DETERMINATION OF OPTIMUM POPULATION DENSITY OF BASIL (*Ocimum basilicum* L.) FOR INTERCROPPING WITH HOT GREEN PEPPER (*Capsicum annum* L.) AT HAWASSA, SOUTHERN ETHIOPIA

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DETERMINATION OF OPTIMUM POPULATION DENSITY OF BASIL (*Ocimum basilicum* L.) FOR INTERCROPPING WITH HOT GREEN PEPPER (*Capsicum annum* L.) AT HAWASSA, SOUTHERN ETHIOPIA

MSc. Thesis

Submitted to the School of Graduate Studies, College of Agriculture and Veterinary Medicine, Jimma University, in Partial Fulfillment of the Requirements for the Degree of Master of Science in Horticulture

By:

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SCHOOL OF GRADUATE STUDIES

JIMMA UNIVERSITY

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DEDICATION

This thesis is dedicated to my father who passed away in 2016, and to my families.

STATEMENT OF THE AUTHOR

I, Habtamu Gudisa, hereby declare that this thesis is a genuine result of my own work that all sources of materials used for writing have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for the MSc. degree at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM). The thesis is placed at the university's library to be made available to borrowers under the rules and regulations of the library. I solemnly declare that I have not submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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LISTS OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CSA	Central Statistics Authority
EARO	Ethiopian Agricultural Research Organization
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agricultural Organization
GLM	General Linear Model
IPGRI	International Plant Genetic Resource Institute
LER	Land Equivalent Ratio
MAI	Monetary Advantage Index
MARC	Melkasa Agricultural Research Centre
MoARD	Ministry of Agriculture and Rural Development
P.L.C	Private Limited Company
PLER	Partial Land Equivalent Ratio
PAR	Photosynthetically Active Radiation
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SNNPR	South Nation Nationality Peoples Region
WGARC	Wondo Genet Agricultural Research Centre

BIOGRAPHICAL SKETCH

The author, Habtamu Gudisa, was born on July 18, 1989, in Jimma Rare woreda, Goben town, Horro Guduru Wollega of Oromia Regional State. He followed his primary education from 1997-2004 and secondary education from 2005-2006 at Lelise Wayu primary and Secondary school and his preparatory education from 2007-2008 at Burayu preparatory school. He joined Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) in 2008 and graduated with Bachelor of Sciences degree in Horticulture in 2011. Soon after graduation, he was employed by Chemical Industry Corporation, Rubber Plantations, and Processing Industry as Agronomist from June 2011 to May 2014. In May 2014, he was employed by Ethiopian Institute of Agricultural Research (EIAR) and served at Wondo Genet Agricultural Research Center (WGARC), and he joined Jimma University in October 2016 to pursue his MSc. study in Horticulture.

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Determination of Optimum Population Density of Basil (*Ocimum basilicum* L.) for Intercropping with Hot Green Pepper (*Capsicum annum* L.) at Hawassa, Southern Ethiopia

ABSTRACT

Hot pepper (Capsicum annum L.*), its green pod and Basil (Ocimum basilicum* L.*) are widely grown in Hawassa area by smallholder farmers as a mixed cropping system with different population densities of basil. Hence, an experiment was conducted in a field at Hawassa Green Mark Herbs Private Limited Company site to determine optimum basil population densities for intercropping with hot pepper and assess yield advantage and economic returns. Two hot pepper varieties (Melka Shote and Melka Awaze) and four basil population densities (100% (55556), 75% (41667), 50% (27778) and 25% (13889) plant ha^{-1}) and their soles as check were factorialy arranged and laid out in randomized complete block design with three replications. Data on phenology, growth, yield components, yields and quality parameters were collected for both crops and analyzed using SAS software (version 9.3). The analysis of variance revealed that the green hot pepper yield was not significantly ($P \leq 0.05$) influenced by variety. However, the highest marketable fruit yield (8.05 t ha^{-1}) was obtained from a plot with the lowest population density of basil (25%). Similarly, the sole cropping system of green hot pepper had the highest yield (8.58 t ha^{-1}) and intercropping with basil reduced its yield by 23 %. On the other hand, the interaction was not significant ($P \leq 0.05$) for fresh leaf yield and essential oil yields of basil. However, the highest fresh leaf yield of basil (8.92 t ha^{-1}, 6.24 t ha^{-1}and 12.02 t ha^{-1}) was obtained from Melka Awaze variety, 100% density and sole cropping system, respectively. The essential oil yield of basil was not influenced by hot pepper varieties, but significant higher mean essential oil yields of (14.73 kg ha^{-1}and 19.46 kg ha^{-1}) were obtained from 100% density, which was statistically at par with 75%, and the intercropped system of basil, respectively. Intercropping of Melka Awaze variety with 50% density of basil resulted in the maximum total LER value of 1.86 and MAI value of 251,525 ETB ha^{-1}, Whereas intercropping of Melka Shote with 50%, 75% and 25% population densities had maximum total LER values of 1.78, 1.74 and 1.74, and MAI values of 240,755 ETB ha^{-1}, 242,385 ETB ha^{-1} and 236,808 ETB ha^{-1}, respectively. Furthermore, correlation analysis showed that growth and yield components had significant and positive contribution to the yields of both crops. Therefore, the population density of 27778 basil plants ha^{-1} with Melka Awaze variety and 41667 basil plants ha^{-1} with Melka Shote variety could be recommended to the targeted area. However, further studies across locations, seasons, under both rainfed condition and full irrigation systems, and for dry pod of hot pepper would be important to assess the yield and economic advantages of intercropping hot pepper with basil and come up with a more compressive conclusion.*

Key Words: *Competition, Essential Oil, LER, MAI, Oleoresin, Productivity*

1. INTRODUCTION

Hot pepper *(Capsicum spp.)* is a member of the Solanaceae family, which is large, economically important vegetable crop in the category (Bosland and De Witt, 2009). It is the most widely cultivated species and may be categorized into green and dry pod (Heiser, 1976; Russo, 2012). The fruits of green hot pepper are the most consumed fresh vegetable crop around the world, for its pungent properties and nutritional values. It is highly demanded year round in Ethiopia as sources of daily diet (Samira *et al*, 2013; Tilahun *et al*., 2013). Hence it is categorized as 'functional food' for its beneficial activity in the human body, being source of vitamins and mineral (Eshbaugh, 2012; Quartey *et al.*, 2014). The hot pepper has dominated today's world and is a source of cash income for smallholder farmers in developing countries like Ethiopia (Lin *et al.*, 2013). It is categorized among the leading cultivated vegetables and covers over 4.10% of the whole area under vegetable production in Ethiopia (CSA, 2017). According to the report of CSA (2017); 9832.28 ha of land was covered by green hot pepper with a total yield of 61794.33 tons and average productivity of 6.29 tons per ha in 2016/2017, which is very low compared with world average, 18.57 tons per hectare (FAO, 2015; Haileslassie *et al.,* 2015).

Basil (*Ocimum basilicum* L.), on the other hand, is popularly known as an aromatic plant, belonging to the Labiates family (Edet, 2013). It is an important medicinal herb, which is traditionally used for centuries to different diseases (Khalid, 2006). The essential oil extract from this crop is widely used in industrial applications (food industries, pharmaceutical, and cosmetics industry) (Svecova and Neugebauerova, 2010). It contains high concentrations of important compounds like linalool, methyl chavicol and/or 1, 8 cineole, which are used in food flavoring, aromatherapy, pharmaceuticals, and perfumery industries (Simon *et al.*, 1999; Svecova and Neugebauerova, 2010). Furthermore, it has been used for the insecticidal purpose and found to be effective in vivo as anti-malaria bioagent (Zheljazkov *et al*., 2007; Al-Azzazy, 2016). In Ethiopia, basil has been commonly produced as a sole or intercropped with other vegetable crops for home consumption and local markets. However, information on production and productivity of the crop are still scarce at the country level despite to its daily uses and immense important benefits.

Nowadays, the Ethiopian population is increasing at an alarming rate, which ultimately leads to rapid urbanization and decreasing area of arable land owned by individual households. Like with other rural areas of the country, Hawassa zuria woreda in Sidama zone is a densely populated area and has a constraint for cultivation and thus land farm size at the household level is very small. Hence, increasing the production and productivity of crops to feed the growing population is undoubtedly the most issue. This could definitely be achieved through intensification of the production system like by intercropping of different crop plants for effective resource (sun radiation, water and mineral nutrients) utilization and maintaining of productivity per unit area of cultivated land.

The main purpose of crop production by such system is to produce a higher yield by allowing efficient resource (sun radiation, water and mineral nutrients) utilization, which has not been used by a single crop grown on the same land area (Brooker *et al*., 2015; Temesgen *et al.,* 2015; Sabbagh and Lakzayi, 2016). It has been evident that intercropping systems capture and utilize more water, nitrogen and light than sole crops (Temesgen *et al.,* 2015). The light exposure to the growing plants (canopy orientation and branching habit) is the most determinant factor for plant growth and crop productivity in the intercropping system. In addition, moisture and nutrient use efficiency over sole cropping is the most important merit of intercropping over sole cropping system of component crops. To this effect, intercropping of component crops is believed to increase land productivity by intensifying the system and reducing the risk of total crop failure by enhancing the crop diversification, which creates greater yield stability over seasons, and finally increases the gross returns per unit area. It involves growing of crops that have different life cycles such as annual plants with annuals, annual plants with perennials and perennial plants with perennials are common practices according to crop compatibility.

Yield advantage and economic benefits of intercropping the hot pepper with different specious (Fruits, vegetables, forages, aromatic and medicinal including basil) were reported (Kahn, 2010). Also, intercropping of basil with hot pepper has been reported to improve the yields of main crops reducing the losses caused by insect pests, diseases, and weeds due to the presence of phytonutrients (glucosinlates, capsaicin and sulfides) (Coolman and Hoyt, 1993; Parker *et al*, 2013; Mutisya *et al*., 2016). It was reported that growing of basil with hot pepper increased the well-beingness of component crops that finally obtained the highest yield of hot pepper per unit area of lands (Pereira *et al*., 2015). Therefore, intercropping is an important farm activity, which allows genuine yield gains by utilizing the growth resources (sun radiation, water, and nutrients) efficiently without additional inputs, and could be the best option for sustainable intensification of crop production (Brooker *et al*., 2015).

To this effect, the smallholder farmers in Hawassa area of Sidama zone commonly produce green hot pepper with basil as a mixed cropping system without having a defined plant density per unit area of lands. Although basil is widely grown with hot pepper in the area, there is little scientific information about yield advantage and economic returns from intercropping of these crops with supplementary irrigation under rain feed condition. Therefore, this experiment was designed to address the gap in Hawassa area, southern Ethiopia.

Objectives

General objective

- To assess the effect of intercropping of hot pepper with basil on yield and economic returns of both crops.

Specific objectives

- To determine appropriate population density of basil for intercropping with hot pepper
- To assess the yield advantage and economic return of green hot pepper-basil intercropping system.

2. LITERATURE REVIEW

2.1 Hot pepper (*Capsicum annum* L.)

2.1.1 Taxonomy, origin and distribution

Hot pepper (*Capsicum annum* L.) is a member of the Solanaceae family. It was believed to be originated in the western hemisphere and is native to the tropical regions of the Americas that botanically grown as perennial sub shrubs when grown in their native habitats, but it is grown as annuals in colder climate regions (Bosland and DeWitt, 2009). The genus of *Capsicum* consists of about 22 wild families. From this, human beings independently domesticated five species; *Capsicum pubescens*, *Capsicum frutescens, Capsicum baccatum, Capsicum chinense, and Capsicum annuum* (Bosland and DeWitt, 2009). The introduction history of *Capsicum* to the world was associated with the voyage of Columbus who has brought from its original areas to Spain in 1493 then spread to other European and subsequently spread to African and Asian countries (Desalegn, 2011). But, the exact time of introduction to Africa generally and to Ethiopia specifically was not well known but, assumed to have been grown in Ethiopia since its introduction in the early 17th century by Portuguese (Huffnagel, 1961; Bosland and Votava. 2012)

Capsicum annum L. is the most cultivated species of its genus and shows great variability, which encompassing bell peppers, paprika and spicy peppers (Csillery, 2006; Do Rego *et al.*, 2012). Based on their pungent properties, peppers are divided into hot (Fresh [green pepper] and Dry pod) and sweet pepper. The hot pepper contains a capsaicin compound that is responsible for the pungency principles (Saleh, 2016). It greatly varies in their habit and sizes (Bosland *et al.,* 2009). The cultivated plants grow averagely up to 90 cm in height. The hot pepper can easily be identified by its flower color, morphology, and seeds (Andrews, 1995). It is a short-lived perennial erect or sub-shrub plant in the tropics and subtropical areas but cultivated as an annual plant for commercial values (Grubben and El Tahir, 2004).

2.1.2. Ecology and production of hot pepper (*Capsicum annum* L.)

Hot pepper is naturally tolerated in tropical and subtropical climates but adapted to temperate climate regions for cultivation purpose, during summer or in protected areas year-round (Crosby, 2008). Following its introduction, the crop has adapted to the temperate regions, as an interest became rise for its pungent properties with spicy cuisine in traditional foods of many countries (Wien, 1997). Therefore, the protected culture has developed in northern latitude countries such as Holland, Canada, and Mediterranean countries (Spain and Israel), to fulfill an increased world hot pepper demand (Wien, 1997).

The production of hot pepper highly dependent on climatic condition, soil types and fertilities for the best quantity and quality of hot pepper fruit yield (Ashilenje, 2014). Even though it has grown on diverse soil types, a well-drained sandy loam soil with a pH range of 5.5–6.8 and a high water retention capacity is very important but the crop is moderately sensitive to soil salinity (Grubben and El Tahir, 2004). The optimal temperature required for its growth and development is in ranges of 18°C and 30°C. According to MoARD (2009) reported that the temperature between 25–30°C is best to germinate seeds of hot pepper to produce vigor seedlings. The altitudinal range of the production area can influence hot pepper production and productivities. The crop has grown on a wide altitudinal range from the lowland to 2000 m.a.s.l (Ashilenje, 2014 and can even exceed up to 3000 m.a.s.l. with unsatisfactory yields (Grubben and El Tahir, 2004). It also needs sufficient water to give good productivity throughout its ontogeny. Therefore, the mean annual rainfall of at least 600 mm for the area where access to irrigation water is limited is important to produce an optimum yield of hot pepper fruits (Ashilenje, 2014). The relative humidity between 65 – 85% has considered as optimal for normal growth and development of *Capsicum annum* L. (Grubben and El Tahir, 2004).

Hot pepper suffers from wide ranges of diseases and insect pests (Grubben and El Tahir, 2004). It has commonly affected (Damping off, bacterial wilt and fusarium wilt) by different fungal, bacterial, viral disease and insect pests and root knot nematodes at all developmental stages (Ashilenje, 2014; Alemu *et al*., 2015).

The productivity of hot pepper is highly affected by agro-ecological climate conditions and agronomic practices. In Ethiopia, the productivity of green hot pepper is 6.29 t ha^{-1} which are far below the world production trends (18.57 t ha^{-1}) despite to available suitable environment for potential productivity (CSA, 2017). This might be due to the inability to exploit the potential capacity of the crop by using recommended production standards in the country. There is number of hot pepper varieties recommended for the diverse agro-ecological area of the country. However, most of the growers use poor planting materials, which has obtained from their local markets and imported from abroad without registration (Alemu *et al*., 2015). In addition, failure of using recommended agronomic practices have contributed a lion share for the *Capsicum annum* L. yield reduction in Ethiopia. However, much effort has been made to solve the production constraints at country level and therefore; different national and regional research centers and higher learning institutes are working to solve these vivid production constraints to boost the crop productivity (Fekadu and Dandena, 2006).

