomato grown in plots applied with fresh goat dung regardless of the agronet cover levels or cropping regimes.

The three-way interaction between agronet cover, cropping regime and fresh organic manure significantly influenced tomato fruit lycopene content in comparison with the control treatment (monocrop tomato grown in the open with no fresh manure applied) in both trials (Table 28). Overall, the highest fruit lycopene content was obtained on fruits produced by monocrop tomato grown in plots applied with fresh goat dung and covered with agronet in trial 1 and in trial 2, intercropped tomato grown with fresh goat dung and covered with agronet produced fruits with highest fruit lycopene content while the least fruit lycopene content was registered in fruits from the control in the two trials (Table 28). Amongst the agronet covered treatments in trial 1, monocrop tomato grown with fresh goat dung produced fruits with highest lycopene content followed by monocrop tomato grown without fresh organic manure then intercropped tomato grown with fresh goat dung, followed intercropped tomato grown with fresh cow dung, followed by intercropped tomato grown without fresh manure and the least lycopene content was obtained on fruits produced by monocrop tomato grown with fresh cow dung. In trial 2, intercropped tomato grown with fresh goat dung produced fruits with highest lycopene content followed by intercropped tomato grown with fresh cow dung, then monocrop tomato grown with fresh goat dung, followed by intercropped tomato grown without fresh organic manure, then monocrop tomato grown with fresh cow dung and the least lycopene content was obtained on fruits produced by monocrop tomato grown without fresh manure. Monocrop or intercropped tomato grown in the open without agronet cover but with fresh cow or goat dung produced tomato fruits with significantly higher lycopene content compared to the control treatment in both trials (Table 28).

CHAPTER FIVE

DISCUSSION

In this chapter five, the same order of presentation of results in chapter four has been followed in the discussion.

5.1 Effects of Agronet Cover, Slender Leaf Intercrop and Fresh Organic Manure on Carbon Dioxide (CO_2) Concentration within the Crop Vicinity

In the current study, growing tomato under agronet cover with application of fresh organic manure influenced CO_2 concentration within the plant vicinity. Carbon dioxide concentration remained higher under agronet cover and fresh organic manure treatments than in the control treatment with no net cover and with no fresh manure applied throughout the study. Organic amendments like organic manures have been widely used in agro ecosystems due to their positive role in soil fertility improvement and climate change mitigation via soil carbon sequestration (Gong *et al*., 2012; Li *et al*., 2013). Studies by Li *et al*. (2013) reported that cumulative CO_2 emission during the growing season is affected by the organic amendments applied, soil temperature and moisture. Based on the results of the current study, combined use of agronet cover and application of fresh organic manure enhanced CO_2 concentration compared to using the two technologies in isolation. The higher CO_2 concentration recorded under agronet cover with application of fresh organic manure treatments compared to treatments where fresh organic manure was applied but in the open field could be attributed to the barrier for free gaseous exchange created by net cover as demonstrated by Harmanto *et al*. (2006), higher soil moisture retention and air temperatures favoured under net covers (Gogo *et al*., 2014) and CO_2 emitted by the fresh organic manure as it decomposed (Ma *et al*., 2006).

According to Fangueiro *et al*. (2007), the magnitude of CO_2 emissions from organic amendments is affected by the particle size of slurry fractions with enhanced emissions from smaller than from larger fractions. This offers support for the observations of the current study where a higher CO_2 concentration was recorded on plots applied with fresh goat dung than in those applied with fresh cow dung. Smaller particles sizes have a larger surface area to volume ratio therefore increasing accessibility to soil microbes. According to Magid *et al*. (2010), larger surface area to volume ratio of organo-mineral increases microbial biomass and residual products. Goat dung tends to be of smaller particle size than cow dung, which could imply that goat dung led to better enhancement of microbial activity in comparison with cow dung which tends to be of larger particle size. Besides, goat dung could also have provided more easily degradable and potentially more soluble carbon resulting in more interactions with microorganisms than cow dung resulting to greater CO_2 emission. According to Azeez and Van Averbeke (2010), goat manure is richer in total nitrogen (N) and total carbon (C) than cattle manure. Microbial activities are influenced by soluble carbon and nitrogen compounds in the organic material added into the soils (Muhammad *et al*., 2011).

