DETERMINATION OF PLANTING DENSITY AND ROW ARRANGEMENT OF BASIL (*Ocimum basilicum* L.) FOR INTRCROPPING WITH TOMATO (*Solanum lycopersicum* L.) AT WONDO GENET, SOUTHERN ETHIOPIA

M.Sc. THESIS

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Determination of Planting Density and Row Arrangement of Basil (*Ocimum basilicum* L.) For Intercropping with Tomato (*Solanum lycopersicum* L.) at Wondo Genet, Southern Ethiopia

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

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October, 2018
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DEDICATION

This thesis is dedicated to my beloved cute son, Tokkumma Midekesa, whom I got him while writing up this thesis on May 03, 2018 G.C

STATEMENT OF THE AUTHOR

First, I declare that this thesis is a genuine result of my own work and I have properly acknowledged all sources of materials that I used for writing it. I have submitted this thesis in partial fulfillment of the requirements for the Degree of Master of Science at Jimma University College of Agriculture and Veterinary Medicine and deposited it at the University's library to be made available to borrowers for reference 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 an academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author, Midekesa Chala Mamo was born on October 12, 1991, at Mida kegn district, Western Shewa Zone, Oromia Regional State. He followed his primary education from 1998 to 2005 at Haro Alunko Junior Elementary School. He then pursued secondary and preparatory education from September 2005 to June 2009 at Mida secondary school and Gedo preparatory school. Passing the university entrance examination, he joined Jimma University, College of Agriculture and veterinary medicine in October 2009 where he obtained the Degree of Bachelor of Sciences in plant science in June 2012. After graduation, he was employed by Oromia Technical and Vocational Education and Training Agency as an instructor at Burayu TVET College and worked for two years. In May 2014, he was employed by the Ethiopian Institute of Agricultural Research and served at Wondo Genet Agricultural Research Center as Assistant Researcher and joined Jimma University in September 2016 to pursue a study leading to the degree of Master of Science in Agronomy.

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ABBREVIATIONS AND ACRONYMS

CEC	Cation exchange capacity
EIAR	Ethiopia Institute of Agricultural Research
FAO	Food and Agricultural Organization
IPM	Integrated Pest Management
LER	Land Equivalent Ratio
MAI	Monetary Advantage Index
MAPs	Medicinal and Aromatic Plants
MARC	Melkassa Agricultural Research Center
PAR	Photosynthetically Active Radiation
SMC	Soil Moisture Content
SNNPR	Southern Nations Nationalities and People's Region
WGARC	Wondo Genet Agricultural Research Center

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ABSTRACT

Intensive crop cultivation through inter-cropping is a reasonable agronomic practice to fulfill and sustain food security in areas like Wondo Genet where there is shortage of arable land. An experiment was conducted at Wondo Genet Agricultural Research Center to determine the optimum planting density and row arrangement of basil for intercropping with tomato and to examine yield advantage and economic return of the system. The experiment was conducted with a 2 × 4 factorial arrangement in RCBD with three replications each consisting of ten treatments: two basil row arrangement (one tomato row alternating with one basil rows (1T:1B) or with two basil rows (1T:2B)) and four basil population densities (66666, 50000, 33333 and 16666 plants ha $^{-1}$). Results of the study indicated that cropping system significantly ($p<0.05$) affected yield and yield components of tomato. Intercropped tomato with basil had the highest yield (36657.8 kg ha^{-1}) as compared to sole cropped tomato (31004.3kg ha^{-1}) and intercropping with basil increased its yield by 15.42%. On the other hand, row arrangement by planting density interaction significantly influenced yield of basil with the maximum dry herbal (341.49 kg ha^{-1}) and essential oil (22.86 kg ha^{-1}) yields recorded for 100% basil population density with a 1T:2B row arrangement. Cropping system also significantly influenced essential oil content and essential oil yield of basil. The highest essential oil content (1.26%) and essential oil yield (21.83 kg ha^{-1}) of basil were obtained with sole planting, compared to that of intercropping (0.96%) and (15.36 kg ha^{-1})with tomato showing, showing 23.81% and 29.64% reduction, respectively. In general, yields of tomato increased in intercropped plots while basil yield was best when planted alone as compared to intercropped with tomato. Additionally, intercropping of tomato with basil had total land equivalent ratio (LER) value greater than one, which showed the advantage of intercropping over sole cropping of each crop. Intercropping of tomato with basil at 100% population density gave total LER value of 1.9 and monetary advantage index (MAI) value of 194600 ETB ha^{-1}, respectively. Therefore, basil with a density of 33,333 plants ha^{-1}and intercropped with tomato with 1T:1B row arrangement could be recommended for the target area. However, the effect of tomato-basil intercropping on the incidence and severity of major tomato insects and diseases needs further study.