Hot pepper, its green pod, is widely consumed worldwide for its nutritional values. Many countries have incorporated the consumption of green hot pepper in their food culture because it aids in stimulation of appetite and improving digestion. For instance in Ethiopia, the green hot pepper is believed to stimulate an appetite for food consumption, and seasoning of different food types and commonly served with lunch (Grubben and El Tahir, 2004). In Sudan, the fresh fruit has also used to make a fresh for food seasoning. Different literature also reported that the green hot pepper has used to relieve various diseases due to the chemical constituent used as medicine. Luo *et al*. (2011) have reported that the hot pepper contains up to 69% of burning compound 'capsaicin ($C_{18}H_{27}NO$)' based on genetic factor, cultivar and maturity stage, which has the potential of medicinal properties as pain relievers, cancer drugs, anti-inflammatory, antioxidants, and weight loss aids (Imatake *et al*., 2009; Stoica *et al.,* 2016). The capsaicin used to produce the tear gas for police defense. The benefits of the crop are not restricted to this indeed. According to Lin *et al*. (2013) report, it is one of the leading globally traded vegetable crops for its diverse benefits. Hence, the green hot pepper is used as sources of income for smallholder growers and traders in the developing countries like Ethiopia.

2.2 Basil (*Ocimum basilicum* L.)

2.2.1 Ecology and production status of basil *(Ocimum basilicum* L.*)* in Ethiopia

Basil is a tropical herb that requires plenty of heat and light for good herbal and essential oil yield production (Meyer, 2003). It can grow in varieties of soil types, well-drained and fertile soils with optimum pH of 6.5 for normal growth. Due to basil is a shallow rooting system, frequent watering is an important activity to give good herbal products and essential oil contents (Kumar *et al*., 2014). *Ocimum basilicum* L. requires an ideal growing environmental condition and mostly performs at an optimum temperature of 20 °C for seed germination and 7 to 27 °C for plant growth.

Basil has been cultivated since ancient times for its ornamental uses, essence extraction and therapeutic qualities (De Masi *et al*., 2006). Nowadays the genus *Ocimum basilicum* L. is most widely cultivated commercially for its green aromatic leaves and flowers in worldwide, which used in dry or fresh as a condiment or production of essential oil (Davis, 1993).

The crop was cultivated for centuries in Ethiopia and found wild in most part of the country (Jansen, 1981). Despite an estimated and quantity of production is not available to authorities, small-scale cultivation of basil is commonly widespread around the homestead of growers for its important uses. A fresh and/or dried plant part (fresh and dry leaf, stem and inflorescence) are used for sale on almost every Ethiopian markets (Jansen, 1981). These plant parts are dried, grounded and added to sauces either alone or blended with other spices to provide a good flavor to every stew (Atey, 2008). Despite this immense demand, the production of basil usually limited to the home garden cultivation in a small plot area as a sole crop and/or intercropped with other vegetable crops. Nowadays, the herbal form of basil is under cultivation by different production companies in Ethiopia (Hawassa Green Mark Herbs P.L.C and Joy Tech P.L.C) for export to European and Middle East markets. These companies are producing the herbal products of basil for their needs by importing the planting materials due to the absence of improved cultivars in the country.

Despite to it was marginalized for longer periods, currently, the production of basil for domestic uses and export market got an attention from the government for diversifying exporting agricultural commodity, with other aromatic and medicinal plants. Therefore, different research activities for basil are underway which includes the varietal developments and fulfillments of production packages at Wondo Genet Agricultural Research Center (WGARC), Ethiopian Agricultural Research Institute (EIAR), national aromatic and medicinal research coordinator (Egata *et al*., 2017). Despite different aromatic and medicinal plants have a long history associated with societies in the country, their economic importance did not consider before for industrial application by farmers out growers. Therefore, to acquaint the production technology of the crop easily to the farmers out growers, adopting the crop with familiarized vegetable crops is very important in order to reduce the total crop failure occur by monocropping.

2.3 Cropping systems

As early humans replaced hunting and gathering food by growing of crops and husbandering of animals, the history of crop production has begun to this planet. Through a gradual process, the practice of crop production became advanced due to the significance of food has risen with population growth. Since the 21st century, the growth of world population has to increased and expected to grow from 7 billion in 2011 to 9.3 billion in 2050, which needs a proportionate food supply (FAO, 2017). However, increasing of population density has put pressure on cultivating land to increase crop productivity per unit area, unit time and for unit resource used. In addition, crop production increasingly threatened by unusual weather, water shortages and insufficiently available land areas (Kozai *et al.*, 2015). Therefore, due to limited natural resources, 90% of growth in global crop production is expected from higher yields and increased cropping intensity, and the remaining of 10% from the expansion of productive land (FAO, 2009). Therefore, the trends of recent year's agricultural production systems have changed towards achieving high productivity and promote sustainability over time to feed these peoples (Aasim *et al*., 2008).

Farmers have developed different production methods like crop rotation, relay cropping and intercropping of major crops with their companions to increase the productivity and sustainability since ancient times. This crop productivity will be realized by efficient utilization of available resources (sun radiation, water, and nutrients) by adjusting the cropping systems per unit area. The cropping system is the way in which different crops are grown in the specified area for a fixed period and depending on the cropping season, crop type, available resources and technologies, it has been categorized into the crop rotation, mono-cropping and mixed/intercropping (Ali, 2003). The crop rotation is a systematic way of planting different crops in a particular order over several years in the same growing space by aiming to maintain nutrients in the soil, reduce soil erosion and prevents plant diseases and pests. It replaces depleted soil nutrients by previous plants and believed to prevent diseases and insect pest developments year after year on particular land. The monocropping or single cropping by other hand is a system of growing one crop on a specified piece of land year after year or repetitive growing of the same sole crop in the same land area, which might encourage the disease and insect pest developments over time. The multiple cropping or poly-cropping is also a system of two or three crops are grown annually on the same piece of land using high input without affecting the basic fertility of the soil (Singh *et al*., 2013). Multi-cropping is often more stable than monocropping, particularly where inputs such as fertilizers, pest and disease control, and irrigation are limited or unavailable (Ali, 2003).

2.3.1 Crop production by intercropping

Intercropping (mixed cropping), is a farming practice involving two or more crop species (genotypes) growing together and coexisting for specific time (Brooker *et al.*, 2015). It is the method of simultaneous growth of two or more crops in the same area of land, which has been a common intensification practice in both time and space dimensions by low input–low output for small-scale farmers (Temesgen *et al.,* 2015; Sabbagh and Lakzayi, 2016). The ability of different plant species to cooperate to mutual advantage is often the result of physical changes in plant structures or manipulation of the surrounding environment (Coolman and Hoyt, 1993, Trenbath, 1976). This principle of mutualism can apply to plant interactions in the agricultural system by intercropping system (Innis, 1997). The intercropping involves the growing of crops that have different life cycles; annual plants with annuals, annual plants with perennials and perennial plants with perennials are common practices (Kahn, 2010). Crops in the intercropping system are not sown always exactly at the same time but usually grow simultaneously for the significant part of their life cycle (Singh *et al*., 2013). Such production of different companion crop has benefits of crop diversification and sustainable production by efficient utilization of available resources to ensure the crop productivities (Alabi *et al*., 2014).

Intercropping different companion crops per unit area were reported to have different merit than producing their sole (Dudas *et al*., 2016). It can increase phyto availability and acquisition of limited resources and management of root/rhizosphere interactions which can improve resource-use efficiency by crops (Brooker *et al*., 2014). It has been evident that intercropping systems capture and utilize more water, nitrogen and light than sole crops (Temesgen *et al*., 2015). This efficient utilization of interspaced available growth resources (light, water, nutrients, and temperature) between main crops are the major merit over the sole cropping system (Singh *et al*, 2013). The Photosynthetically Active Radiation (PAR) is the major resource which is determining growth (determines the canopy architecture and branching orientation) and yield of component crops in intercrops when other growth resources are not limiting (Mahapatra, 2011). It is evident that the greater solar radiation interception, higher light use efficiency and/or the combination of the two can improve the productivity of the crops (Najafi and Keshtehgar, 2014). For maximum yield, the crop must fully intercept the incoming solar radiation, make efficient use within the canopy and produce the canopy at a time when incoming radiation is at its maximum (Singh *et al*., 2013).

The moisture availability is also crucially important factor for growth and determining the crop productivity. The area where water is the major limitation, intercropping often increases water availability or the efficient use of the available resource (including enhanced water-use efficiency) (Brooker *et al*., 2014). It has been shown that the intercropped systems had slightly higher values of water use and water use efficiencies relative to sole crops (Temesgen *et al*., 2015). Also, in an area where is the soil fertility is poor intercropping of crops with legumes can reduce the additional costs of input than the monocropping system by fixing the atmospheric nitrogen to the usable form for plants growth. It is reported that the component crops in intercropping may exploit different soil layers thus exploiting greater volume of soil by deeper rooting of crops, which is not absorbed by shallow rooting component (Brooker *et al*., 2014). Therefore, intercropping of these component crops have the mutual and synergetic effects by reducing the risks of total crop failure due to crop diversification, for greater yield stability over the seasons, for better control over weeds, pests and diseases, and prevent soil erosion (Singh *et al*., 2013; Brooker *et al*., 2014).

Intercropping has been widely practiced worldwide especially in developing countries like India, China, Nigeria and Ethiopia to enhance crop productivity (Wang *et al*., 2014). The crop productivity in this system depends on the varietal used, planting density, planting arrangement, cropping seasons and agricultural practices like irrigation and fertilization (Bantie *et al*., 2014). It has been classified based on the characteristics of various crops in spatial distribution and cropping goals (Singh *et al*., 2013). (1) Row intercropping; in this system, at least one crop is planted in rows, (2) Mixed intercropping; there is no distinct row arrangement in such types of intercropping system and (3) Stripe intercropping; is a system of raising two or more crops simultaneously in different stripes. The strip intercropping systems are arranged in various ways. The first one is the parallel intercropping system in which both crops have different growth habits but zero competitiveness, and the second is a companion-cropping system, which the production of both intercrops is equal to the production of both crops grown individually. In both arrangements, the two crops not much affected significantly as compared to growing them individually (Singh *et al*., 2013). The third system is multi-storied/ multitier cropping system in which two or more crops of different heights have grown simultaneously on a certain piece of lands in any certain period. Multitier cropping system has aimed at the better use of production components such as soil water, air, space, radiation and other inputs on a sustainable basis. The fourth intercropping type is synergetic cropping system where the yield of one crop has a synergetic effect on the second crop. Therefore, both crops produce a higher yield than when they grew as a single crop on a unit area basis. This system has two components; (1) Additive series intercropping system; if the plant population of base/ the main crop within an intercropping system are the same and (2) Replacement series intercropping; if the plant population of both component crops is less than their recommended population in pure stand (Singh *et al*., 2013).

The results of findings under different agro-climate condition have indicated the presence of yield advantage under intercropping system over the sole (Singh *et al*., 2013). It has mainly gained importance in dry land agriculture than wetland, which may reduce the risk of total crop failure due to crop diversification (Wang *et al*., 2014). There is also the best utilization of available interspaced between two rows of main crops by using efficient growth resources that stabilize the yield over the season by intercropping (Bantie, 2015). Furthermore, better control of weeds, pests and diseases and prevention of soil erosion is its merit over sole cropping system, which finally increases the gross returns per unit area than sole cropping system (Hiebsch and Mc Collum, 1987; Wang *et al*., 2014).

Regardless of intercropping design used, the performance of intercropping to that of the sole crop is incomplete if the analysis is not used at least one index (Innis, 1997; Yahuza, 2011). Therefore, several indices for estimating intercrop efficiencies have been introduced (Wang *et al*., 2014). Land Equivalent Ratio (LER) is the most widely used indices to estimate intercropping efficiency, to measure the land productivity of component crops and, an indicator to determine the biological efficacy and productivity of intercrop to that of the sole cropping system (Hiebsch and Mc Collum, 1987; Brintha and Seran, 2009; Amanullah *et al*., 2016). It is expressed as the ratio of land required by the sole crop to produce the same yield as that of the intercropping system (Onwueme and Sinha, 1991). Therefore, the results obtained from LER leads to the decision whether intercropping is productive or not than sole crop. As the value of LER becomes greater than one (> 1), it indicates that the overall biological advantage of the intercropping system than the sole cropping system (Singh *et al*., 2013). Hence, the value of one (1) is the critical point at which the above favor the intercropping system whereas below is favoring the sole cropping (Yahuza, 2011).

The agronomic advantages from intercropping alone do not always ensure the economic advantages of intercropping unless it has gone to evaluate for further economic yield comparison (Bantie *et al*., 2014). Therefore, the value index used to access economic return from intercropping over sole cropping system is the Monetary Advantage Index (MAI) (Ghosh, 2004). It computes the return gained by intercropping of different component crops over the sole cropping system. Hence, the highest MAI value indicates more profitability of the cropping system. Therefore, the value of combined intercrops in each cropping system will be the lowest prevailing market prices of each component crops in area price per kg at the time of the experiment (Ghosh, 2004; Mahapatra, 2011). Generally, the purpose of intercropping is used to maximize the yield and increases returns by efficient utilization of growth resources than they grown individually per unit of lands.

2.3.1.1 Yield advantage and economic benefits

Many scientific findings have justified the presence of yield and economic advantages of intercropping over the sole cropping system. However, several factors like cultivar selection, seeding ratios, planting pattern and competition between mixtures of component crops can affect the growth of species in intercropping systems (Aasim *et al*., 2008). Different scholars reported the yield advantages and economic benefits of intercropping across the world and most of them were focused on cereal-legume intercropping. Therefore, Kebebew *et al*. (2014) reported the yield advantage (32%) of maize over sole cropping by intercropping with soybean. Nigussie (2015) also reported the presence of 40% yield advantages of maize over sole cropping system by intercropping with haricot bean. This might be due to efficient utilization of nutrients by both crops and the haricot bean was improved the nitrogen capture to provide for better performances of companion crops (Temesgen *et al*., 2015).

In addition, the effects of intercropping medicinal plants with cereals on yield advantages and economic returns have been reported. According to Bagheri *et al.* (2014) reported the yield advantages of maize by intercropping with basil and borage. Bilasvar and Salmasi (2016) also reported the presence of herbage yield advantage of sweet basil with intercropping of corn.

Furthermore, the study for intercropping of different vegetables with various component crops also reported in different areas. According to Bantie (2015) study report on intercropping of potato with maize in south wollo of Ethiopia, found the presence of yield advantage and higher economic returns from both crops in intercropping than their mono cropping system. Ram and Kumar, (1998) also studied the effects of intercropping sweet-scented geranium with hot pepper and reported the presence of yield advantage by 36% over sole cropping. Further, Da Mota *et al*. (2012) reported the yield advantage of intercropping onion with lettuce from the highest population density than the sole cropping. Mehdi *et al.* (2015) also reported the yield and economic advantages of intercropping roselle with aloe vera, from the ratio of 25% Roselle + 75% aloe vera than the sole cropping. Furthermore, intercropping of carrot with French Marigold (*Tagetes patula nana* L.) and Pot Marigold (*Calendula officinalis* L.) have shown the yield advantage than sole cropping system and decreased number of roots damaged by carrot rust fly, *Psila rosae*, and nematodes (Jankowska *et al*., 2012). In general, the different crop can be intercrop with their companions per unit area for efficient utilization of growth resources (Light, water and nutrients) which is not utilized by a single crop.

However, intercropping system may be undesirable when a single standardized product is required, and may lack economies of scale for labour and time management (Brooker *et al*., 2013). It has not usually been seen as suitable for mechanization in an intensive farming areas. Consequently, and despite its potential benefits, intercropping faces huge competition from large-scale, intensive mono crop farming system (Brooker *et al*., 2013). In intercropping system an improved implements cannot be used efficiently and harvesting of component crops is difficult related to mono cropping (Singh *et al*., 2013).