On the other hand, intercropping creates favourable conditions for soil microorganisms leading to enhanced microbial activity (Brady & Weil, 1996; Matteucci *et al*., 2000). It is possible that the higher CO_2 concentration recorded on intercropped tomato could be as a result of enhanced microbial activity and more vegetation. Chirinda *et al*. (2010) considered enhanced N availability as an important factor behind the increasing microbial activity and soil respiration rates. Addition of nitrogen leads to activation of soil microbial communities (Meijide *et al*., 2010), which then increase organic matter mineralization leading to release of CO_2 (Bol *et al*., 2003). According to Meijide *et al*. (2010), increase in CO_2 emissions by organic waste is either a consequence of the activation of soil microbial communities or as a result of the increase of plant growth, which then increase the plant's respiration rate. In the current study, CO_2 concentration generally tended to be higher as the crop approached maturity. Within each sampling date, CO_2 concentration also tended to be higher for treatments with more vigorous vegetative growth than those with less vegetative growth which could probably be attributed to higher net respiration of the plants in such treatments leading to higher CO_2 emission and accumulation in the immediate crop vicinity.

5.2 Effects of Agronet Cover, Slender Leaf Intercrop and Fresh Organic Manure on Tomato Nematode Infestation

Use of agronet cover, fresh organic manure and slender leaf intercrop in the current study proved of potential benefit in management root-knot nematode. Root-knot nematode species both in the soil and on the roots of tomato plant were lower under agronet cover, fresh organic manure and slender leaf intercrop treatments than in the control treatment were none of these treatments was applied. The lower number of root-knot nematode registered under agronet cover in the recent study might be due to manipulation of the light spectrum by the agronet cover leading to a poor host environment for nematodes and improved plant growth. According to Chindo *et al*. (2012), enhanced plant growth can indirectly affect the plant tolerance or resistance to nematode infection. The suppression of *Meloidogyne* species populations by fresh organic manure in the current study could be as a result of toxic effects produced during decomposition of organic manure and increased microbial activities leading to a poor host environment for the root-knot nematodes thereby inhibiting their penetration into the roots.

Suppression of *Meloidogyne* species by fresh organic manure could also be due to increased number of root-knot nematode antagonists generated during decomposition of the fresh organic manure in the soil. Fresh organic manures can be more effective to control root-knot nematodes compared to composted manures since toxic compounds can quickly reach threshold level required to control nematodes with rapid increase in number of beneficial microorganisms and microbial activities. Compositing of amendments in soil enhances microbial activities and increases number of antagonists (Wachira *et al*., 2009). According to Mohammed and Alam (2003), organic amendments such as animal left-over arouses the generation of root-knot nematode predators and parasites. Studies by Abolusoro and Abolusoro (2012) established a substantial decrease in the soil population of root-knot nematode and root gall index by organic manure amendment compared with the control treatment. On the other hand, in the current study, intercropping tomato with slender leaf reduced juvenile root-knot nematode populations and number of root-knot nematode galls compared to tomato grown as a monocrop. Comparable to the findings of the recent study, Bello *et al*. (2014) reported significantly lower number of juvenile nematodes in the soil and root galls in tomato plants when *Crotalaria* plants were used as intercrop. According to Wang *et al*. (2002), *Crotalaria* intercrop suppresses plant-parasitic nematodes by enhancing microbial activities against *Meloidogyne* species, by increasing bacterivorous nematode population densities and nematode-trapping fungal propagules. Some compounds of microbial origin disrupt biological activities of the root-knot nematodes that are essential for the successful plant-nematode interaction (Varkey *et al*., 2018).

Based on the current study's results, treatments with lower number of juvenile root-knot nematode populations registered fewer number of root galls. This implies that root-knot nematodes stimulate formation of root galls. Studies by Kankam and Adomako (2014) reported strong positive correlation of nematode juveniles and root galling where the root galling on tomato plant roots increased with increasing nematode population in the rhizosphere of the tomato plant. The interactions between agronet cover, fresh organic manure and slender leaf intercrop in the current study registered higher reduction in root-knot nematode (juvenile) population in the soil and tomato root gall numbers. This might be accredited to combined capability of the technologies to enhance microbial activity and modify crop microclimate to the disadvantage of nematode multiplication and survival. The possible combined diverse mechanisms that led to reduced number of nematodes in the soil and on roots of tomato plants could include but not limited to reduced egg hatching, enhancing plant growth, inducing systemic resistance in the plant, alteration of root exudates and inhibition of nematode penetration into the roots as well as reduced galling (Khalil *et al*., 2012).