***Keywords**:* Cropping system, essential oil, LER, MAI

1. INTRODUCTION

Globally, cultivable land has decreased due to rapid population growth and industrialization. Particularly in Asia and Africa where producers have small plots, agricultural areas are under pressure to produce greater quantities of food, feed and biofuel on limited land resources (Ebert, 2014). While global demand for food increases, agricultural expansion faces more strong environmental preservation demands and sustainability laws aimed at prevention of deforestation (Crusciol *et al*., 2014). Industrialization and globalization in coupled with climate changes endanger agriculture and the future of humanity and environment. Modern industrialized agriculture based on monoculture has resulted in increased crop yields with huge costs of production for synthetic fertilizers and pesticides (Yildirim and Ekinci, 2017).

Tomato is a widely grown vegetable crop in Ethiopia. It is consumed by every household in different forms and as an important co-staple food (Gemechis *et al*., 2012). It is mainly cultivated as mono-crop by intensive use of chemical inputs**.** Different agricultural systems that can increase crop production or yield per unit area have been investigated in order to overcome the problem of with the decrease arable land worldwide. Intercropping is one of these systems, characterized as production of two or more different crop species simultaneously on the same land by utilizing resources such as soil, water, nutrients and solar radiation more efficiently (Bocken *et al*., 2013). Intercropping is one of the most effective methods in agricultural production with a long history and wide spread application in the tropics, as it reduces losses caused by pests, diseases, and weeds, and also guarantee better yields. Some short duration crops, especially spices condiments and medicinal plants, if planted as an intercrop in or around the main crop, may reduce pest incidence, due to their pungent aromatic odor in the field (Gebru, 2015).

Medicinal and aromatic plants (MAPs) play an important role in uplifting rural economy and thus, their demand is increasing all over the world (Neelam and Lokho, 2009). However, they are less cultivated by farmers, because their cultivation as a mono crop involves certain risk and their economic returns are uncertain. One of the means to address the issue would be to promote cultivation of medicinal plants as inter-crop with local food crops. Various studies reported that such inter-cropping system would increase the marginal incomes, especially for the small farmers, apart from meeting the market demand and helping in conservation of the wild types (Neelam and Lokho, 2009; Nigussie *et al*., 2017).

Tomato and basil are pair of crops that are commonly intercropped in different parts of the world (Bomford, 2009). Several studies have reported the performance of inter-cropping of aromatic and medicinal plant species with selected major horticultural crops in Ethiopia and in different countries (Bomford, 2004; Neelam and Lokho, 2009; Girma, 2015; Mutisya *et al*, .2016; Nigussie *et al*., 2017). Girma (2015) reported that inter-cropping of maize with basil at 1:1-row arrangement could provide farmers with the best yield advantage and income over sole planting of component (maize) crops. Basil and tomato are believed to be companion plants with similar light and water requirements and in the same cases, tomatoes taste better when they neighbor basil (Bomford, 2004). According to Carvalho *et al.* (2017), higher tomato yields have been observed under intercropping with aromatic plants as compared to tomato alone and thus, intercropping is a more profitable system. It has also been observed that basil has the ability to attract some bacteria and *Arbuscular mycorrhizal* fungi (AMF) and helps prevent diseases in tomatoes and increases the biomass yield of tomatoes (Hage-Ahmed *et al.,* 2013).

For vegetable crops, intercropping system to be successful in a given geographical location, effective cultural practices such as optimum plant population must be determined. Success in intercropping over sole cropping systems can be achieved by some agronomic manipulations. These manipulations involve plant density, planting time, available resources and intercropping patterns (Mousavi and Eskandari, 2011). Enhancing productivity of tomato and basil intercrops requires improving the interspecies complementary action or reducing the competition effects. Planting density is one of the most important agronomic management decisions to be considered when deciding to practice intercropping. Wheeler *et al.* (2000) noted that poor management of planting density could be detrimental to intercropping. Plant densities that are too low may limit the potential yield while plant densities that are too high may lead to increased stress on the plants, and increased interplant competition for light, water and nutrients (Adeniyi *et al*., 2001) which also decrease the yield. The other important management aspect is row arrangement which can improve radiation interception through more complete ground cover and determine whether an intercropping system would be advantageous or not with regard to yield gains (Nthabiseng *et al.*, 2015). However, the greater challenge for farmers is to know the correct combination of the intercropping pattern and planting density that would maintain or enhance growth and yield of main crop under increased population of component crop in the intercrop (Lulie *et al*., 2016).