2.3.1.2 Yield advantage and economic benefit of hot pepper (*Capsicum annum* L.) in intercropping system

The hot pepper could be cultivated with different companion crops for multiple advantages. Different species of crops have intercropped with hot pepper as the companion; fruit, vegetables, forages, aromatic and medicinal plants and others representing over 12 botanical families (Kahn, 2010). The *Capsicum annum* L. also often relay-cropped with tomatoes, onions, garlic, okra, *Brassica* species, cucurbits, pulses and among newly established perennial crops (Grubben and El Tahir, 2004). Accordingly, Brintha and Seran (2012) have reported the presence of highest yield advantages and economic return of *Capsicum annum* L. by intercropping with onion than their mono cropping system. The growing of hot pepper with other companion crops was also reported for reducing disease and pest infestation of component crops. Mitiku *et al*. (2013) were intercropped maize with hot pepper to determine the effect of intercropping on infection of pepper by potyvirus on yield and its productivities and intercropping of both component crops found advantageous for managing diseases and insect pests to enhance productivity than solitary cropping system. This might be due to some neighboring plant pushed the pests away and served to distract from the main crops (Kuepper and Dodson, 2001). Moreover, Kabura *et al.* (2008) intercropped pepper with onion to determine their population size, found that adding of onion in interspaces of pepper at a spacing of 60 cm x 30 cm with onion at 15 cm x 40 cm gave 18% yield advantage than sole cropping system. This might be due to onion benefited from available growth resources and microclimate between the rows of pepper (De Pailhe, 2014). Furthermore, Pereira *et al*. (2015) were intercropped basil with hot pepper by aiming to investigate the pepper pollination enhancement by beneficial insects and found the abundance and richness of bees (Apoidea) in the intercropping system than the sole crop. Consequently, the fruit yield obtained from the intercropped system was wider, longer, and heavier and, developed more seeds than the solitary cropping system. To this extent, the most intercropping system of hot pepper with other companion crops showed the yield advantages and economic return than their solitary cropping.

The economic advantages of *Capsicum* intercropped with other companion crops also reported. Accordingly, Prabhakar and Shukla (1990) studied the advantages of economic return from intercropping of *Capsicum annum* L. with onion and reported that the presence of higher return by 59% than its sole cropping in India. In addition, intercropping of hot pepper with garlic was conducted to assess the economic advantages and found that an intercropping of hot pepper fetched the highest net return than sole cropping system. Furthermore, Olasantan *et al.* (2007) evaluated the intercropping effects of cassava with hot pepper to yield advantages and higher economic returns and they found that intercropping of *Capsicum annum* L. with cassava increased the yield and total gross return than sole cropping system. Therefore, intercropping of *Capsicum annum* L. with its component crops has a yield advantage and economic benefit than its solitary cropping system especially for smallholders' producers due to efficient utilization of growth resources (solar radiation, water, and nutrients) not yet utilized by a single crop of component crops.

2.3.1.3 Yield advantage and economic benefit of basil (*Ocimum basilicum* L.) in intercropping system

Basil has traditionally grown with most vegetable crops for sustainable production for centuries (Kuepper and Dodson, 2001). According to different reports indicated that basil could be intercropped with different crops to enhance the productivity and well-beingness of the companion crops. De Carvalho *et al*. (2010) reported intercropping of basil with tomato gave yield advantage and higher economic return than its sole cropping system. According to the finding, the highest basil herbage yield (96.5 t ha^{-1}) was gained in the intercropped system over the sole. The yield and economic advantages of intercropping basil with other companion crops also studied from different areas. Girma (2015) reported that intercropping of basil with maize gave yield advantage and used to provide farmers with income profitability over sole cropping system. This might be due to the growth resources (solar radiation, water, and nutrients) found under maize was efficiently utilized by basil and, the phytonutrients released by basil inhibited infestation of insect pest from maize. A similar study also conducted by Bilasvar *et al*. (2016) who reported the presence of yield improvement by intercropping of basil with maize than sole cropping system in Iran.

The intercropping of basil with other vegetable crops also further for reported to developing and maintaining a sustainable production by enhancing a natural pest control. The intercropping of basil with tomato has reduced infestation of *B. tabaci* on tomato and improved the fruit quality and yields of the crop (Mutisya *et al.,* 2016). Similarly, intercropping of basil with kale has reduced aphid infestation on kale and improved its qualities and yields (Tiroesele and Matshela, 2015). This might be due to intercropping of basil with other companion crop found to be repelled the harmful insect pests and enhanced crop pollination status by attracting beneficial insect pollinators. Generally, basil could be enhanced the companion crop productivity by reducing different diseases and insect pests' occurrences due to the presence of photochemical, which repeals harmful organisms from the companion plants.

Furthermore, the intercropping of basil with other crops could bring additional income for growers without affecting the productivity of companion crops. In Ethiopia, basil is traditionally cultivated by intercropping with various vegetables and other companion crops for home consumption and market purposes in different parts of the country as mixed cropping system. The study on productivity and economic returns of basil with most crops especially with vegetables did not well assessed despite to its wide demands in the daily diet and economic contribution for most Ethiopian smallholder farmers. The production of hot pepper with basil through intercropping in mixed cropping system is common in most parts of the country. However, the yield and economic return from the production system at the country level in general and in Sidama zone, Hawassa area in particular, is not yet assessed and reported (Gabiso *et al*., 2015). Therefore, this assessment of yield advantage and economic return from intercropping of hot pepper varieties with different population density of basil at Hawassa area would be contributed to alleviate the gap and produces information on intercropping of defined population density of basil with hot pepper in the targeted area.

3. MATERIALS AND METHODS

3.1 Description of the experimental site

The experiment was conducted in open field at Hawassa Green Mark Herbs P.L.C in southern Ethiopia with supplemental irrigation under rain feed condition in 2017 season. Hawassa green mark herb P.L.C is located within great rift valley in the Southern Nations, Nationalities and Peoples Region (SNNPR) in Sidama zone, Hawassa Zuria woreda, 270 km away from the capital city, Addis Ababa and an altitude of 1652 m.a.s.l, with 7^{o} 05' N latitude and 39^{o}29'E longitude. Its minimum and the maximum mean annual temperature are 12.94 ^{0}C and 27.34 ^{0}C, respectively. The average annual rainfall of the area is 1000-1800 mm. The soil in the area is dominated by sandy clay loam texture and is classified as andosol with pH of 7.84 (Kassahun *et al.*, 2014).

3.2 Experimental materials

Two hot pepper varieties (Melka Shote and Melka Awaze) and one elite basil genotype (Won.06) were used for the experiment where hot pepper considered as main crop and basil as a companion crop. Seeds of hot pepper varieties previously adapted to Hawassa environmental condition were obtained from Melkasa Agricultural Research Center (MARC). The varieties are different in terms of growth habit (erect, semi-erect and spreading), plant height, canopy size, and branching nature. They also vary in maturity and number of days required from flowering to pod maturity and in pods also vary in their fruit position, color at maturity and ripening, shape, length, width, wall thickness and level of pungency of fruits (MoANR, 2016). However, the hot pepper varieties have some common features in terms of climatic requirements (Table 1). The recommended spacing for hot pepper was 70 cm x 30 cm (EARO, 2004).

Table 1. Description of hot pepper varieties

Varieties	Environmental condition requirement			Year of release	Yield t ha^{-1}
	Adaptation m.a.s.l	Temperature (^{0}C)	Rain fall (mm)		
Melka Awaze	1000-1800	18/29	900-1300	2006	2.5 -2.8
Melka Shote	1000-1800	15/27	900-1300	2006	2.5 – 3.0

Source: MoANR (2016)

Basil seed was obtained from Wondo Genet Agricultural Research Center (WGARC). The recommended spacing for basil was 60cm x 30cm (Egata *et al.,* 2017)

3.3 Treatments and plot arrangement

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications in 2 x 4 factorial arrangement of two hot pepper varieties (Melka Shote and Melka Awaze) and four basil population densities (100% or 55556 plants ha^{-1}, 75% or 41667 plants ha^{-1}, 50% or 27778 plants ha^{-1} and 25% or 13889 plants ha^{-1}) with their soles as a check (Appendix Table 1). The experiment had a total area of 499.5m^{2} (13.5m width and 37m length) with a plot area of 8.4m^{2} (3.5m width and 2.4m length). The spacing between replications and plots was 1.5m and 1m respectively. Each plot consisted of five rows of hot pepper planted 70 cm apart and each contained eight plants per row and, thus, had a total of forty (40) plants. In addition, the plots consisted of six rows of basil, which were 60 cm apart and contained a varied number of plants p.er row according to the pre-determined population density. One month-old seedlings of both crops were transplanted to the plots in the last week of August 2017 based on their predetermined arrangements.

3.4 Experimental procedures

3.4.1 Land preparation

The land was prepared by removing all unwanted materials before planting. Then, the land was plowed by a moldboard plow and leveled by breaking the large soil aggregate into pieces. The field layout was followed based on the determined number of treatments and experimental design.

3.4.2 Nursery management

Seeds of hot pepper were sown on seedling trays at Green Mark Herb P.L.C, Hawassa and covered with one to two cm thick soil layer until the seedling emergence in a propagation room. Regular watering and other management practices were applied until the seedlings got ready for transplanting (Alemu *et al*., 2015). Similarly, Seeds of basil were sown in polyethylene pots (12cm length and 10cm diameter) filled with recommended nursery media and arranged on standard seedbeds at Hawassa nursery site. Then, all nursery management practices including mulching, shading, and, regular watering and weed control were applied as per the recommendation until seedlings of both crops attained transplanting stage (a month after sowing) (Egata *et al*., 2017).

3.4.3 Field transplanting

A month after seed sowing seedlings of both crops were carefully transplanted to the field plots based on the pre-determined population densities.

3.4.4 Field managements

After field transplanting of hot pepper and basil seedlings, weed management was done regularly by hand weeding as required. Supplementary irrigation was supplied at two to three days interval in the off-season based on plant water requirement until the end of the experiment. Time and rate of nutrient application were determined based on the crop growth stages. Therefore, 200 kg ha^{-1} of DAP as a side dressing along with 100 kg ha^{-1} of urea was applied during transplanting time and half of the urea was applied 15-20 days after transplanting (After the seedlings recovered from the transplanting shock) based on the recommendation for hot pepper (EARO, 2004). In general, the required field management practices of hot pepper were applied as per EARO (2004) recommendation while basil plants were managed based on the farmers' best practices.

3.5 Data collection

Data on phenology, growth, yield components, crop yield, and quality-related parameters were collected from six randomly sampled plants in the central rows of each plot for the two crops. Hot pepper was harvested twice within two weeks and the yield was composited while basil was harvested once at the end of the experiment for data analysis.

3.5.1 Phenological responses of hot pepper

- Data on phenological parameters were collected based on the guideline set by IPGRI *et al.* (1995):

  - **Days to 50% flowering**: Number of days taken from transplanting to 50% of plants produced at least one open flower was recorded for each plot. It was taken for six plants from the plots and the sum total was divided by number of sampled plants to get mean days to 50% flowering per plant.

- **Days to 50% fruit set:** Numbers of days taken from transplanting to 50% of plants set fruit was recorded. It was taken for six plants from the plots and the sum total was divided by number of sampled plants to get mean days to 50% fruit setting per plant.

- **Days to 50% fruit maturity:** Number of days taken from transplanting to 50% of fruit reached physiological maturity. It was taken for six plants from the plots by counting the days of fruit maturity. The sum total was divided by the number of sampled plants to get mean days to 50% fruit maturity per plant.

3.5.2 Growth parameters of hot pepper

- **Plant height (cm):** Plant height was measured for six randomly sampled plants using a measuring tape (Model No. Tape Measure-6201 and reading scale 5m) in centimeter from the base to tip of the main stem when 50% of the first fruit has begun to mature. Mean plant height was calculated as the sum total divided by the number of sampled plants.

- **Number of primary branches per plant:** Primary branches were counted at harvesting time for randomly sampled plants. Mean number of primary branches was calculated as the sum total divided by the number of sampled plants.

- **Canopy diameter (cm):** Canopy coverage was measured for six randomly sampled plants using a measuring tape (Model No. Tape Measure-6201 and reading scale 5m) from the tip of the longest branch at one corner to the other in both directions (North to South and East to West) before the first harvest and was expressed in centimeter. Mean canopy diameter was obtained by dividing the sum total by the number of sampled plants.

3.5.3 Yield components and yield of green hot pepper

- **Fruit number per plant**: Number of fruits per plant was recorded for six randomly sampled plants at physiological maturity (where the fruit get firm and before turning to red). Mean number of fruits per plant was calculated as the sum total divided by the number of sampled plants.

- **Fruit length (cm)**: Fruit length was measured from base to the tipping point of fruit immediately after harvest and expressed by centimeter for six randomly sampled plants using digital caliper (Model No. 4141 and reading scale 0-30 cm). Mean fruit length was obtained by dividing sum total by the number of sampled plants.

- **Fruit diameter (cm)**: Green fruit diameter was measured for six randomly sampled plants using digital caliper (Model No. 4141 and reading scale 0-30cm) at the central points each of fruit immediately after harvest and expressed by centimeter. Mean of fruit diameter was obtained by dividing the sum total by the number of sampled fruits

- **Total marketable fresh fruit yield (t ha^{-1})**: Marketable green fruit yield was harvested from six randomly sampled plants, and weighted using sensitive balance (Model No. yt-1002 and reading scale 0.01) at green stage before turning to red and expressed by gram. Mean of marketable fruit yield was obtained by dividing the sum total to the number of sampled plants and converted into ton per hectare.

- **Oleoresin content (%):** The dried pods of green hot pepper were used to determine the oleoresin content of green hot pepper was obtained by the solvent extraction method. The composite sample of grounded dry fruit having 70 g weight was charged in Soxhlet apparatus with acetone solvent and trapped for 4 hours. After non-volatile components were dissolved in the acetone solvent, the desired compound was collected in the distillation flask and the oleoresin content was obtained after evaporation of the solvent. It was expressed as (% w/w) on dry weight basis.

$$\text{Oleoresin content (\%)} = \frac{\text{Amount of oleoresin extracted (g)}}{\text{Amount of dried green pepper subjected to extract (g)}} \text{x100}$$

3.5.4 Growth parameters of basil

- **Number of primary branch per plant**: Primary branches were counted for six a randomly sampled plants at harvesting time. Mean number of primary branches was obtained by dividing the sum total to the number of sampled plants and used

- **Canopy diameter (cm):** Canopy coverage was measured for six randomly sampled plants using a measuring tape (Model No. Tape Measure-6201 and reading scale 5m) from the tips of the widest part at one corner to the other on both directions (North to South and East to West) before harvest and was expressed in centimeter. Mean of canopy diameter was obtained by dividing the sum total to the number of sampled plants.

3.5.5 Yield components and yield of basil

- **Fresh leaf yield (t ha^{-1})**: Fresh leaves were harvested from six randomly sampled plants and weighted using sensitive balance (Model No. yt-1002 and reading scale 0.01) immediately after the leaves were separated from the stem and expressed by gram. Mean of Fresh leaf yield per plant was obtained by dividing the sum total to the number of sampled plants and converted to tone per hectare.

- **Dry leaf yield (t ha^{-1})**: Leaf dry weight per plant was estimated by taking 100 g from the sampled plants and was dried in an oven at 100 ^{o}C to a constant weight. Then, the dried sample was weighed by sensitive balance (Model No. yt-1002 and reading scale 0.01) and expressed by gram and the mean dry leaf yield was obtained by dividing the sum total to the number of sampled plants and converted to tone per hectare.

- **Leaf to stem ratio**: Leaf to stem dry weight ratio was calculated as total weight of dried leaf divided by the dry weight of stem for six randomly sampled plants. Mean leaf to stem ratio was obtained by dividing the sum total to the number of sampled plants.