According to Ravindra *et al*. (2014), combination of treatments is more effective than individual treatment in management of root-knot nematodes. In the current study, the highest suppression of root-knot nematode in tomato plant was recorded in the treatment that combined the use of agronet cover, fresh goat dung and slender leaf intercrop. The higher decrease of root-knot nematode on tomato plants achieved for this treatment could possibly have been as a result of production of more root-knot nematode predatory microorganism and other competing beneficial organisms by the fresh goat dung manure and slender leaf as well as increased plant tolerance or resistance to nematode infection through enhanced plant growth by the agronet cover.

Based on the present studies result, treatments with higher CO_2 concentration level registered higher reduction in root-knot nematode (juvenile) population in the soil and tomato root gall numbers. This could be attributed to ability of the carbon dioxide to alter partitioning of plant resources between growth and defence. Increased CO_2 level cause plants to transfer carbon and nitrogen resources among plant tissues thus altering the production of food and secondary metabolites in plant tissue as well as chemical components in root exudates (Allard *et al*., 2006; Phillips *et al*., 2006: Sun *et al*., 2010). Furthermore, this can lead to initiation of the jasmonic acid (JA) pathway which is considered as essential for defence against a broad spectrum of herbivores which includes cell content feeders such as root-knot nematodes (Cooper & Goggin, 2005; Li *et al*., 2002; Thaler *et al*., 2002). Studies by Yeates and Newton (2009) reported that high CO_2 concentration level increased the number of root feeding nematodes, microbial-feeding nematodes and predacious nematodes in soil, signifying that high CO_2 concentration level may alter interaction between root-knot nematodes and their host plants. Besides, high CO_2 concentration level led to buildup of extra carbon in plant tissues, which is possibly assigned to more carbon-based secondary metabolites (Hamilton *et al*., 2001). Moreover, under high CO_2 concentration level the performance of root-feeding nematodes would logically be changed due to increased plant photosynthetic capacity and root growth, as well as changes in the nutrient level of the plant tissue.

5.3 Effects of Agronet Cover, Slender Leaf Intercrop and Fresh Organic Manure on Tomato Plant Growth

Use of agronet cover, fresh organic manure and slender leaf intercrop enhanced tomato plant growth in the present study. Plants grown with agronet cover, fresh organic manure and slender leaf intercrop were taller with thick stems and higher internodes and branches in relation with those grown without agronet or without application of fresh organic manure or without slender leaf intercrop. The observation made in this study is accredited to the capability of these technologies to enhance microbial activity, increase CO_2 emission and suppress root-knot nematode numbers in the growing media.

Modified crop microclimate provided by the net cover could also have favored increased meristematic and physiological activities in the plant leading to better plant growth. Agronet cover has been reported to improve crop performance as a result of modified and stabilized crop microclimate under the cover (Gogo *et al*., 2014). Net technology stabilizes crop microclimate as well as blockage of high light intensity within crop vicinity, a trait that favors better crop performance. Besides the modification of crop microclimate, net cover increases light scattering making light reach a larger volume of the plant in a more homogenous way thus influencing plant branching and crop compactness (Abul-Soud *et al*., 2014).

Proper light distribution favors photosynthesis and metabolites translocation for better plant growth (Setiawati *et al*., 2014). Moreover, changes on the local microclimate under net cover and application of fresh manure modify CO_2 concentration and assimilation thus influencing crop growth and development (Kittas *et al*., 2012). In this study, correlation analysis indicated CO_2 enrichment favored by use of agronet cover and fresh manure is positively correlated with tomato plant growth variables. Increased CO_2 concentration within the crop vicinity could probably have led to improved plant water-use efficiency, photosynthetic efficiency and light-use efficiency leading to increased supply of photoassimilates and improved plant growth (Ainsworth & Long 2005; Drake *et al*., 1997; Ji *et al*., 2015). Besides, improved plant growth following application of organic manure in the current study could also have been favoured by the fact that fresh organic manures release essential nutrient elements as they decompose which are associated with high photosynthetic activities that promote root and vegetative growth (John *et al*., 2004). Increased photosynthetic activities lead to additional food being produced and transferred to active sinks thus encouraging vigorous growth rate (Dauda *et al*., 2008). Also, use of slender leaf plants is associated with increased supply of plant nutrient as they perform symbiosis with rhizobium in the rhizosphere to fix nitrogen. Apart from improving soil fertility, slender leaf plants compete with weeds without becoming a weed and grow vigorously (Wang *et al*., 2002) which could have led to improved performance of tomato plants that were intercropped with slender leaf. Application of organic nutrient sources has also been documented to enhance beneficial microorganism's activities owing to high organic materials in the soil, resulting in production of growth promoting substances and high nutrient levels (Soni *et al*., 2018).