Wondo Genet area, which is located in Sidama zone of southern Ethiopia, is characterized by rapidly increasing human population and suitable for vegetable production but with scarcity of arable land per household. There is a need for developing an efficient cropping system in order to use the limited land efficiently and to enhance food security. Since shortage of arable land is a constraint; optimizing inter-cropping performance can assist the effective use of space and nutrients (Lulie *et al.*, 2016). Smallholder farmers in Wondo Genet area grow tomato both under rain fed and irrigated condition. Moreover, growers have been challenged by inconsistent production and low yields. Inter-cropping vegetables on small land of the home garden is traditionally a common practice in Wondo Genet area. However arrangement of crops is at random with improper planting density of component crops, which results in poor crop yields. Even though it is possible to increase tomato production by intercropping with basil, yet no research has been done to determine optimum population density and row arrangement of basil for tomato-basil intercropping in the area. Considering the above indicated gaps this work was initiated with the following objectives.

General objective

- To assess the yield advantage and economic return of tomato-basil intercropping at Wondo Genet

Specific objectives

- To determine the optimum planting density and row arrangements of basil for inter-cropping with tomato.
- To examine yield advantage and economic return of the tomato-basil inter-cropping system under irrigation

2. LITERATURE REVIEW

2.1 Overview of tomato and basil crops

2.1.1 The Tomato plant

Tomato (*Solanum lycopersicum* L) is one of the biggest vegetable crops in the world, supplying a wide range of vitamins, minerals, and fiber in human diets (Mutisya *et al.*, 2016). It belong*s* to the *Solanaceae* family and has its origin in the South American Andes. The cultivated tomato was brought to Europe by the Spanish conquistadors in the sixteenth century and later introduced from Europe to southern and eastern Asia, Africa and the Middle East (Harlan, 1992). The introduction of cultivated tomato into Ethiopian agriculture dates back to the period between 1935 and 1940 Samuel *et al.* (2009) as cited by Gemechis *et al*. (2012).

Tomato is a perennial but is grown as an annual plant and a branching, herbaceous plant with hairy, weak, trailing stems (Benti *et al.*, 2017). The leaves are hairy and vary in size. It bears yellow flowers in clusters. The fruits are round to lobed and they vary in size and color ranging from red, pink or yellow when ripe. Flat, slightly curved, hairy, light brown seeds are produced. Plants are either indeterminate which when side shoots are removed, produce a continuously growing single stem or determinate, ending in the formation of a flower cluster and a bush like structure (da Silva *et al.,* 2008). Determinate plants are usually earlier to mature, because, once flowers are formed they divert all energy into filling and producing a uniform crop. They are more often used where seasons are shorter and just one crop is produced. They are bushy in character with a short main stem, and ideal for mechanical harvesting of processed crops and field cultivation of fresh tomatoes (da Silva *et al.,* 2008). Indeterminate plants continue to produce flowers. Officially the cultivated tomato belongs to the order Scrophulariales, suborder Solanineae, family Solanaceae, tribe Solaneae, genus Lycopersicon, subgenus Eulycopersicon, species *Lycopersicon esculentum* (Lycopersicon =wolf peach, esculentum = edible). *Lycopersicon esculentum* var. *cerasiforme* is typically known as the cherry tomato; the fruits are small, normally with diameters from 2 to 5 cm. *Lycopersicon esculentum* var**.** *pyriforme* has a pear-shaped fruit, with an average length of 4 cm (da Silva *et al.*, 2008).

Tomato is a seasonal climbing plant which is one of economically important and widely grown vegetable crop as annual both in the rainy and dry seasons for their fruits by smallholder farmers, commercial state, and private farms in Ethiopia (Bezabeh, 2014). It is also a source of basic raw material required for fresh consumption and local processing industry for the production of processed tomato like tomato paste, tomato juice and etc. (EIA, 2008). Tomato has very wide importance both as a source of food and health care i.e. it constitutes vitamins like vitamin A and C which play an important role in human health and is widely consumed in every household in different modes including raw, as an ingredient in many dishes, sauces, salads, and drinks (Tesfaye *et al*., 2012).