- **Aboveground dry biomass (t ha^{-1})**: Aboveground dry biomass yield was obtained by harvesting six randomly sampled plants and drying in an oven at 100^0c to a constant weight. The dried samples were weight using sensitive balance (Model No. yt-1002 and reading scale 0.01) and mean above-ground dry biomass was calculated as the sum total divided by the number of sampled plants and converted tone per hectare

- **Essential oil content (%)**: The essential oil content was obtained by hydrodistillation, using the procedure described by Bisrat *et al*. (2009) where the dried leaves of basil placed in round bottom flask and subjected to hydrodistillation in Clevenger apparatus. The harvested plants were separated into leaf and stem parts then composite samples of dry leaves having a biomass of 300 g was put in the Clevenger apparatus along with 700 ml of water and trapped for 3 h (Guenther, 1972). Water was poured into the flask until the plant sample submerged completely. The round bottom flask was placed on a heated mantle, the water with the plant sample was allowed to boil for 3 hours, and the essential oil was collected and measured by using pipette reading. Then, the essential oil content was determined according to the following formula (Rao *et al*., 2005).

$$\text{Essential oil content (\%)} = \frac{\text{Amount of essential oil recovered (g)}}{\text{Amount of dried basil biomass distilled (g)}} x100$$

- **Essential oil yield (kg ha^{-1})**: The oil collected in the tube of the apparatus, was dehydrated, weighted and expressed in dry weight dry basis (% w/w). Then, essential oil, yield per hectare was determined by the following formula (Badawy *et al*., 2009).

$$\text{Essential oil yield (kg/ha)} = \frac{\text{Dry leaf yield (kg/ha) X Esssential oil content (\%w/w)}}{100}$$

- **Harvest Index**: Harvest index was calculated as the ratio of marketable oil-bearing dry leaf yield (kg ha^{-1}) to the harvested aboveground dry biomass yield (kg ha^{-1}). It was an indication of oil concentration in the harvested basil leaf and determined by the following formula (Okwany *et al*., 2012):

$$\text{Harvest index (\%)} = \frac{\text{Essential oil yield(kg/ha)}}{\text{Dry above ground biomass yield (kg/ha)}} X100$$

3.5.6 Crop productivity indices and economic benefits of intercropping

Crop productivity (yield advantage and economic return) indices were computed for the intercropping of hot pepper with different population densities of basil. The values of, land equivalent ratio, and monetary advantage index were obtained from the comparison of intercropping with the sole cropped system and subjected to analysis of variance.

3.5.6.1 Partial Land Equivalent Ratio (Partial LER)

The yield advantage of individual crops used for intercropping was calculated separately by the partial land equivalent ratio for both crops by formula as described by Willey (1979)

$$\text{Partial land equivalent ratio} = \frac{\text{Yin Hot green pepper/Basil/}}{\text{Ys Hot green pepper/Basil/}}$$

Yin = yield by intercropping

Ys = yield by sole crop

3.5.6.2 Total Land Equivalent Ratio (Total LER)

The yield advantage of intercropping was estimated by LER. The value of LER greater than unity was used to express the yield advantages over sole cropping system, whereas less than unity was used to indicate the disadvantage of intercropping. It was calculated using the formula as described by Willey (1979) and Onwueme and Sinha (1991).

$$\text{Total LER} = \frac{\text{Yin hot green pepper}}{\text{Ys hot green pepper}} + \frac{\text{Yin basil}}{\text{Ys in basil}}$$

Where;

Yin = yield by intercropping

Ys = yield by sole crop

3.5.6.3 Monetary Advantage Index (MAI)

The economic advantage of intercropping was expressed by MAI and it was calculated using the formula described by Ghosh (2004):

$$\text{MAI} = \text{Value of combined intercrops} + \frac{(\text{LER} - 1)}{\text{LER}}$$

The higher value of MAI was used to express the profitability of cropping systems. The value of combined intercrops in each cropping system was the lowest prevailing market prices of each component crop in Ethiopian Birr (ETB) per kg at the time of the experiment. The price of green hot paper and basil leaf was taken from Hawassa vegetables and herbs market at the time of harvest in the first week of January 2018. Accordingly, the prices were 56 and 27 ETB kg^{-1} for green hot pepper and basil leaf, respectively

3.6 Data analysis

Analysis of variance and correlation

Analysis of variances (ANOVA) for the data recorded for two factors (variety and population density) and the pooled data of population densities with sole cropped to see the cropping effect were done using the General Linear Model (GLM) of Statistical Analysis System (SAS) software version 9.3 (SAS, 2012). Duncan's Multiple Range Test (DMRT) at 5% probability was used for mean separation when analysis of variance indicated the presence of significant differences (Gomez and Gomez, 1984). The Pearson correlation analysis for different characters was also carried out to observe the association between characters.

4. RESULTS AND DISCUSSION

4.1 Response of hot pepper

4.1.1 Phenology

4.1.1.1 Days to 50% flowering

The analysis of variance revealed that the interaction between hot pepper variety and basil population density was significant (P=0.497) for days to 50% flowering of hot pepper plants (Appendix Table 2). However, days to 50% flowering was significantly influenced by hot pepper varieties (P=0.0001) and population density of basil (P=0.0001) (Appendix Table 2). As a result, variety Melka Shote took longer days (50.00) to flowering than did Melka Awaze (Table 2), which might be because of the genetic variation that exists between the varieties. In agreement with this, Godfrey and Tuku (1985) have reported that earliness and tenderness of flowering could be related with the genetic inheritance of crops and the growing environmental factors. However, Melese and Gebreselassie (2015) and, Simon and Tesfaye (2014) have reported a non-significant variation in days to 50% flowering of hot pepper varieties. This might be due to the growing environmental condition, which triggered physiological processes of plants to bear flower bud at the early or late stages despite the genetic variation.

The more (51.33) days to 50% flowering was recorded for the highest population density of basil (100%), which was statistically at par with 75% (Table 2). The delayed flowering at higher plant densities might be due to the presence of competition for light that shifted the growth and development of flowering buds to vertical growth to capture the Photosynthetically Active Radiation (PAR) (Singh *et al*., 2013). In line with this study, Ozer (2003) has reported delayed flowering of rapeseed cultivars in densely populated plants than in lower population density. Early flowering of hot pepper with the lowest population density of basil (50%) was statistically at par with (25%) in the present study (Table 2). This might be due to initiation and differentiation of more number of flower buds as a result of increased concentration of phyto hormones of growth regulators specially gibberellin, which regulate the transition from juvenile to adult phase, in response to reduced mutual shading by plants and increased irradiance at lowers densities.

However, cropping systems did not significantly (P=0.06) affect days to 50% flowering of hot pepper (Appendix Table 2).

Table 2. Mean values for phenological parameters of hot pepper as affected by hot pepper varieties with different population densities of basil and cropping system at Hawassa during 2017 season

Treatments	Days to 50%		
	Flowering	**Fruit set**	**Fruit maturity**
Hot pepper varieties			
Melka Shote	50.00[a]	84.75[a]	105.04[a]
Melka Awaze	47.33[b]	77.00[b]	95.05[b]
CR (0.05)	0.90	2.63	3.96
Basil population density			
100%	51.33[a]	85.50[a]	102.54
75%	50.33[a]	80.33[b]	99.52
50%	46.67[b]	77.83[b]	100.23
25%	46.33[b]	79.83[b]	97.05
CR (0.05)	1.27	3.72	ns
CV (%)	2.09	3.52	4.51
Cropping systems			
Sole hot pepper	46.17	80.86	89.74[b]
Intercropped	48.67	76.17	99.58[a]
CR (0.05)	ns	ns	7.01
CV (%)	5.66	6.51	7.66

Note: ns, CV, and CR= indicate None Significance, Coefficient of Variation and Critical Ranges. Means followed by the same letter/s within a column for a given variable are not significantly different at P>5% level.

4.1.1.2 Days to 50% fruit set

According to the result of ANOVA, days to 50% fruit set were not significantly influenced by the interaction (P=0.89). However, the varieties between hot pepper were (P=0.0001) significant for days to days to 50% fruit setting (Appendix Table 2). Accordingly, variety Melka Shote took more days (84.75) to 50% fruit set than did Melka Awaze (Table 2) which might be because of the genetic difference between the two varieties. In agreement with this, Idowu-Agida *et al*. (2012) have reported the presence of variation between pepper varieties for days of 50% flowering.

Similarly, days to 50% fruit set were significantly (P=0.0039) affected by population density of basil (Appendix Table 2) where early flower set was observed for the lowest population density (25%), though statistically at par with 50% and 75% (Table 2). Conversely, the highest population density of basil (100%) was delayed the time taken (85.50) for days to 50% fruit set of hot pepper plants (Table 2). This might be due to initiation and differentiation of more number of flower buds as a result of increased concentration of phyto hormones of growth regulators specially gibberellin, which regulate the transition from juvenile to adult phase, in response to reduced mutual shading by plants and increased irradiance at lowest densities. In line with this, Thakur *et al*. (2018) reported that days to 50% fruit setting of *Capsicum annum* L. was delayed for higher population densities.

Conversely, cropping system did not exert a significant (P=0.058) influence on days to 50% flower setting of hot pepper (Appendix Table 2).

4.1.1.3 Days to 50% fruit maturity

The present study revealed that days to 50% fruit maturity was not significantly affected by the interaction (P=0.32) and by population density of basil (P=0.38). Hot pepper varieties, however, showed a significant (P=0.0001) variation for days to 50% fruit maturity (Appendix Table 2) where variety Melka Shote took the more (105.04) days than did Melka Awaze

(Table 2). This implies that fruit maturity of hot pepper could be influenced by varietal differences, which agreed with the study of Haileslassie *et al.* (2015) and Melese (2015) who have reported the presence of variation among hot pepper varieties for days to 50% fruit maturity. This might be because of variation in environmental factors like temperature, which could trigger the physiological processes of fruit maturity in warmer areas beside to genetic influences. Contrastingly, Simon and Tesfaye (2014) have reported the absence of variation among hot pepper varieties for 50% fruit maturity.

The cropping systems also showed significant (P=0.007) difference for days to 50% fruit maturity of hot pepper (Appendix Table 2). Accordingly, the 50% fruit maturity of hot pepper was delayed by 9.84 days for intercropping than for sole cropping system (89.74) days (Table 2). This might be because of the competition for growth resources that delayed fruit maturity by encouraging the vertical vegetative growth in higher population density unlike responses to lower population density in the sole cropping system. In line with this, Kabura *et al.* (2008) have reported that the competition of individual crops in the intercropping system start beyond a certain limit of population density, which affects the normal growth and developments and finally crop productivity.

4.1.2 Growth parameters of hot pepper

4.1.2.1 Plant height

Plant height was not significantly (P=0.15) affected by the interaction between factors (Appendix Table 3). However, it was significantly (P=0.0001) affected by hot pepper varieties (Appendix Table 3). Hence, variety Melka Shote had taller plants (59.10 cm) than did Melka Awaze (Table 3). This difference might be because of genetic variation exists between the varieties (Russo, 2012). Melese and Gebreselassie (2015) have also reported the existence of variations in plant height among hot pepper varieties. Similarly, Haileslassie *et al.* (2015) have reported the presence of variation in plant height among hot pepper varieties where the plants of Melka Awaze were taller than those of Melka Shote and Mareko Fana varieties.

Population density of basil significantly (P=0.0003) influenced the height of hot pepper plants (Appendix Table 3). The highest value (61.51 cm) was obtained from the lowest population density (25%) (Table 3). In contrary to the present result, it has been reported that the phytochrome system of plants in higher population density undergoes changes from red to far-red light ratios caused by excessive shade and increases the internodal length of plants, which consequently increases plant height (Xiao *et al.*, 2006). However, in this study, the plants in higher population density might have been arriving on the competition threshold for PAR to affect height of the plants. This was supported by Kabura *et al.* (2008) who have reported that the competition of individual crops in the intercropping system for PAR started beyond a certain limit in higher population density. However, on the other hand, Islam *et al*. (2011), Alabi *et al*. (2014) and Thakur *et al*. (2018) have reported maximum plant height value for the higher population densities, which might be because of heavy shading in higher population density that triggered plants to compete for solar radiation, resulting in increased internodal length.

Furthermore, cropping system had significant (P=0.0034) effect on plant height (Appendix Table 3), while sole cropping resulted in 13.97% taller plants than did the intercropped system (55.46 cm) (Table 3). This might be associated with efficient utilization of the natural growth resource by the plants in wider spacing without competition to attain the potential height. In agreement with this, Oskoii *et al*. (2015) and Degri and Ayuba (2016) have observed taller plants in sole cropping than in the intercropped system. In contrast, Lulie *et al.* (2016) have reported higher values for maize height under intercropping of maize with haricot bean, which might be because of competition for solar radiation and fixation of nitrogen by haricot bean that increased vegetative growth of maize in the intercropped system. On the other hand, Agegnehu *et al*. (2008) have reported non-significant variation for plant height in wheat intercropped with faba bean, which implied the complementary action of faba bean and wheat in resource utilization.

4.1.2.2 Number of primary branches per plant

The present study revealed that the number of primary branches per plant of hot pepper was not significantly (P=0.90) influenced by the interaction between factors. However, the hot pepper varieties showed significant (P=0.0001) differences for numbers of branches per plant (Appendix Table 3). Accordingly, variety Melka Shote had more number of primary branches (11.28) than did Melka Awaze (9.41) (Table 3). This might be because of the genetic difference between the varieties. In line with this, Desalegn (2011) has reported the existence of variations among hot pepper varieties for number of primary branches per plants.

Similarly, population density of basil had a significant (P=0.01) influence on number of primary branches per plant of hot pepper (Appendix Table 3). The maximum number of primary branches per plant (10.99) was obtained from the lower population density of basil (25%), which was statistically at par with 50% (Table 3). This might be because of availability of growth resources (sunlight, nutrient, and water) in adequate amounts in wider spacing or lower population density was favored the growth of primary branch bearing buds (Singh *et al*., 2013). On the other hand, different studies indicated that the phytochrome system of plants undergoes changes from red to far-red light ratios due to mutual shading of plants in higher population density resulting in increased vertical extension growth and decreased lateral branching of plants (Xiao *et al.*, 2006). In line with the result of present study, Islam *et al*. (2011), Alabi *et al*. (2014), Abu and Odo (2017) and Thakur *et al*. (2018) have reported maximum number of primary branches per plant for the lower population density of *Capsicum annum* L. However, El-Gaid *et al.* (2014) reported non-significant difference for number of primary branches per plant of tomato due to intercropping tomato with common bean, which could be due to the complementary action of common bean and tomato in resource utilization in all population densities.

Furthermore, the number of primary branches of hot pepper was significantly (P=0.0001) affected by the cropping systems (Appendix Table 3) and sole cropping of hot pepper varieties exhibited higher value (12.93) than did intercropped plots (10.93) (Table 3). This might be due to the wider spacing allowed an efficient utilization of growth resources (light, water, and nutrients) to produce more number of primary branches (Quartey *et al.*, 2014). Similarly, Begum *et al.* (2015) and Mollah *et al*. (2016) have reported maximum number of primary branches per plants of Chilli for the sole cropping in a study with Chilli and Jute intercropping. Conversely, El-Gaid *et al.* (2014) have reported maximum number of primary branches per plants of tomato for the plots intercropped with common bean, which could be due to the nitrogen fixation effects of common bean that encouraged branch-bearing buds of tomato plants regardless of population density. On the other hand, Khan *et al*. (2017) have reported a non-significant response of number of primary branches per plant of sesame intercropped with groundnut.

4.1.2.3 Canopy spread

Results of statistical analysis revealed that canopy spread of hot pepper was not significantly affected by the interaction main factors (P=0.16). However, it was significantly (P=0.016) influenced by variety (Appendix Table 3). In line with this, it has been reported that canopy structure of plants can be affected by different growth factors including light interception, population density per unit area, and type of cultivar used for intercropping (Rezaei-Chianeh *et al*., 2011). It was observed that the variety Melka Awaze showed more (28.65 cm) canopy spread than did Melka Shote (Table 3). This might be because of the genetic difference between the varieties (Nsabiyera *et al.*, 2012). In agreement with this study, Mends-Cole (2015) has reported the presence of variation in canopy spreading of Chilli peppers due to genetic effects for the particular trait.