Increased soil organic matter content through decomposition and mineralization of the fresh organic manure and soil moisture content conservation under agronet cover and slender leaf intercrop through reducing direct sun light reaching the ground level hence reducing soil water loss and enhanced microbial activities (Midega & Khan, 2003; Midega *et al.,* 2009). Enhancing soil moisture content and microbial activity give rise to rapid root development and growth and improved plant growth and productivity (Richardson *et al*., 2009; Fan *et al*., 2011). Tomato plant needs enough moisture content for better development (Moreno *et al.,* 2002), enhanced moisture content and root growth increases absorption of water and nutrients which hasten faster general plant growth.

Better plant performance in the current study could also have been attributed to reduced number of root-knot nematodes and root galls registered under these treatments leading to the better crop performance. On the other hand, the reduced plant growth under the control treatment could partly have been as a result of high number of root galls which could have hinder plant water and nutrients supply by the roots. The root galls caused by root-knot nematode lead to vascular damage which disturbs water and mineral uptake resulting in severe reduction in plant growth (Abolusoro *et al*., 2013). Root galls are feeding sites in the plant that encourages movement of photosyntates down to the roots at the expense of other parts, hence decreasing the crop performance. Parasitism by root-knot nematode comprises the formation of permanent feeding sites in the root cortex, endodermis, pericycle and vascular parenchyma which are sinks for photosynthates resulting in reduced plant development (Volvas *et al*., 2005).

5.4 Effects of Agronet Cover, Slender Leaf Intercrop and Fresh Organic Manure on Yield Components and Yield of Tomato

The current study has revealed that use of agronet cover, fresh organic manure and slender leaf intercrop led to rise flower trusses, flowers per truss and the consequent increase in economic yield compared with the control treatment. According to Adams *et al.* (2001) enhanced moisture content under agronet cover translates to increased flowers per plant compared to control treatments. Higher flowers per plant of tomato grown with fresh organic manure could be as a result of organic manure containing nutrients which are gradually released to the plants thus reducing nutrient loss through leaching as well as enhancing nutrient use efficiency resulting to greater economic yield (Ilupeju *et al*., 2015). Studies on how water affect plants growth have established that water stress during seedling and flowering stages have higher effects on crop economic yield (Shou *et al.,* 1991). Slender leaf used as an intercrop and growing tomato plants under agronet cover might have mitigated the tomato plant against unnecessary water loss resulting to higher flower trusses, flowers per truss and ultimately higher tomato fruit yield.

The better growth of tomato plants grown with fresh manure and covered with agronet cover observed in the current study reflected into a greater number of flower trusses and fruit yield. Better yield obtained with use of fresh manure and agronet cover can be attributed to the enhanced vigorous growth recorded under these treatments. Increased plant growth portrays better biomass accumulation and provides a greater bearing surface and more stored food reserves for yield formation. Higher carbon assimilation accelerates plant growth and development which stimulates development of new sinks through increased plant biomass production, more branching and new leaf production (Tissue *et al*., 1996). Such plant parts develop to new source surfaces hence favoring enhanced photosynthesis with ultimate increase in plant yield (Iqbal *et al*., 2011). According to Chaudhary *et al*. (2006), more efficient utilization of food for reproductive growth (flowering and fruit set) and enhanced source to sink relationship of the plant results in improvement yield. Reduction in transmitted solar radiation under nets (Ilić *et al*., 2017) and good ground coverage by slender leaf intercrop could have led to reduced evapotranspiration rate resulting in to improved soil moisture status as well as reduced transpiration rate, leading to better growth and the high yields of tomato recorded in the current study. It is also possible that the higher tomato fruit yield obtained under agronet cover, and with application of fresh goat and cow dung and slender leaf intercrop could partly have been as a result of higher fruit set percent and development of a greater number of fruits per plant favoured by these treatments.

Comparing the two cropping regimes, marketable fruit yield for plants intercropped with slender leaf was higher than for those grown as a monocrop. Study by Miyazawa *et al.* (2010) found improved yield of intercropped plants in relation with yield of the crops grown as sole crop. Use of *Crotalaria* spp is associated with increased supply of plant nutrient and provide good ground coverage as a result of the vigorous growth pattern displayed by the crop (Wang *et al*., 2002). Such observation could explain the better tomato development resulting to higher marketable yield recorded in intercropped plots in the present study. The increase in marketable yield under agronet cover, fresh organic manure and slender leaf intercrop compared to control treatments could also have been owing to production of increased fruit numbers with greater weights as a result of improved photosynthetic rate of tomato plants resulting to additional food being produced and transferred to active sinks under these treatments. Besides, the modified microclimate under agronet covered plots could also have led to the enhanced crop development and decreased physiological disorders leading to higher marketable yield.