In Ethiopia, Tomato is grown between 700 and 2000 m above sea level, with about 700 to over 1400 mm annual rain fall, in different areas and seasons, in different soils, under different weather conditions, but also at different levels of technology (e.g. with furrow, drip or spate irrigation) (Gemechis *et al*., 2012). Currently distribution of crop production in relation to agro-ecological conditions in the different administrative zones (North Wallo, East Hararghe, East Shewa, Jimma and East Wallaga) and mostly in a country large scale production of tomato takes place in the upper Awash valley, under irrigated and rain-fed conditions whereas small-scale production for fresh market is a common practice around Koka, Ziway, Wondo-Genet, Guder, Bako, and many other areas (Gemechis *et al*., 2012).

2.1.2 The basil plant

Basil (*Ocimum basilicum* L.) is an important group of the aromatic and medicinal plant belonging to Lamiaceae family (mint family) (Jansen, 1981). The genus *Ocimum* was originated from Asia and Africa and then distributed over different parts of the world. Sadeghi *et al.* (2009) revealed that Egypt and East Mediterranean are the center of origin and widely cultivated in Iran, Japan, China and Turkey. Basil is usually referred as the “King of the herbs”, being widely utilized due to its economic, culinary, industrial and medicinal importance. It is an aromatic, medicinal, culinary and multi-functional herb grown in different parts of Ethiopia (Alemu, 2017). Its leaves and soft stems are considered to have medicinal value to treat stomach upset, colic, scabies, cough, asthma, irritated and inflamed bowel conditions, arthritis and menstrual problems. It is also used to increase breast milk and to help during child birth (Mishra and Tiwari, 2011). It is considered as one of the most important sources of medicine and drugs due to the presence of various phytochemical active compounds like alkaloids, saponins, tannins, anthraquinone, flavonoids, steroids, terpenoids and cardiac glycosides. Basil contains mostly methyl chavicol (estragole), eugenol and linalool. The amount of each of these chemical constituents differs depending on the type of species or cultivar and the cultivation, such as soil type, weather, irrigation, pruning and other horticultural practices (Abewoy, 2018).

Basil is a vital component of several industrial applications, ranging from food to cosmetics to pharmaceuticals (Assefa *et al.,* 2016). The tender stems, leaves, and flowers are dried, ground and added to sauces either alone or blended with other spices to provide good flavor to the stew. It is an important ingredient of *berbere* and *Shiro* powders (Assefa *et al.,* 2016). The fresh leaves can be cooked or roasted in preparing roasted beef locally called *tibsi,* when the fast preparation is required (Assefa *et al.*, 2016). In Jansen (1981), it is explained that both dried and fresh inflorescences and leaves of basil are used as flavoring agent in the preparation of all kinds of *wat.* Dried ground basil is also used to flavor butter and is sometimes sprinkled in tea or coffee to add flavor. Basil oil is a useful source of compounds like methyl chavicol, eugenol, (E)-methyl cinnamate, thymol, Linalool etc. (Jansen, 1981). It is the presence of this essential oil that enables the plant to provide good flavor to the *berbere, Shiro*, or butter (clarified). Basil is a great addition to any kitchen; it adds both flavour and character to many dishes (Hosseini *et al*., 2015) and key ingredient in vinegar, oils, cheeses, jams, teas, drinks and liqueurs.

Basil has an extensive list of traditional medicinal uses. It has more than 50 medicinal uses, from analgesic to anthelmintic, and is supposed to treat fungal infections, acne, headaches and over 100 such conditions (Duke, 2002, as cited by Meyers, 2003). The unique health benefits of basil are primarily due to its very high antioxidant content. Basil has been utilized to treat kidney problems, gum ulcers, as a haemostyptic in childbirth and for problems as diverse as malaria, arthritis, anorexia, menstrual irregularities and earache (Muthukumar *et al.,* 2016). Basil juice is an effective medicine for inflamed eyes and night blindness, which is often caused by vitamin A deficiency (Hosseini *et al*., 2015). The essential oil of basil was successful against the fungi causing damping-off disease, *Pythium aphanidermatum, and P. debaryanum* and *Rhizoctonia solani*. Basil gave a 50% reduction in damping-off disease of tomato (Muthukumar *et al.*, 2016).