Similarly in the present study, canopy spread of hot pepper was significantly (P=0.0001) influenced by population density of basil (Appendix Table 3) and the highest value (33.72 cm) was recorded for the lowest population density (25%) whereas the lowest was for the highest population density (100%) (Table 3). This might be because of plants enhanced the canopy spread and lateral growth of branches in wider spacing or lower population densities could be attributed to less competition for light, which favors horizontal branching by depressing apical dominance and thus, vertical growth of the main stem (Maddonni *et al*., 2001). It has been reported that density of plants per unit area determines crop canopy structure and horizontal growth that influences the micro environment of plants (light, temperature, and relative humidity) for crop growth and developments (Yang *et al.*, 2014). In line with this, Vanderpuye (2010) has noted that the rate of canopy development could be influenced by a combination of leaf type, growth habit, and population density. Besides, Abu and Odo (2017) have also reported the widest canopy spreading of *Capsicum annum* L. for the lower population density.

The extent of canopy spreading of hot pepper was further significantly (P=0.0001) influenced by cropping systems (Appendix Table 3) where the narrower canopy spread (27.39 cm) was observed for the intercropped system than for mono-cropping (Table 3). This might be because of plants inhibited the canopy spread and lateral growth of branches in narrower spacing or highest population densities could be attributed to more competition for light, which favors the vertical growth of main stems by encouraging apical dominance and inhibiting the horizontal growth of plants (Maddonni *et al*., 2001). Girardin and Tollenar (1994) have reported the presence of variation in leaf orientation due to population density of plants where the leaves of the upper canopy tender to be perpendicular to the rows for higher population than for lower density. Therefore, the wider canopy structure in less populated/sole cropping of hot pepper could be associated with the tendency to intercept maximum sunlight for photo assimilation preparation, which has a direct linkage with the yield, and yield components of the crops (Quartey *et al.*, 2014).

Table 3. Mean values for growth parameters, yield components and yield of hot pepper varieties as affected by population densities of basil and cropping system under intercropped condition at Hawassa during 2017 season

Treatments	**Plant height (cm)**	**Number of primary branches plant^{-1}**	**Canopy spreading (cm)**
Hot pepper varieties			
Melka Shote	59.03^{a}	11.28^{a}	26.12^{b}
Melka Awaze	51.89^{b}	9.41^{b}	28.65^{a}
CR (0.05)	2.88	0.54	1.98
Basil population density			
100%	50.01^{c}	9.63^{c}	20.74^{d}
75%	54.09^{b}	10.11^{bc}	25.47^{c}
50%	56.24^{b}	10.65^{ab}	29.63^{b}
25%	61.51^{a}	10.99^{a}	33.72^{a}
CR (0.05)	4.07	0.77	2.81
CV (%)	5.19	6.94	7.94
Cropping systems			
Sole hot pepper	64.47^{a}	12.93^{a}	36.74^{a}
Intercropped	55.46^{b}	10.38^{b}	27.39^{b}
CR (0.05)	5.75	1.081	4.21
CV (%)	10.68	10.60	15.35

Note: ns, CR and CV indicate nonsignificant differences, Critical Ranges and Coefficient of Variation, respectively. Means with the same letter/s within a column for a given variable/treatments are not significantly different at (P>0.05).

4.1.3 Yield components and yield of green hot pepper

4.1.3.1 Number of fruits per plant

The analysis of variance revealed that the number of fresh fruits per plant was not affected significantly (P=0.91) affected by the interaction (Appendix Table 4). However, it was significantly (P=0.0007) influenced by hot pepper varieties (Appendix Table 4). As a result, the maximum number fresh fruit per plant was obtained from variety Melka Shote (39.19) (Table 4) which might be because of varietal genetic effect. Number of fruits per plant is the cumulative result of crop genetic inheritance and various associated traits like canopy spread and number of branches per plant that produce the fruit-bearing buds (Desalegn, 2011; Simon and Tesfaye, 2014). In agreement with this, Tesfaw (2013) has also reported the presence of variation in fruit number per plant among hot pepper varieties. Similarly, Melese and Gebreselassie (2015) have reported that there was variation between hot pepper varieties for fruit number per plant in which variety Melka Awaze gave higher fruit number per plant than did Bako local.

Furthermore, fresh fruit number per plant was significantly (P=0.0001) affected by population density of basil (Appendix Table 4), while the maximum value (41.50) was obtained from the lowest population density (25%), which was statistically at par with 50%, whereas the minimum was from the highest population density (100%) (Table 4). In line with this, Kabura *et al*. (2008) have reported the lowest fruit number per plant (18.00) for the higher population density in intercropping of hot pepper with onion. Similarly, Islam *et al*. (2011), Abu and Odo (2017) and Thakur *et al*. (2018) have reported the presence of maximum fruit number of hot pepper per plant in lower population densities. This might be due to initiation and differentiation of more number of flower buds as a result of increased concentration of phyto hormones of growth regulators specially gibberellin, which regulate the transition from juvenile to adult phase, in response to reduced mutual shading by plants and increased irradiance at lower densities.

However, cropping systems did not significantly (P=0.0894) affect fresh fruit number per plant of hot pepper (Appendix Table 4) though sole cropping resulted in higher values (Table 4).

4.1.3.2 Fruit length

The interaction between hot pepper varieties and population density of basil was not significant (P=0.39) for fruit length of green hot pepper (Appendix Table 4). However, fruit length was significantly (P=0.0001) affected by hot pepper variety (Appendix Table 4). Accordingly, longer fruit length (10.52 cm) was produced by variety Melka Shote than did Melka Awaze (Table 4). In agreement with this results, Russo (2012) and, Simon and Tesfaye (2014) have reported the presence of variation in fruit length among the pepper varieties.

The present study revealed that population density of basil was significantly (P=0.387) influenced fruit length of green hot pepper (Appendix Table 4). It was observed that the lower population density (25%), which was statistically at par with 50%, gave the longest (10.57 cm) fruit whereas the shortest was obtained from the higher population density (100%) (Table 4). The increase in fruit size (fruit length and diameter) could be attributed to sink-source relationship and more partitioning or allocation to fruits as fruits are more stronger sinks than vegetative plant parts (Li *et al*., 2011). In line with this, Kabura *et al*. (2008) have also observed the largest fruit length for the lower population density in intercropping hot pepper with onion. Similarly, Islam *et al*. (2011) have reported larger fruit size for lower than the highest density of hot pepper.

Similarly, cropping systems significantly (P=0.0009) influenced fruit length of green hot pepper (Appendix Table 4) while, sole cropping resulted in higher fruit length (11.44 cm) than did the intercropped system (Table 4). This might be because of lower competition for light interception by canopy of plants in lower population density in the sole crop. In line with the result of this study, Brintha and Seran (2009) reported increased fruit length in sole cropping than the intercropped system of hot pepper. Conversely, the study of Degri and

Ayuba (2016) has shown smaller fruit length from the sole cropping system than from intercropping of hot pepper with cereals. In line with this, it has been reported that the resource utilization by crops for dry matter accumulation for the developments of different plant parts varies greatly with different cropping systems (Li *et al*., 2011).

4.1.3.3 Fruit diameter

The analysis of variance revealed non-significant difference due to the interaction (P=0.28) for fruit diameter of hot pepper and population density of basil (P=0.34) (Appendix Table 4). However, the difference between hot pepper varieties was significant (P=0.0001) (Appendix Table 4) wherein variety Melka Awaze resulted in higher values of fruit diameter (1.12 cm) than did Melka Shote (Table 4). In agreement with this result, Russo (2012) and Melese and Gebreselassie (2015) have reported the presence of variation in fruit diameter of hot pepper, in which the largest fruit diameter was recorded for variety Mareko Fana than for the other varieties.

Similarly, cropping systems showed a significant (P=0.004) difference for green hot pepper fruit diameter (Appendix Table 4), wherein the higher values (1.17 cm) was recorded for the sole cropping system than did the intercropped (Table 4). The increase in fruit size (fruit length and diameter) could be attributed to sink-source relationship and more partitioning or allocation to fruits as fruits are more stronger sinks than vegetative plant parts (Li *et al*., 2011). In line with the present study, Brintha and Seran (2009) have reported larger fruits of hot pepper for sole cropping than for the intercropped system with onion.

Table 4. Mean values for growth parameters, yield and yield components of hot pepper varieties as affected by population densities of basil and cropping system under intercropped condition at Hawassa during 2017 season

Treatments	Fruit			Marketable fruit yield (t ha^{-1})
	Number plant^{-1}	**Length (cm)**	**Diameter (cm)**	
Hot pepper varieties				
Melka Shote	39.19^{a}	10.52^{a}	0.90^{b}	6.87
Melka Awaze	33.38^{b}	9.31^{b}	1.12^{a}	6.42
CR (0.05)	2.89	0.45	0.04	ns
Basil population density				
100%	28.92^{c}	9.25^{c}	1.04	4.54^{c}
75%	35.22^{b}	9.78^{bc}	1.04	6.73^{b}
50%	39.49^{a}	10.07^{ab}	1.04	7.26^{b}
25%	41.50^{a}	10.57^{a}	1.08	8.05^{a}
CR (0.05)	4.08	0.64	ns	0.68
CV (%)	11. 65	4.57	4.66	11.80
Cropping systems				
Sole hot pepper	41.08	11.44^{a}	1.17^{a}	8.58^{a}
Intercropped	36.28	9.92^{b}	1.05^{b}	6.65^{b}
CR (0.05)	ns	0.83	0.08	0.95
CV (%)	16.01	8.69	7.87	14.45

Note: ns, CR and CV indicate nonsignificant differences, Critical Ranges and Coefficient of Variation, respectively. Means with the same letter/s with in a column for a given variable/treatments are not significantly different at (P>0.05).

4.1.3.4 Marketable fruit yield

The present study revealed that the interaction between hot pepper varieties and population density of basil did not significantly (P=0.23) affect marketable fresh fruit yields of hot pepper. However, population density of basil significantly (P=0.0001) influenced marketable fruit yield of green hot pepper (Appendix Table 4). It was observed that the lowest population density (25%) of basil gave the maximum marketable fruit yield per hectare (8.05 t ha^{-1}), while the highest population density (100%) had the lowest value (Table 4). The increase in fruit size (fruit length and diameter) could be attributed to sink to source relationship and more partitioning or allocation to fruits as fruits are more stronger sinks than vegetative plant parts (Li *et al*., 2011; Quartey *et al.*, 2014). In line with the present study, Kabura *et al*. (2008), Islam *et al*. (2011), Alabi *et al*. (2014) and Thakur *et al*. (2018) have reported maximum fruit yields of hot pepper for the lower density. Similarly, Agegnew *et al*. (2008) have reported yield reduction of wheat with increasing population density of faba bean in mixed intercropping system. Furthermore, Lulie *et al*. (2016) have reported the minimum maize yield with increasing population density of haricot bean in maize-haricot bean intercropping which could probably be due to the nitrogen-fixing effect of haricot bean that enhanced vegetative growth rather than fruit yields in densely populated plants.

Cropping system also showed a significant (P=0.0003) response to marketable fruit yield of green hot pepper (Appendix Table 4). As a result, intercropping of basil with hot pepper reduced the marketable fruit yield of green hot pepper by 23% as compared to the sole cropping system (8.58 t ha^{-1}) (Table 4). The yield advantage of sole cropping probably is due to the less intra-specific competition of hot pepper plants for growth resources (light, water, and nutrients) compared to the intercropped system. Planting pattern in the intercropping system affects the canopy structure of crops and influences other physiological characteristics such as light interception and radiation use efficiency, which have significant effects on crop yields (Ren *et al*., 2011). In line with this study, Kabura *et al*. (2008) have reported the yield advantage for the sole cropping over intercropping in hot pepper and onion intercropping system. Similarly, kebebew *et al*. (2014) have reported the yield advantage of sole cropped over intercropping maize with soya bean. However, the study of Khan *et al*. (2017) has shown more yield advantage of groundnut and sesame in the intercropping system than the sole cropping of an individual component. In line with this, it has been reported that productivity of a crop depends on the ability of the plant to intercept the incident radiation, which is a function of vegetation architecture and conversion efficiency of the energy captured by the plant into biomass (Campillo *et al.*, 2012).

4.1.3.5 Oleoresin content (%)

The analysis of variance revealed that oleoresin content of green hot pepper was significantly affected by the interaction effects (P=0.0001), hot pepper variety (P=0.0001) and by population density of basil (P=0.0001) (Appendix Table 4). Hence, the variety Melka Shote intercropped with 50% population density of basil gave the highest percentage of oleoresin contents (8.59 %) (Fig.1), while the lowest (3.69 %) was obtained from the combination of Melka Awaze variety planted with higher population densities of basil (100%). The increment in oleoresin content at lower population densities might be because of the wider spacing attributed to improved supply and minimum competition for resources and, thus, enhanced physiological and biochemical processes of plants.

Furthermore, cropping system was significantly (P=0.0119) influenced oleoresin content of green hot pepper (Appendix Table 4). Hence, intercropping was favored oleoresin percentage by 0.74% as compared to the sole cropping system (5.06 %) (Fig. 2).

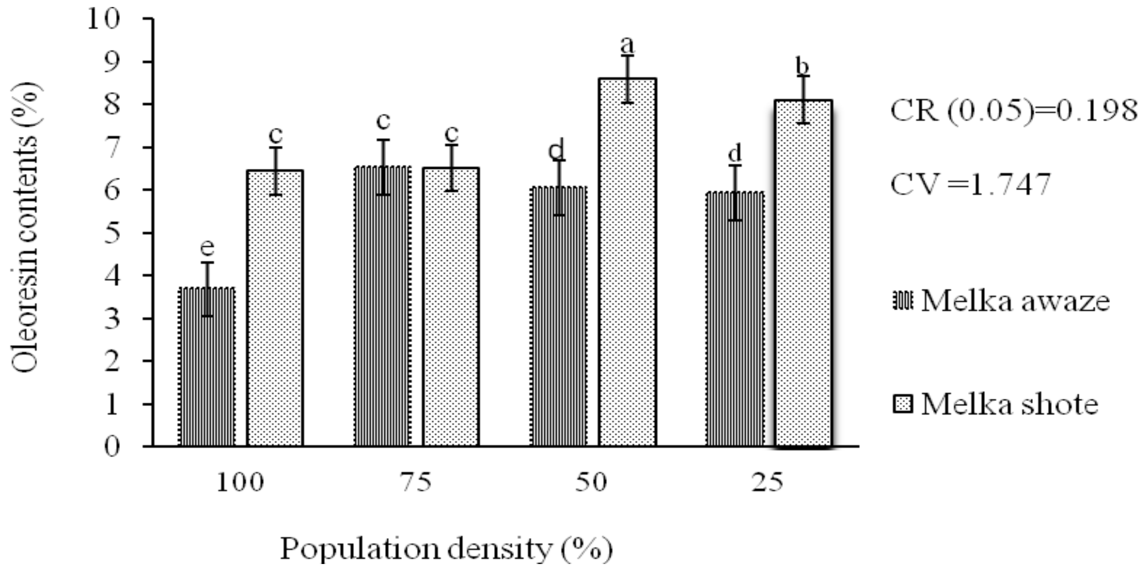

Figure 1. Interaction of hot pepper variety (Melka Shote and Melka Awaze) with different population densities of basil for oleoresin content of green hot pepper fruits at Hawassa, in 2017 season. Bars capped with the same letter/s are not significantly different at (P>0.05). CR and CV indicate Critical Ranges and Coefficient of Variation, respectively.