5.5 Effects of Agronet Cover, Slender Leaf Intercrop and Fresh Organic Manure on Postharvest Quality of Tomato Fruit

The quality variables considered in this study were fruit firmness, total soluble solids (TSS), titratable acidity (TA), total soluble solids to titratable acidity ratio (TSS/TA ratio) and lycopene content. Results of the present study have revealed that agronet cover, slender leaf intercrop and fresh organic manure result in increased tomato fruit firmness, total soluble solids, and sugar acid ratio, but decrease titratable acidity compared to the control treatment. The observations made in this study are attributed to the combined ability of these technologies to enhance fruit quality. Better quality of fruits under the different treatment combinations of agronet cover, slender leaf intercrop and fresh organic manure could have been as a result of better plant growth observed under these treatments. According to Singh *et al*. (2007), better plant growth produces fruits of better quality. In the current study, the better fruit quality recorded under agronet cover and slender leaf intercrop with application of fresh organic manure treatments could also be attributed to enhanced light intensity or dispersion by agronet cover (Ilic *et al*., 2015), higher soil moisture retention and air temperatures under agronet covers (Gogo *et al*., 2014), increased supply of plant nutrients following application of fresh organic manure (John *et al*., 2004) and use of slender leaf (Wang *et al*., 2002) thus enhancing nutrients availability and improving the plant ability to absorb more nutrients.

Light intensity and temperature influence greatly the sugar accumulation in tomatoes. Exposing fruits to higher temperatures, especially during fruit cell division and prior to harvest, results in increased total soluble solids and total soluble solids to titratable acidity ratio of tomato fruits (Ilic *et al*., 2015). It is possible that the higher total soluble solids of fruits obtained from tomato plants produced under agronet cover in relation to those grown without agronet cover in the present study can partly have been as a consequence of higher temperatures favoured by these treatments. On the other hand, titratable acidity has been shown to decrease with increased temperature (Cowan *et al*., 2014) possibly explaining the low titratable acidity observed for treatments that favoured high temperatures in the growth environment. This attributed to changes in activities of carbohydrate biosynthetic (Walker & Ho, 1977) and higher rate of transpiration (Gautier *et al*., 2009). Moreover, modification of crop microclimate by the agronet cover (Gogo *et al*., 2014) increases meristematic and physiological activities in the plant and ripening process of fruits leading to better fruit quality (Adams *et al*., 2001).

Enhanced uptake of nutrients such as calcium, nitrogen and magnesium could also have played a vital role in development of better-quality tomato fruits. In particular, calcium is responsible for cell wall integrity and probably this would have been its contribution to better firmness observed under agronet cover, slender leaf intercrop and fresh organic manure treatments compared to fruits produced under the control treatment as fruit firmness is associated with cell turgor and cell wall characteristics (Knee, 2002). On the other hand, nitrogen and magnesium are an integral part of chlorophyll molecule and at higher level they may support the intake of potassium, hence resulting in the enhanced sweetness of tomato fruits. Organic manure contains many active sites which improve soil cation exchange capacity (CEC) and fertility thus improving nutrient uptake and utilization by the crop (Ilupeju *et al*., 2015). This could explain the improved quality of tomato fruit grown with fresh organic manure in the current study. Intercropping has also been reported to enhance efficient water and nutrients use giving rise to high quality fruits (Shou *et al.*, 1991).

Tomato fruit flavour is associated with high soluble solids (Joshi & Vig, 2010) and titratable acidity (Bilalis *et al*., 2018). The total soluble solids to titratable acidity ratio establish a better predictor of the impact of an acid on fruit flavor than soluble solids or acidity alone, acidity decrease with fruit maturity while sugar content increase with fruit maturity (Ilić *et al*., 2014). A higher total soluble solid recorded in fresh organic manure treatments in the recent study could be accredited to improved phosphorous and potassium contents. These results are similar with those by Bilalis *et al*. (2018) who reported higher total soluble solids from tomato plants grown under organic production systems. Potassium and phosphorous nutrition have a positive effect on fruit sugar (Joshi & Vig, 2010; Lacatus *et al*., 1994). According to Duraisami and Mani (2002), increased availability of phosphorus and potassium increases total soluble solids. The tomato fruit quality could also be influenced by changes in carbon dioxide adjustment and water accessibility. According to Pieper and Barrett (2009), increase in carbon allocation in the leaves or the increased shading of the fruits due to excess foliage could decrease titratable acidity.