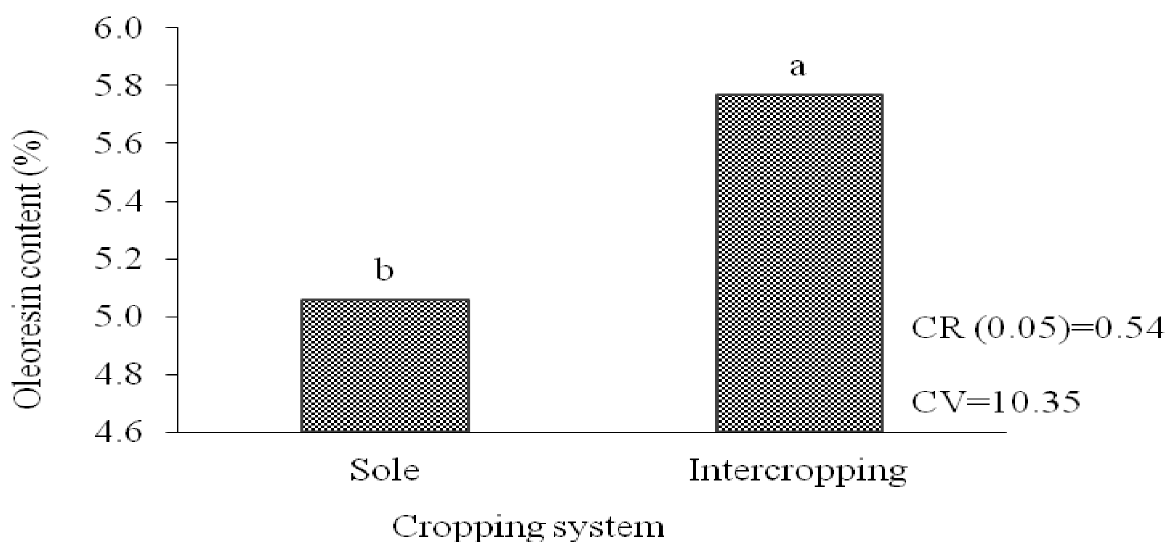

Figure 2. Effect of cropping system on oleoresin content of hot pepper intercropped with different population densities of basil at Hawassa, in 2017 season. Bars capped with the same letter/s are not significantly different at (P>0.05). CR and CV indicate Critical Ranges and Coefficient of Variation, respectively.

4.2 Response of basil

4.2.1 Growth, yield components and yield response of basil

4.2.1.1 Number of primary branches per plant

The ANOVA revealed that the number of primary branches per plant did not show a significant response to the interaction (P=0.90), hot pepper varieties (P=0.81) or to the cropping systems (P=0.63) (Appendix Table 5). However, population density of basil had a significant (P=0.036) influence on number of primary branches per plant of basil (Appendix Table 5). As a result, the lowest population density (25%) of basil intercropped with hot pepper exhibited the maximum number of primary branches per plants (15.88), which was statistically at par with 50% and 75%, while the highest population density gave the lowest value (13.61) (Table 5). This might be because of plants enhanced the canopy spread and lateral growth of branches in wider spacing or lower population densities could be attributed to less competition for light, which favors horizontal branching by depressing apical dominance and thus, vertical growth of the main stem (Maddonni *et al*., 2001). In line with the present study, Girma (2015) has reported more number of primary branches per plant of basil for lower population density than for higher densities. Similarly, Bilasvar and Salmasi (2016) have reported the reduction of branches number per plant of two basil cultivars by increasing the population density of basil intercropped with corn. Mutual shading effects in higher densities would increase the vertical growth and decrease branching of plants (Xiao *et al*., 2006).

4.2.1.2 Canopy spread

Combined effects of hot pepper variety and population density of basil significantly affected canopy spread of basil (P=0.0004) (Appendix Table 5). Therefore, the widest canopy spread (39.33 cm) was recorded for intercropping of variety Melka Awaze with 75% population density of basil, while the lowest value (33.16 cm) was for 100% population density with same hot pepper variety (Fig. 3). Canopy structure determines the extent of interception of solar radiation by component crops in the intercropping system (Najafi and Keshtehgar, 2014). Therefore, the wider canopy structure in less populated plants could be advantageous for maximum sunlight interception for photo assimilation, which influences the final yield of a crop (Quartey *et al.*, 2014). In line with the present study, Alemu (2017) has observed wider canopy spread for less populated basil genotypes.

On the other hand, canopy spreading of basil was not significantly (P=0.434) influenced by cropping systems (Appendix table 5).

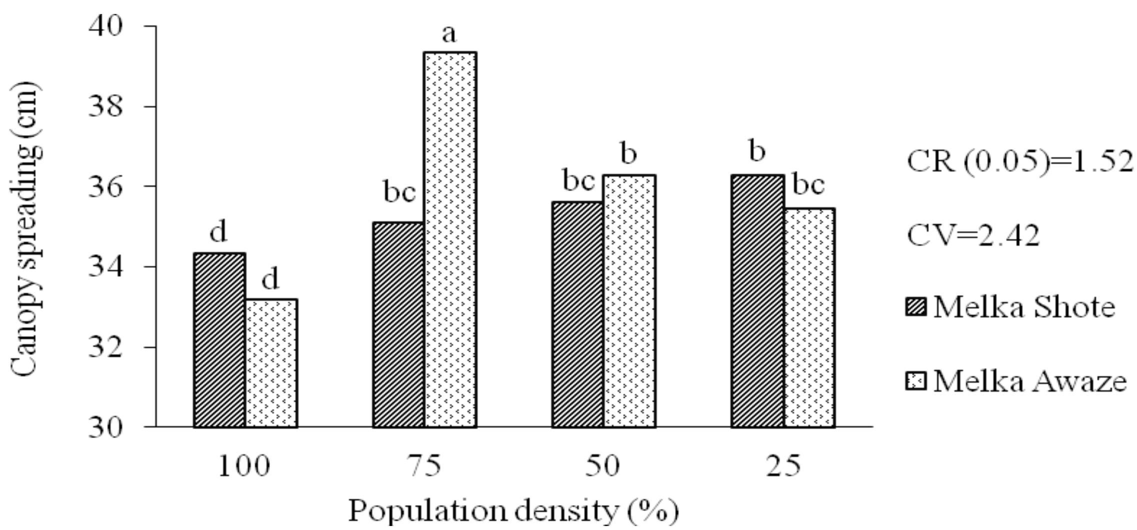

Figure 3. Interaction of hot pepper varieties (Melka Shote and Melka Awaze) with different population densities of basil at Hawassa in 2017 season. Bars capped with the same letter/s are not significantly different at (P>0.05). CR and CV indicate Critical Ranges and Coefficient of Variation, respectively.

4.2.1.3 Fresh leaf yield

Results of the statistical analysis revealed that the interaction between treatments did not significantly (P=0.176) affect fresh leaf yield per hectare of basil. However, the hot pepper varieties (P=0.0009) and population densities of basil significantly (P=0.0001) influenced basil fresh leaf yield (Appendix Table 5). Accordingly, the maximum fresh leaf yield per hectare (6.24 t) was obtained from intercropping of basil with variety Melka Awaze variety

(Table 5). This indicates that varietal difference has affected horizontal growth and branching of basil, which substantially influenced its leaf yield.

The maximum fresh yield per hectare of basil (8.92 t) was obtained from the higher population density than lower density and significantly and consistently decreased with wider spacing (Table 5). This result indicated that fresh leaf yield per unit area was higher while the leaf yield per plant decreased with increasing plant density. It has been reported that in higher population density of plants in the intercropping system reduced light penetration into the lower canopy of basil affecting the photosynthetic rate and, thus, following dark respiration and death of lower leaves of individual plants (Lawlor, 1995; Ren *et al*., 2017). In line with the study, Bekhradi *et al*. (2014) have recorded maximum fresh leaf yield for the highest population density of basil. Similarly, Maboko and Du Plooy (2013), Girma (5015) and Bilasvar and Salmasi (2016) have recorded maximum fresh leaf yield of basil per unit area in higher population density than in lower densities. Alemu (2017) have reported that fresh yield of basil is the cumulative effect of branch number per plant, canopy spread and population density per unit area of the plant.

The intercropped system significantly (P=0.0001) reduced (Appendix Table 5) fresh leaf yield per hectare (by 50.21%) compared to sole cropping system (6.00 t) (Table 5). The highest population density of plants in the intercropping system might have also reduced light penetration into the lower canopy of basil affecting the photosynthetic rate and, thus, following dark respiration and death of lower leaves of individual plants (Lawlor, 1995; Ren *et al*., 2017). Therefore, best utilization of nutrients, moisture, space and solar energy in lower population densities of basil (lower inter competition) might have gave the maximum yield per hectare (Najafi and Keshtehgar, 2014). In line with the study, Bilasvar and Salmasi (2016) have reported that maximum fresh yield of basil in sole cropping was greater than that of the intercropped system. Similarly, Girma (2015) has reported maximum leaf yield per hectare of basil in sole cropping than in the intercropped system with maize.

4.2.1.4 Dry leaf yield

The result of the present study revealed that dry leaf yield of basil was not significantly affected by the interaction (P=0.66) and hot pepper variety (Appendix Table 5). Conversely, population density of basil showed significant (P=0.0001) influence on dry leaf yield per hectare. Accordingly, the highest population density (100%) gave the maximum dry leaf yield of basil (1.46 t) per hectare while the lowest population density (25%) resulted in the lowest value, indicated that basil dry leaf yield increment with increasing population density (Table 5). It was indicated that dry leaf yield per unit area increased while dry leaf yield per plant decreased with increasing plant density. It has been reported that in higher population density of plants in the intercropping system reduced light penetration into the lower canopy of basil affecting photosynthetic rate and, thus, following dark respiration and death of lower leaves of individual plants (Lawlor, 1995; Ren *et al*., 2017). In line with this study, Bekhradi *et al*. (2014) have reported maximum dry leaf yield of basil for the higher population density by intercropping basil with corn. Similarly, Maboko and Du Plooy (2013) have reported maximum dry leaf weight of basil per unit area for the higher population density of basil. This might be because of greater interception of solar radiation, higher light use efficiency or combination of the two improved dry leaf yield of basil in higher population densities (Najafi and Keshtehgar, 2014).

Furthermore, the dry leaf yield of basil per hectare was significantly (P=0.0001) affected by cropping systems (Appendix Table 5). The sole cropping gave higher dry leaf yield per hectare of basil (1.68 t) than did intercrop system (Table 5). Similarly, Bilasvar and Salmasi (2016) have also reported maximum dry leaf yield of basil per hectare for the sole cropping system in intercropping of basil with corn. It has been reported that in lower population density of plants in the intercropping system allows light penetration into the lower canopy of basil favoring photosynthetic rate in lower leaves of individual plants that increases photoassimilate partitioning for higher leaf yield (Lawlor, 1995; Ren *et al*., 2017).

Table 5. Mean values for growth parameters, yield and yield components of basil intercropped with hot pepper as affected by hot pepper varieties, population densities of basil and cropping system at Hawassa during 2017 season

Treatments	Number of primary branches plant^{-1}	Fresh leaf yield (t ha^{-1})	Dry leaf yield (t ha^{-1})
Hot pepper varieties			
Melka Shote	14.98	5.68^{b}	0.86
Melka Awaze	14.86	6.24^{a}	0.97
CR (0.05)	ns	0.28	ns
Basil population density			
100%	13.61^{b}	8.92^{a}	1.46^{a}
75%	15.33^{a}	6.97^{b}	1.00^{b}
50%	14.86^{ab}	5.20^{c}	0.78^{c}
25%	15.88^{a}	2.75^{d}	0.42^{d}
CR(0.05)	1.52	0.40	0.19
CV (%)	8.24	5.45	16.99
Cropping systems			
Sole basil	14.50	12.02^{a}	1.68^{a}
Intercropped	14.92	6.01^{b}	0.92^{b}
CR (0.05)	ns	0.73	0.17
CV (%)	9.49	8.66	13.31

Note**:** ns, CR and CV, indicate none significant difference, Critical Ranges and Coefficient of Variation, respectively. Means followed by the same letter within a column for a given treatment are not significantly different at P>5%.

4.2.1.5 Leaf to stem dry weight ratio of basil

The ANOVA revealed that the interaction between the two (P=0.10), hot pepper varieties (P=0.94), population density of basil (P=0.75) and cropping systems (P=0.63) did not significantly affect leaf to stem dry weight ratio of basil (Appendix Table 6).

4.2.1.6 Aboveground dry biomass yield

Results of statistical analysis revealed that above-ground dry biomass yield was not significantly affected by interaction of factors (P=0.37) nor by hot pepper varieties (P=0.06) (Appendix Table 6). However, it was significantly influenced by population density of basil (P=0.0001) (Appendix Table 6). Accordingly, the highest population density (100%) showed more 70.99 % above-ground dry biomass yield advantage over the lowest density (25%) of basil (Table 6). These results also indicated that above-ground dry biomass yield of basil per unit area increased while per plant decreased with increasing plant density.

It has been reported that in higher population density of plants in the intercropping system reduced light penetration in to the lower canopy of basil affecting photosynthetic rate and, thus, following dark respiration and death of lower leaves and lateral branches of individual plants that affects the above-ground dry biomass yield (Lawlor, 1995; Ren *et al*., 2017). In agreement with this, Bilasvar and Salmasi (2016) have reported that aboveground dry biomass yield per unit area increased with increasing population density of basil. This might be due to efficient utilization of light, water, and nutrients by plants in higher population density to convert into dry matter yield per unit area than in lower population densities (Najafi and Keshtehgar, 2014). The aboveground dry biomass of basil is the cumulative result of leaf and stem dry biomass yield, which could be affected by the growth factors (nutrients, light, water, and spacing) (Najafi and Keshtehgar, 2014).

Furthermore, cropping system significantly (P=0.0001) affected aboveground dry biomass yield of basil per hectare (Appendix Table 6). While the maximum (5.28 t ha^{-1}) value was obtained from sole cropping than intercropped system (Table 6). This might indicate that higher interception by solar radiation to the plant parts for maximum photo assimilation and, greater absorption of water and nutrients in wider spacing without a significant competition followed above dry ground biomass accumulation than the case in narrower spacing (Schader *et al*., 2005).

4.2.1.7 Essential oil contents (EOC)

The present study revealed that the EOC of basil was not significantly (P=0.66) affected by the interaction effects (P=0.66), hot pepper varieties (P=0.66) and the cropping systems (P=0.87), respectively (Appendix Table 6). However, the population density of basil showed significant influence (P=0.045) on EOC (Appendix Table 6). Hence, higher oil content (1.42%) was obtained from the higher population density (75%), though it was statistically at par with 50% and 100%, while the lowest value of EOC was obtained from the lowest population density of basil (25%), which was in turn statistically at par with 50% and 100% (Table 6). The physiological and/or biochemical change occurred to plants due to limitation of growth resources (light, water, and nutrients) might have influenced the EOC either by acting directly on key enzyme pathways or indirectly by altering the allocation of biomass to oil-producing part of plants (Chang, 2005). In agreement with the result of this study, Alemu (2017) have reported the presence of variation in EOC of basil at different plant density. On the other hand, Bilasvar and Salmasi (2016) have reported that EOC linearly decreased with increasing population density of basil. In general, it is believed that genetic factors, plant ontogeny, environmental factors, and plant population density determine the constituents, yields, and qualities of essential oil of *Ocimum basilicum* L. (Wogiatzi *et al*., 2011; Nurzynska *et al*., 2012).

4.2.1.8 Essential oil yield (EOY) of basil

The ANOVA result revealed that the essential oil yield of basil was not significantly (P=0.57) affected by treatment interactions and hot pepper varieties (Appendix Table 6). Conversely, population density of basil imposed a significant (P=0.0001) influence on the essential oil yield (EOY) per hectare (Appendix Table 6). Accordingly, the highest population density gave the maximum EOY (14.73 kg ha^{-1}), thought it was statistically at par with 75%, whereas the minimum value was from the lowest population density of basil (Table 6). This might be associated with the leaf yield of basil obtained per unit area; therefore, the higher EOY was from the densely populated basil. In line with the study, Dudas *et al*. (2016) reported the maximum EOY for densely populated basil. This could probably be due to efficient utilization of growth resources eventually increased the oil yield of basil in higher population densities (Bagheri *et al*., 2014; Bekhradi *et al*., 2014). In line with this, it has been reported that EOY of basil is greatly influenced by different growth factors like photosynthetic rate, climate condition and soil moisture content, nutrient availabilities in the soil and crop population density per unit areas (De Masi *et al*., 2006).

Similarly, EOY was significantly affected by cropping system (P=0.0001) (Appendix Table 6). As a result, the maximum oil yield (19.46 kg ha^{-1}) was obtained from sole cropping of basil (Table 6). This could be because of proper utilization of growth resources in the wider space between sole cropped might have contributed to the maximum leaf oil yields. In agreement with this, Bilasvar and Salmasi, (2016) have reported that the maximum oil yield of basil was obtained from the sole cropping system in intercropping basil with corn. The biosynthesis active of substances of basil is dependent on different factors like light interception by the plant canopy, absorption of nutrient and water from the soil and temperature of the growth environment (Rehman *et al.*, 2016).

4.2.1.9 Harvest Index of basil

Result of the present study revealed that harvesting index of basil was not significantly influenced by treatment the interaction (P=0.86), by hot pepper varieties (P=0.29), nor by population density (P=0.21) and cropping systems (P=0.99) (Appendix Table 6).

Table 6. Mean values for growth parameters, yield and yield components of basil intercropped hot pepper as affected by hot pepper varieties, population densities of basil and cropping system at Hawassa during the 2017 season

Treatments	Leaf to stem dry weight ratio	Dry above ground biomass (t ha^{-1})	Essential oil content (%)	Essential oil yield (kg ha^{-1})	Harvest index
Hot pepper varieties					
Melka Shote	0.48	2.58	1.2	9.98	0.38
Melka Awaze	0.48	2.98	1.07	10.73	0.33
CR (0.05)	ns	ns	ns	ns	ns
Bail Population density					
100%	0.50	4.31^{a}	1.06^{ab}	14.73^{a}	0.35
75%	0.46	3.14^{b}	1.42^{a}	13.85^{a}	0.43
50%	0.47	2.44^{c}	1.18^{ab}	9.22^{b}	0.35
25%	0.50	1.25^{d}	0.87^{b}	3.60^{c}	0.29
CR (0.05)	ns	0.60	0.37	3.92	ns
CV (%)	18.74	17.37	26.56	30.6	31.51
Cropping systems					
Sole basil	0.45	5.28^{a}	1.16	19.46^{a}	0.35
Intercropped	0.48	2.78^{b}	1.14	10.35^{b}	0.35
CR (0.05)	ns	0.86	ns	2.463	ns
CV (%)	18.82	22.23	18.04	17.11	30.63

Note: ns, CR and CV indicate none significant difference, Critical Ranges and Coefficient of Variation, respectively. Means followed by the same letter/ within a column for a given treatment are not significantly different at P>5%.

4.3 Productivity indices of hot pepper-basil intercropping

4.3.1 Land Equivalent Ratio (LER)

4.3.1.1 Partial LER

Results of the statistical analysis revealed that the partial LER values for green hot pepper and basil were not significantly affected by the treatment interaction (P=0.92) and by hot pepper varieties (P=0.39). However, population density of basil showed a significant (P=0.0004) variation for partial LER value of green hot pepper (Appendix Table 7). Accordingly, the maximum partial LER value (0.91) of green hot pepper was obtained from the lower population density of basil (25%), though it was statistically at par with 50% densities, while the 75% and the minimum value was recorded for 100% (Table 7). Partial LER value of green hot pepper decreased with increasing population density of basil. In line with this, it has been reported that lower yield is expected when competition between the two species in the mixture is higher than the competition within the same species (Ghosh, 2004). Horwith (1985) has also noted that as the distance between plants reaches some critical points; they start to compete for growth resources, which directly reduce crop productivity per unit area.

The main advantage of intercropping is more efficient utilization of the available growth resources and increased the productivity compared with sole cropping of each component. In this study, the overall partial LER value of green hot pepper was greater than 0.5, which indicates the yield advantage of intercropping hot pepper with basil. The decrease in partial LER value of green hot pepper with increasing population density of basil probably show the presence of higher competition after some critical points for growth resources. In line with this, Agegnehu *et al*. (2008) have reported the decrement of partial LER of the main crop with increasing population density of the component crop in wheat with faba bean intercropping system.

Conversely, population density of basil did not show significant (P=0.318) variation for partial LER value of basil (Appendix Table 7). However, the result indicates that LER of basil was greater than 0.5 (within the ranges of 0.88 and 0.91), which show the presence of yield advantage due to intercropping of basil with green hot pepper (Table 7). In line with this study, Bantie *et al*. (2014) reported a non-significant variation for partial LER of lupine when different with barley population densities.

Table 7. Productivity measurements for intercropping of hot pepper with different population densities of basil at Hawassa, during 2017 season

Treatments	**Partial LER of hot pepper**	**Partial LER of basil**
Hot pepper varieties		
Melka Shote	0.76	0.88
Melka Awaze	0.80	0.93
CR (0.05)	ns	ns
Basil population density		
100%	0.55[b]	0.89
75%	0.79[a]	0.91
50%	0.89[a]	0.96
25%	0.91[a]	0.88
CR (0.05)	0.14	Ns
CV (%)	14.77	11.26

Note: ns, CR and CV indicate none significant difference, Critical Ranges and Coefficient of Variation, respectively. Means followed by the same letter/ within a column for a given treatment are not significantly different at P>5%.

4.3.1.2 Total LER

It was observed that total LER value was significantly (P=0.04) influenced by the interaction between hot pepper varieties and basil population densities (Appendix Table 7). The LER values for intercropping green hot pepper with basil were greater than unity for all population densities and both hot pepper varieties (Fig. 4). This show more complimentary of the component crops for utilization of efficient growth resources than in sole cropping system (Mousavi and Eskandari, 2011). Higher yield advantages were reported when competition between two species of the mixture is lower than competition within the same species (Ghosh, 2004).

Higher total LER value (1.78) was recorded for intercropping of variety Melka Shote with 50% population density of basil while intercropping Melka Shote with 100% basil resulted in the minimum value of LER (1.30) (Fig.4). In line with this, it has been reported that increment in population density leads to competition for available natural growth resources, which reduces the yield advantages (Singh *et al*., 2013). Similarly, the interaction of variety Melka Awaze with 50% population density of basil resulted in the maximum LER value (1.86), though it was statistically at par with 25%. This might be because of the complementary effect of Melka Awaze intercropped with 50% population density of basil to enhance yields than their sole cropped plots. However, the interaction of Melka Awaze with 100% basil gave lower LER value (1.56), though it was statistically at par with 75% of basil which justified that the yield advantages of component crops are affected by competition for growth resources when the distance between two plants reaches some critical point (Horwith, 1985).

In general, total LER value of intercropping hot pepper with different population densities of basil resulted in greater than unity, which implies that growing of the two crops has yield advantages than their solitary system. In line with this, Kebebew *et al*. (2014) have reported LER values of greater than unity for all population densities of soya bean intercropped with maize. Furthermore, different researchers have reported higher total LER intercropping of different component crops (Agegnehu *et al*., 2008; Bantie *et al*., 2014; Nigussie, 2015; Lulie *et al*., 2016). Generally, the result of the present study implies that intercropping of hot pepper varieties with different population densities of basil would bring about more yield advantages than do sole cropping systems, especially for small landholder producers of the targeted area.

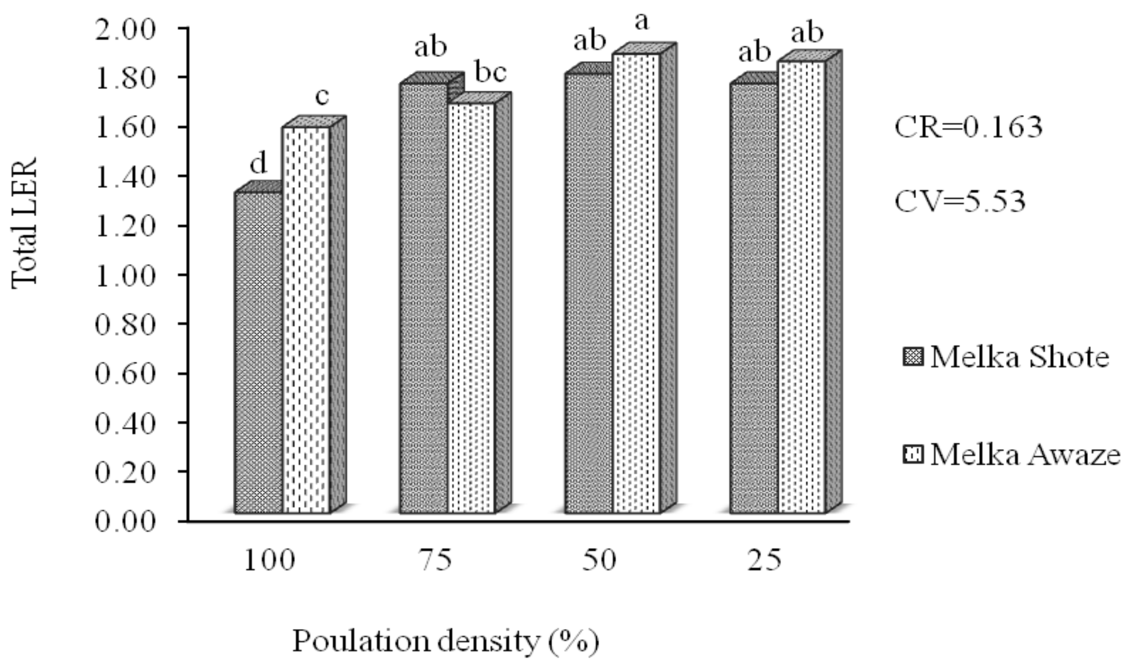

Figure 4. Interaction of hot pepper varieties (Melka Awaze and Melka Shote) and different population densities of basil for total LER at Hawassa in 2017 season. Bars capped with the same letter/s are not significantly different at (P>0.05). LER, CR, and CV indicate land Equivalent Ratio, Critical Differences, and Critical Values, respectively.

4.3.2 Monitory Advantage Index (MAI)

The results of the present study revealed that the MAI value was significantly affected by the interaction effects (P=0.03). However, the hot pepper varieties did not show significant effects on MAI (P=0.25) (Appendix Table 7). Hence, the maximum positive MAI value (251525 ETB ha^{-1}) was found from intercropping of Melka Awaze variety with 50% population density of basil. Similarly, the intercropping of variety Melka Shote with 75% population density of basil gave higher MAI values (242385 ETB ha^{-1}) whereas the minimum value (111475 ETB ha^{-1}) was obtained from variety Melka Shote with 100% population density of basil (Fig. 5). The presence of significant interaction for MAI indicates efficient utilization of available growth resources, which contributed to the yield and economic advantages of the crops than their sole cropped system. These results further showed producing of hot pepper with an optimum population density of basil could maximize the economic returns arranged to their sole cropped system.

Even though the minimum values of MAI was obtained from intercropping of hot pepper with the highest population density of basil, the economic return obtained was positive and profitable which showed the presence of more economic advantage from intercropping than from sole cropping system. The economic advantage of intercropping of component crops could be due to efficient utilization of growth resources by reducing weed competition, increased nutrient utilization and light use efficiencies among crops (Willy, 1979). This finding is in line with the study of Ghosh (2004), Aasim *et al*. (2008) and Agegnehu *et al*. (2008) who have reported the presence of positive MAI values from different proportions of intercropping component crops. Therefore, intercropping of hot pepper with basil herb could be an additional income source for the small landholder growers and for those who need to diversify the production of their crops to reduce the risk of relying on the monocropping system in the targeted areas.

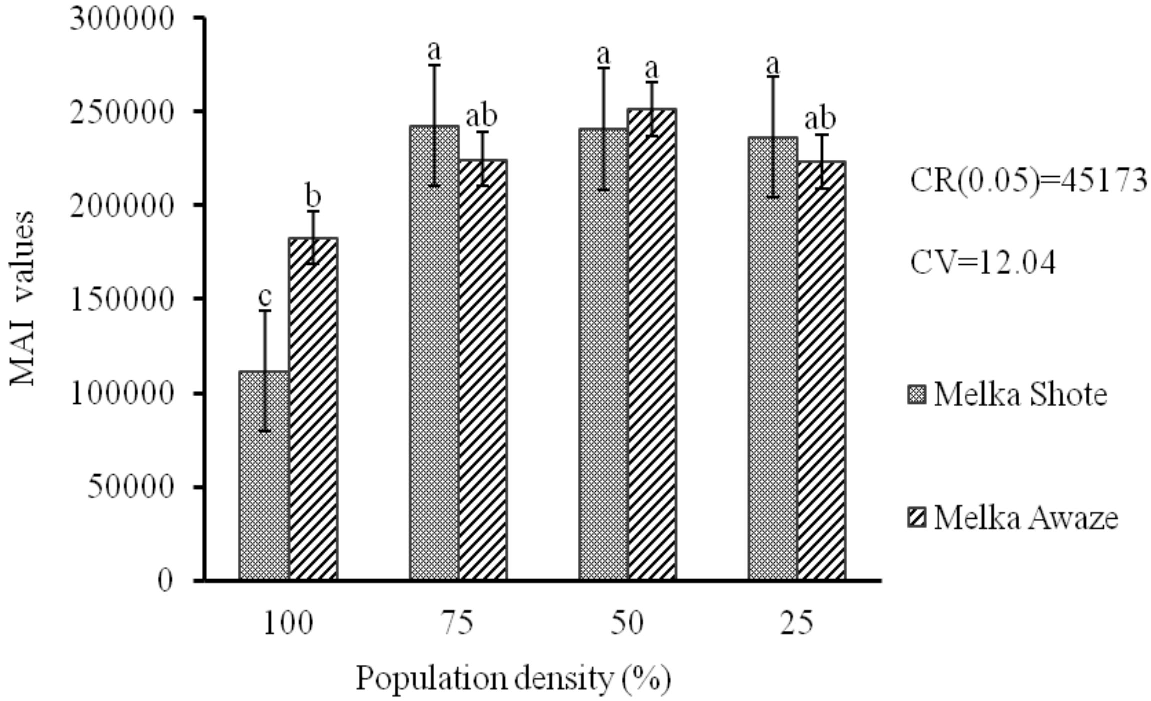

Figure 5. The interaction of intercropping hot pepper with different population densities of basil on MAI at Hawassa in 2017 season. Bars capped with the same letter/s are not significantly different at (P>0.05). CR, CV and MAI indicate critical range, Coefficient of Variations, and Monitory Advantage Index, respectively

4.4 Pearson correlation

4.4.1 Pearson correlation of hot pepper intercropped with basil

The correlation analysis of growth and yield parameters of hot pepper showed positive and negative associations (Table 8). Accordingly, marketable fruit yield was highly, significantly and positively correlated with plant height (r=0.69***), numbers of primary branches per plant (r=0.67***), canopy spreading (r=0.71***), fruit number per plant (r=0.69***), fruit length (r=0.73***) and fruit diameter (0.31***).

This shows that plant height, number of primary branches, canopy spread, fruit number per plant, fruit length and fruit diameter had considerable contribution for the increased marketable fruit yield of green hot pepper per hectare. In line with this, Desalegn (2011) has reported the positive and significant association of different traits with marketable fruit yield of green hot pepper. However, marketable green fruit yield was highly, significantly and negatively correlated with days to 50% flowering (r=-0.50**) (Table 8). Additionally, the marketable green fruit of hot pepper yield was negatively associated with days to 50% fruit setting and fruit maturity. This might be because of the longer vegetative growth period in the intercropping system that delayed flowering, fruit setting and fruit maturity which consequently reduced the marketable green fruit yield of hot pepper in the intercropped system. On the other hand, Aklilu *et al.* (2016) have reported positive correlation of flower and fruit setting with marketable green yield of hot pepper.