Tomato lycopene content plays a major role in fruit appearance and its attractiveness to consumers, apart from its enormous health profits (Kirimi *et al*., 2011; Otieno *et al*., 2017). It constitutes up to 90% of the total carotenoids present (Viskelis *et al*., 2015), and is the most important antioxidant with a high oxygen free radical scavenging and quenching capacity, and thus provides protection against chronic diseases, such as cancer and cardiovascular diseases (Perveen *et al.*, 2015). Soil moisture content and soil nutrient status affects lycopene content of tomato. Therefore, higher lycopene content recorded in slender leaf intercrop and fresh organic manure treatments in the present study could be accredited to enhanced soil moisture status and nutrient availability leading to synthesis of carotenoids responsible for tomato fruit color particularly lycopene (Ghorbani *et al*., 2008). Various studies have established higher nutritional values on yields of vegetables crop grown with organic amendment (Ilupeju *et al*., 2015). According to Agbede *et al*. (2019), improved lycopene content in tomato fruits grown with green manures compared with the control treatment was associated with improved accessibility of nutrients as a result of the mineralization of the organic manures, hence higher absorption by tomato plants. Net technology stabilizes air temperatures and soil moisture, an attribute that tend to favour lycopene content. According to Ilic *et al*. (2015) lycopene synthesis is highly influenced by temperature with optimum temperature at around 26ºC.

Generally, use of agronet cover in the present study produced firmer tomato fruits in relation to when the plants were grown with no agronet covers. This can be attributed to enhanced plant growth due to modified microclimate under the agronet cover. According to Saidi *et al*. (2013), tomato plants grown under agronet covers produce fruits with better quality. Studies by Ilic and Milenkovic (2012), reported that tomato fruit grown in open produced fruits with higher acidic level compared to those tomato fruits produced under protected structures. Similarly, studies by Caliman *et al*. (2010) found that tomato plants grown in the unprotected environment produced fruit with more titratable acidity compared to tomato fruits produced in protected environment.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

i). Use of the agronet cover, fresh organic manure and slender leaf intercrop results in higher CO_2 concentration in the immediate crop environment compared to the control treatment (monocrop tomato grown in the open with no fresh manure applied).

ii). Growing tomato under agronet cover, fresh organic manure and slender leaf intercrop either alone or in combination reduces juvenile root-knot nematode population in the soil by 23.5 to 89.3% and number of root galls by 56.3 to 78.9% compared with control treatment. Using the three technologies (agronet cover, fresh goat dung and slender leaf intercrop) together results in the highest suppression of root-knot nematode.

iii). Growing tomato under agronet cover, fresh organic manure and slender leaf intercrop enhances plant growth and improves yield and quality of the crop. Growing tomato with fresh goat dung, slender leaf intercrop and covered with agronet results in plants with better growth and development as well as highest number of flower trusses and yield. Using the three technologies together results in firmer fruits with higher total soluble solids and lycopene content, and less titratable acid and non-marketable fruit.

6.2 Recommendations

i). Open field tomato growers are advised to use of agronet cover as a strategy for achieving CO_2 enrichment in open field tomato production in regions with similar climatic conditions to those of our study site. To achieve even better results, it is advised that they combine use of agronet cover, slender leaf intercrop and fresh goat dung to achieve even higher CO_2 concentration in the immediate crop environment.

ii). Regions with similar weather conditions to that of present study are advised to integrate agronet cover, fresh goat dung and slender leaf intercrop as a viable alternative method for the management of tomato root-knot nematode with a resultant increase in growth, yield and quality.

iii). Additional studies on the subject using these technologies in different tomato growing climatic conditions as well as studies incorporating different fresh organic manure sources and different tomato varieties to further validate the viability of the technologies in tomato production. Further studies on post-harvest analysis of tomato produce grown with fresh organic manure need to be conducted to determine its safety for human consumption.

6.3 Areas for Further Studies

While the study lays a good foundation for improving open field tomato crop performance, further studies using other field grown tomato varieties could be useful to ascertain the outcome of our results. Further studies may be essential on several test crops as intercrops and inclusive investigation to be done on fresh organic manure for any possible toxins and root-knot nematode antagonists generated during decomposition.

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APPENDICES

Appendix A. ANOVA Tables

Appendix 1: ANOVA response to use of agronet cover, use of fresh organic manure and cropping regimes on CO_2 concentration and root-knot nematodes infestation

Source	Degree of Freedom	CO_2 concentration	Nematode population	Root galls
Total	35			
Block	2			
Net (N)	1	289.00^{**}	2108.34^{**}	32620.37^{**}
Slender (S)	1	7.11^{ns}	855.56^{**}	13598.15^{**}
Manure (M)	2	85.20^{*}	940.36^{**}	13984.41^{**}
N × S	1	13.44^{ns}	0.34^{ns}	5385.93^{**}
N × M	2	6.75^{ns}	7.11^{ns}	6766.95^{**}
S × M	2	51.36^{ns}	12.25^{ns}	5747.89^{**}
N × S × M	2	0.70^{ns}	62.11^{ns}	7146.58^{**}
Error	22			

ns, *, ** not significant or significant at $p \leq 0.05$ or $p \leq 0.01$, ANOVA.

Appendix 2: ANOVA response to use of agronet cover, use of fresh organic manure and cropping regimes on plant growth variables

Source	Degree of Freedom	Plant height	Stem diameter	Number internodes	Number branches
Total	35				
Block	2				
Net (N)	1	75.21^{ns}	0.35^{ns}	6.23^{ns}	0.14^{ns}
Slender (S)	1	165.48^{*}	0.57^{ns}	6.81^{ns}	1.27^{ns}
Manure (M)	2	28.87^{ns}	0.39^{ns}	1.23^{ns}	0.19^{ns}
N × S	1	10.42^{ns}	2.55^{ns}	1.01^{ns}	2.38^{ns}
N × M	2	96.07^{ns}	0.63^{ns}	2.20^{ns}	1.70^{ns}
S × M	2	225.48^{*}	4.15^{ns}	0.84^{ns}	1.52^{ns}
N × S × M	2	26.96^{ns}	1.44^{ns}	0.75^{ns}	0.83^{ns}
Error	22				

ns, *, ** not significant or significant at $p \leq 0.05$ or $p \leq 0.01$, ANOVA.

Appendix 3: ANOVA response to use of agronet cover, use of fresh organic manure and cropping regimes on yield components and yield of tomato

Source	Degree of Freedom	Number flower trusses	Number fruits	Fresh fruit weight	Marketable fruits	Non-marketable fruits
Total	35					
Block	2					
Net (N)	1	108.51^{ns}	1640.25^{**}	11.61^{**}	14.15^{**}	0.13^{**}
Slender (S)	1	32.11^{ns}	17.36^{ns}	0.24^{ns}	0.45^{ns}	0.03^{*}
Manure (M)	2	116.92^{ns}	202.38^{**}	1.12^{**}	1.63^{**}	0.05^{**}
N × S	1	0.56^{ns}	34.03^{ns}	0.001^{ns}	0.003^{ns}	0.0002^{ns}
N × M	2	2.20^{ns}	8.16^{ns}	0.04^{ns}	0.04^{ns}	0.001^{ns}
S × M	2	81.00^{ns}	15.86^{ns}	0.08^{ns}	0.09^{ns}	0.001^{ns}
N × S × M	2	48.29^{ns}	22.03^{ns}	0.24^{ns}	0.32^{ns}	0.01^{ns}
Error	22					

ns, *, ** not significant or significant at $p \leq 0.05$ or $p \leq 0.01$, ANOVA.

Appendix 4: ANOVA response to use of agronet cover, use of fresh organic manure and cropping regimes on postharvest quality of tomato fruit

Source	Degree of Freedom	Total soluble solids (TSS)	Lycopene content	Fruit Firmness	Titratable Acidity (TA)
Total	35				
Block	2				
Net (N)	1	3.77^{**}	286.03^{**}	0.69^{*}	0.07^{**}
Slender (S)	1	1.23^{*}	61.82^{**}	0.05^{ns}	0.01^{*}
Manure (M)	2	1.06^{**}	71.63^{**}	0.17^{**}	0.01^{**}
N × S	1	0.003^{ns}	29.03^{**}	0.002^{ns}	0.0003^{ns}
N × M	2	0.06^{ns}	9.55^{**}	0.01^{ns}	0.001^{ns}
S × M	2	0.03^{ns}	6.14^{**}	0.01^{ns}	0.0002^{ns}
N × S × M	2	0.02^{ns}	7.31^{**}	0.02^{ns}	0.0004^{ns}
Error	22				

ns, *, ** not significant or significant at $p \leq 0.05$ or $p \leq 0.01$, ANOVA.