4.4.2 Pearson correlation of basil intercropped with hot pepper varieties

The correlation analysis of population density of basil and yield parameters showed positive and negative associations among the traits. Accordingly, fresh leaf yield was highly, significantly and positively correlated with dry leaf yield (r=0.95***), aboveground biomass (r=0.95***) and essential oil yield (r=0.79***) of basil (Table 9). Similarly, dry leaf yield was positively and significantly associated with aboveground biomass (r=0.95***) and essential oil yield (r=0.64**) but negatively and significantly associated with number of primary branches per plant (r=-0.50**).

On the other hand, Alemu (2017) reported absence of significant association between numbers of branches per plant of basil with its dry aboveground biomass. Moreover, basil EOY was highly, significantly and positively correlated with above ground dry biomass (r=0.71***), fresh leaf yield per hectare (0.79***), dry leaf yield per hectare (0.64***) and essential oil contents (0.71***) (Table 9). This shows that an increment in EOY was directly associated with these traits. In agreement with thus, Alemu (2017) reported that above-ground dry biomass yield and essential oil content were positively and significantly associated with essential oil yield of basil.

Table 8. Pearson correlation coefficient of hot pepper for different parameters at Hawassa in 2017 season

	DFFl	DFFr	DFM	PH	PBN	CS	FN	FL	FD	MFY
DFFl	1	0.61**	0.70***	-0.328	-0.137	-0.77***	-0.265	-0.137	-0.55**	-0.50**
DFFr		1	0.65***	0.102	0.115	-0.332	0.078	0.166	-0.37*	-0.120
DFM			1	-0.089	0.120	-0.54**	0.128	0.203	-0.619**	-0.160
PH				1	0.757***	0.67***	0.702***	0.79***	0.129	0.69***
PBN					1	0.436*	0.77***	0.85***	0.010	0.67***
CS						1	0.57**	0.45*	0.657***	0.706***
FN							1	0.745***	-0.034	0.69***
FL								1	-0.037	0.727
FD									1	0.305
MFY										1

Note: DFFl=Days to 50% Flowering; DFFr=Days to 50% Fruit Setting; DFM = days to 50% Green Fruit Maturity; PH=Plant Height; PBN=Primary Branch Number; CS=canopy spreading; FN=fruit number; FL= fruit length; FD= fruit diameter; MFY=Marketable Fruit Yield per hectare (ton)

Table 9. Pearson correlation coefficient of basil for different parameters at Hawassa in 2017 season

	PBN	CS	FLY	DLY	LSR	AGBT	EOC	EOY	HI
PBN	1	0.4	-0.39	-0.50**	-0.03	-0.50*	0.40*	-0.01	0.39*
CS		1	-0.06	-0.17	0.0023	-0.16	0.24	0.07	0.24
FLY			1	0.95***	-0.05	0.95***	0.19	0.79***	0.19
DLY				1	0.11	0.95***	-0.02	0.64**	-0.01
LSR					1	-0.203	-0.410*	-0.263	-0.138
AGB						1	0.09	0.71***	0.03
EOC							1	0.71***	0.94***
EOY								1	0.68***
HI									1

Note: PBN=Primary Branch Number; CS=Canopy Spreading; FLY=Fresh Leaf Yield (t ha^{-1}); DLY= Dry Leaf Yield (t ha^{-1}); LSR=Leaf to Stem Ratio; AGB = Above Ground Biomass (t ha^{-1}); EOC=Essential Oil Contents (%); EOY= Essential Oil Yield (Kg ha^{-1}); HI= Harvesting Index

5. SUMMARY AND CONCLUSIONS

Results of the present study indicated that the phenology, growth, yield, yield components and quality related parameters of both crops were affected by intercropping hot pepper with different population density of basil. Accordingly, the hot pepper variety Melka Shote took more numbers of days to 50% flowering, fruit set, and fruit maturity than did variety Melka Awaze. It was also observed that the higher population densities and intercropping system have prolonged days to phenological response over the lowest population density and sole cropping system of hot pepper. Similarly, Melka Shote variety, lower population density, and sole cropping system exhibited more fruit number and larger fruit size for hot pepper. In addition, the marketable green fruit yield increase of hot pepper was obtained from the lower population density of basil and sole cropping systems, while the higher fresh leaf yield, dry leaf yield and essential oil yield of basil were obtained from the higher population density of basil and the sole cropping system.

Furthermore, intercropping of hot pepper with different population density of basil exhibited higher LER and MAI values. Hence, the maximum total LER (1.86) value was obtained from the combination of variety Melka Awaze with 50% population density of basil and Melka Shote with 75% population density of basil while the highest MAI (242385 ETB ha^{-1}) was from the combination of variety Melka Awaze with 50% population density of basil and Melka Shote with 75% population density of basil, respectively.

In general, the results of the present study showed presence of yield and economic advantages of intercropping hot pepper with different population densities of basil in Hawassa area under rain feed condition with supplementary irrigation. Therefore, the farmers /growers in the study area can achieve higher benefits from their land by growing hot pepper in association with an optimum population density of basil. Therefore, intercropping of 27778 basil population densities (50%) ha^{-1} with hot pepper variety Melka Awaze and, 41667 basil populations densities (75%) ha^{-1} with variety Melka Shote could be recommended for the target area.

As this study was the first of its kind in the area, it would be advisable to evaluate and consider further trials particularly:

- Both in full rainfed and full irrigated condition
- In different seasons and locations.
- For dry pod yield and quality of hot pepper.

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7. APPENDICES

7.1 Appendix Tables

Appendix Table 1. The treatment arrangement for intercropping hot pepper with different population densities of basil at Hawassa Green Mark Herbs P.L.C in 2017 season

S/N	Treatment combination	Population density		Number of plants plot^{-1}		Number of plants row^{-1}		Inter and intra row spacing of plants plot^{-1}		Number of Plants ha^{-1}	
		Pepper	**Basil**	**Pepper**	**Basil**	**Pepper**	**Basil**	**Pepper**	**Basil**	**Pepper**	**Basil**
1	Sole Melka Awaze	100%	-	40	-	8	-	70x30	-	47619	-
2	Sole Melka Shote	100%	-	40	-	8	-	70x30	-	47619	-
3	Sole Basil	-	100%	-	48	-	8	-	60x30	47619	55556
4	Melka Awaze + 100% Basil	100%	100%	40	48	8	8	70x30	60x30	47619	55556
5	Melka Awaze + 75% Basil	100%	75%	40	36	8	6	70x30	60x40	47619	41667
6	Melka Awaze + 50% Basil	100%	50%	40	24	8	4	70x30	60x60	47619	27778
7	Melka Awaze + 25% Basil	100%	25%	40	12	8	2	70x30	60x120	47619	13889
8	Melka Shote + 100% Basil	100%	100%	40	48	8	8	70x30	60x30	47619	55556
9	Melka Shote + 75% Basil	100%	75%	40	36	8	6	70x30	60x40	47619	41667
10	Melka Shote + 50% Basil	100%	50%	40	24	8	4	70x30	60x60	47619	27778
11	Melka Shote + 25% Basil	100%	25%	40	12	8	2	70x30	60x120	47619	13889

Appendix Table 2. Analysis of variance for phenological parameters of hot pepper as affected by hot pepper varieties, the population density of basil and cropping systems under intercropping with basil at Hawassa during 2017 season

Sources of variation	**DF**	**Mean squares**		
		Days to 50%		
		Flowering	**Fruit set**	**Maturity**
Block	2	0.54^{ns}	72.13**	19.84^{ns}
Varieties	1	42.66 ***	360.37 ***	598.80***
Population Density (PD)	3	38.66 ***	64.04 **	22.38 ^{ns}
Varieties x PD	3	0.88 ^{ns}	1.82 ^{ns}	25.75 ^{ns}
Error	14	1.06	9.03	20.41
CV (%)		5.65	3.71	4.51
Cropping systems				
Replication	2	0.53^{ns}	87.43^{ns}	47.20 ^{ns}
Cropping systems	1	30.00^{ns}	106.41^{ns}	465.31**
Error	2	7.43	27.10	55.95
CV (%)		5.65	6.51	7.66

Note**: *, **, ***** = significant at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$ probability levels, respectively; and ns, DF, PD, and CV indicate non-significant difference, Degree of Freedom, Population Density, and Coefficient of Variation, respectively.

Appendix Table 3. Analysis of variance for growth parameters of hot pepper as affected by the hot pepper varieties, the population density of basil and cropping system under intercropping with basil at Hawassa during 2017 season

Sources of Variation	DF	Mean Square		
		Plant Height (cm)	Number of Primary branches plant^{-1}	Canopy spreading (cm)
Block	2	98.29***	7.09***	113.45***
Varieties	1	305.59***	20.88***	38.60**
Population Density (PD)	3	137.63***	2.13**	557.29***
Varieties x PD	3	18.48^{ns}	0.65^{ns}	30.98^{ns}
Error	14	10.80	0.38	5.13
CV (%)		5.92	6.00	8.28
Cropping systems				
Replication	2	117.52^{ns}	6.01*	107.48*
Cropping Systems	1	389.95**	32.06***	419.70***
Error	2	37.43	1.33	20.16
CV (%)		10.68	10.60	15.35

Note**: *, **, ***** = significant at P≤0.05, P≤0.01, and P≤0.001 probability levels, respectively; and ns, DF, PD, and CV indicate non-significant difference, Degree of Freedom, Population Density, and Coefficient of Variation, respectively.

Appendix Table 4. Analysis of variance for yield, yield components and quality parameters of hot pepper as affected by hot pepper varieties, population density and cropping system under intercropping with basil at Hawassa during 2017 season

Sources of variation	DF	Mean Square				
		Fruit			Marketable green Fruit ($t\ ha^{-1}$)	Oleoresin Content (%)
		Number	Length (cm)	Diameter (cm)		
Block	2	151.06***	2.25**	0.02***	6.29***	0.04^{ns}
Varieties	1	202.48***	8.77***	0.12***	1.22^{ns}	0.12***
Population density (PD)	3	185.77***	1.82**	0.00023^{ns}	13.59***	21.08***
Varieties x PD	3	1.82^{ns}	0.29^{ns}	0.003^{ns}	0.48 ^{ns}	23.08***
Error	14	10.86	0.27	0.01	0.31	0.01
CV (%)		9.08	5.21	4.1	8.34	1.74
Cropping systems						
Replication	2	113.43^{ns}	2.74*	0.03*	7.63**	0.30^{ns}
Cropping Systems	1	110.65*	11.18***	0.07**	17.93***	2.46*
Error	2	35.57	0.79	0.007	1.03	0.33
CV (%)		16.01	8.69	7.87	14.45	10.25

Note**: *, **, ***** = significant at P≤0.05, P≤0.01, and P≤0.001 probability levels, respectively; and ns, DF, PD, and CV indicate non-significant difference, Degree of Freedom, Population Density, and Coefficient of Variation, respectively.

Appendix Table 5. Analysis of variance for growth parameters, yield components and yield of basil intercropped with hot pepper at Hawassa during 2017 season

Sources of variation	**DF**	**Mean squares**			
		Number of primary branches plant $^{-1}$	**Canopy spreading (cm)**	**Fresh leaf weight (t ha^{-1})**	**Dry leaf weight (t ha^{-1})**
Block	2	4.43^{ns}	2.56^{ns}	0.51*	0.05^{ns}
Varieties	1	0.09^{ns}	3.13^{ns}	1.86***	0.07^{ns}
Population Density(PD)	3	5.65*	12.41***	41.36***	1.14***
Varieties x PD	3	0.29^{ns}	9.11***	0.20^{ns}	0.01^{ns}
Error	14	1.51	0.75	0.11	0.02
CV (%)		8.24	2.43	5.45	16.99
Cropping systems					
Replication	2	6.26**	2.61^{ns}	0.49^{ns}	0.04^{ns}
Cropping Systems	1	0.48^{ns}	2.23^{ns}	96.41***	1.57***
Error	2	1.00	3.51	0.33	0.02
CV (%)		9.49	5.24	8.66	13.30

Note**: *, **, ***** = significant at P≤0.05, P≤0.01, and P≤0.001 probability levels, respectively; and ns, DF, PD, and CV indicate non-significant difference, Degree of Freedom, Population Density, and Coefficient of Variation, respectively.

Appendix Table 6. Analysis of variance for growth, yield components, yield and quality parameters of basil under hot pepper-basil intercropping as affected by hot pepper varieties, population density and cropping systems of basil at Hawassa during 2017 season

Sources of variation	**DF**	**Mean squares**				
		Leaf to stem dry weight ratios	**Above ground dry biomass (t ha^{-1})**	**Essential Oil Contents (%)**	**Essential Oil Yield (kg ha^{-1})**	**Harvesting index**
Block	2	0.007^{ns}	0.18^{ns}	1.03***	79.76**	0.09**
Varieties	1	0.00004^{ns}	0.98^{ns}	0.10^{ns}	3.36^{ns}	0.02^{ns}
Population Density (PD)	3	0.003^{ns}	9.87***	0.32*	156.53***	0.02^{ns}
Varieties x PD	3	0.02^{ns}	0.27^{ns}	0.05^{ns}	3.92^{ns}	0.003^{ns}
Error	14	0.008	0.23	0.09	10.04	0.01
CV (%)		18.74	17.37	26.56	30.60	31.52
Cropping systems						
Replication	2	0.0087^{ns}	0.09^{ns}	1.23***	123.55***	0.10***
Cropping Systems	1	0. 002^{ns}	16.58***	0.001^{ns}	221.27***	0.000001^{ns}
Error	2	0.008	0.47	0.04	3.78	0.01
CV (%)		18.82	22.23	18.04	17.11	30.63

Note**: *, **, ***** = significant at P≤0.05, P≤0.01, and P≤0.001 probability levels, respectively; and ns, DF, PD, and CV indicate non-significant difference, Degree of Freedom, Population Density, and Coefficient of Variation, respectively.

Appendix Table 7. Analysis of variance for productivity of intercropping of hot pepper with basil as affected by hot pepper varieties and population density of basil at Hawassa during 2017 season

Sources of Variation	DF	Mean squares: Partial LER of Green Hot pepper	Mean squares: Partial LER of Basil	Mean squares: Total LER	Mean squares: MAI
Block	2	0.11^{**}	0.005^{ns}	0.07^{**}	9130784143^{***}
Varieties	1	0.01^{ns}	0.01^{ns}	0.04^{*}	970035360^{ns}
Population Density (PD)	3	0.15^{***}	0.009^{ns}	0.19^{***}	12296809412^{***}
Varieties x PD	3	0.002^{ns}	0.02^{ns}	0.03^{*}	2520269412^{*}
Error	14	0.013	0.01	0.009	665392051
CV (%)		14.77	11.26	5.53	12.04

Note**: *, **, ***** = significant at P≤0.05, P≤0.01, and P≤0.001 probability levels, respectively; and ns, DF, PD, and CV indicate non-significant difference, Degree of Freedom, Population Density, and Coefficient of Variation, respectively.

Appendix Table 8. Climatic data of Hawassa during experimentation time in 2017 cropping season

Months	**Climatic condition**				
	T_{max} (^{O}C)	**T_{min} (^{O}C)**	**RH (%)**	**ETo (mm/day)**	**Rain fall**
January	28.10	9.80	51.82	4.02	26.20
February	28.50	11.50	50.38	4.33	35.20
March	28.90	12.50	55.47	4.40	76.30
April	27.40	13.00	65.20	4.05	109.50
May	26.50	13.00	69.29	3.98	119.60
June	25.30	12.90	69.69	3.71	105.40
July	23.60	13.30	72.90	3.23	124.50
August	24.10	13.30	72.49	3.41	121.20
September	25.00	12.70	73.30	3.54	120.10
October	26.30	11.40	65.16	3.76	68.80
November	27.20	9.80	54.06	3.90	31.00
December	26.45	9.30	52.50	3.85	22.20
Average	**26.45**	**11.88**	**62.69**	**3.85**	**80.00**

Source: Ethiopian Metrological Agency, Hawassa branch (2017/2018)