Appendix B. Research Permit

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

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NAIROBI-KENYA

Ref: No. **NACOSTI/P/19/08712/30917**

Date: **26th June, 2019.**

James Ngelenzi Munywoki
Egerton University
P.O. Box 536-20115
NJORO.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Developing integrated approach to nematode (Meloidogyne spp) management and carbon dioxide enrichment forfield grown tomato (Solanumly copersicum l.)"*** I am pleased to inform you that you have been authorized to undertake research in **Nakuru County** for the period ending **24th June, 2020.**

You are advised to report to **the County Commissioner, and the County Director of Education, Nakuru County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

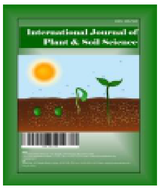
DR. ROY B. MUGIIRA, PhD.
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Nakuru County.

The County Director of Education
Nakuru County.

Appendix C: Abstract of First Published Paper



International Journal of Plant & Soil Science

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ISSN: 2320-7035

Integrated Management of Root-Knot Nematode (*Meloidogyne* Spp.) Using Fresh Organic Manure and *Crotalaria brevidens* Intercrop for Improved Growth and Yield of Tomato

James Ngelenzi Munywoki [a*], Joshua Otieno Ogweno [a] and Mwanarusi Saidi [a]

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

Authors' contributions

This work was carried out in collaboration among all authors. Author JNM was responsible for performing the experiment, data collection, statistical data analysis, interpretation of the results and manuscript preparation. Authors JOO and MS conceived the idea, designed the experiment and edited the manuscript. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetables worldwide. Tomato productivity is limited by, among other factors, biotic constraints including root-knot nematodes (*Meloidogyne* species) which lower both quality and quantity of the crop. Two trials were conducted at the Horticulture Research and Teaching Field, Egerton University, Kenya, to evaluate effects of fresh organic manure and slender leaf (*Crotalaria brevidens* var. *brevidens* Benth.) intercrop on management of root-knot nematode during tomato production as well as establish their effect on tomato growth and yield. Variables measured were nematode infestation, plant height, stem collar diameter, number of internodes and branches, number of fruits, and fresh fruit weight. Use of fresh organic manure and slender leaf intercrop suppressed the nematode population by 27.8% to 53.5% reduction and significantly increased tomato fruit numbers by 22.2% to 49.7% and fresh fruit weight by 24.5% to 80.4% when used alone or in combinations compared to the control treatment. The combination of fresh goat dung and

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Appendix D: Abstract of Second Published Paper

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Improving Carbon Dioxide Concentration, Growth and Yield of Tomato Using Fresh Manure and Agronet Cover

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Abstract

Arable land area is declining in many tropical and sub-tropical regions and increasing tomato (*Solanum lycopersicum* L.) production is necessary due to its high demand. Food security amid scarcity of arable land could be achieved through intensification as a way of maximizing productivity per unit area of available arable land. Trials were conducted at the Horticulture Research and Teaching Field, Egerton University, Njoro, Kenya, to evaluate effects of agronet cover and fresh manure on carbon dioxide (CO_2) concentration in the air around the crop canopy and tomato plant development. In addition to CO_2 concentration levels, stem diameter, plant height, number of internodes and branches, number of fruit and fresh fruit weight were determined. Use of agronet cover and fresh manure resulted in higher CO_2 concentration and enhanced tomato growth and yield. The highest CO_2 concentration in the air around the crop canopy was in plots treated with fresh goat dung and those covered with agronet; the lowest CO_2 concentration was in plots with no manure and those without agronet at all data collection dates. Application of fresh cow dung and covering plots with agronet stimulated tomato stem elongation; application of fresh goat dung and covering with agronet enhanced stem diameter, number of internodes and branches. Higher tomato yields were obtained with use of fresh manure and agronet cover. There were differences in response of tomato plants to fresh manure source with fresh goat dung showing greater potential for use in CO_2 enrichment and enhancing tomato crop performance. Use of fresh manure and agronet covers could enrich CO_2 levels in open field tomato production leading to improved growth and yield.

Keywords: *Solanum lycopersicum*, cow dung, goat dung, technology, crop vicinity