2.2 Tomato and basil production status in Ethiopia

2.2.1 Tomato production status in Ethiopia

Ethiopia ranked 155th country in productivity of tomato (hectogram per hectare), 100th production quantity in tons and 74th in hectarage area production in the world in 2014 (Fact fish, 2016). When compared with international production, productivity, and acre coverage Ethiopia has a large land mass of area and low productivity of tomato. According to Retta and Berhe (2015), the national average yield of tomato in Ethiopia was ranging from 6.5-24.0 ton ha^{-1} compared with average yields of 51, 41, 36 and 34 ton ha^{-1} in America, Europe, Asia and the entire world, respectively. From this, it is understandable that Ethiopia was very underutilization of the yielding potential of tomato productivity. According to data driven from (FAO, 2014) the trend of tomato production, productivity and area coverage in Ethiopia for 23 years since 1991 to 2013 in time series showed that production of tomato was declining from 50,000 tons in 1991/92 to 39,375 tons in 2013. Similarly, the productivity of tomato in 1991/92 was 12.5 t/ha and decreased to 5.4 t/ha in 2013/14. Alemu (2005) reported that fluctuations and instability in yield than area was due to fluctuations in weather conditions, changes in pricing and marketing policies. According CSA (2017) report productivity of tomato in 2015/2016 was 6.2 ton ha^{-1} and decreased to 4.5 ton ha^{-1} in 2016/2017 showing 27.5% yield reduction was due to climate variability and major tomato insect pests and diseases.

2.2.2 Basil production status in Ethiopia

In Ethiopia, basil is commonly cultivated herb by small scale and horticulture farms. Basil is cultivated around the border of main crops fields (teff, sorghum, and maize) and home garden for its herbal yield (leaves and inflorescence) which has high demand in the local market (Girma, 2015; Alemu, 2017). It is also cultivated by a private herbal producer like Green mark and Jotech for export to European and Asian markets. Either fresh or dried plant parts are for sale on almost every Ethiopian market and small-scale cultivation near houses and herbs is widespread. Yimer (2010) reported that Ethiopia has exported 68,786 kg of basil essential oil to Sudan and USA from which a total foreign currency of $ 54,991.20 and 74600, respectively was obtained in 2009. The export volume accounted 19.77% in 2006-2009 and exhibit 0.15 and 0.14% both volume and value share of the total spice export.

Basil has high potential for pharmaceuticals, food and cosmetics industries in Ethiopia (Assefa *et al*., 2016). Ethiopia's economic policy is focusing on Agricultural Development Led Industrialization (ADLI) policy and consequently, value addition and import substitution are key duties in this regard. Furthermore, industry row materials (input) maximization also is crucial task for sustainability of manufacturing sector. Although the oil distilled from the basil as well as its herbal yields are a crucial input in the pharmaceutical industry, perfumery industry, detergent industry and culinary functions (Alemu, 2017). But, the farmers and the agricultural sectors give less attention to basil production.

2.3 Overview of intercropping

World population is growing exponentially and demand for food increases, agricultural expansion faces more severe environmental preservation demands and sustainability laws aimed to prevent deforestation (Crusciol *et al.,* 2014). An attractive strategy for increasing productivity and labour utilization per unit area of available land is to intensify land use. Intercropping is advanced agro technique of cultivating two or more crops in the same space at the same time and has been practiced in past decades and achieved the goal of agriculture (Lulie, 2017)**.** Among the cropping systems, intercropping is practiced by the small-scale farmers in sub-Saharan Africa. It is a type of mixed cropping and defined as the simultaneous cultivation of more than one crop species on the same piece of land (Hauggaard-Nielsen *et al*., 2008). Intercropping offers farmers the opportunity to engage nature's principle of diversity on their farms. Spatial arrangements of plants, planting rates, and maturity dates must be considered when planning intercrops. Intercrops can be more productive than growing pure stands (Yildirim and Ekinci, 2017).

Row-intercropping, mixed- intercropping, strip-intercropping and relay intercropping are most important types of intercropping (Mousavi and Eskandari, 2011). Mixed intercropping: Growing two or more crops simultaneously with no distinct row arrangement. Row intercropping: Growing two or more crops simultaneously where one or more crops are planted in rows. Strip Inter-cropping: Growing two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough for the crops to interact and independent cultivation (Brooker *et al.,* 2015). Relay inter-cropping: Growing two or more crops simultaneously during part of the life cycle of each. A second crop is planted after the first crop has reached its reproductive stage but before it is ready for harvest (Mousavi and Eskandari, 2011). The selection of an appropriate intercropping system for each case is quite complex as the success of intercropping systems depends much on the interactions between the component species, the available management practices, and the environmental conditions (Lithourgidis *et al.,* 2011).

2.4 Advantages of inter-cropping tomato with basil

2.4.1 Increasing production

One of the main reasons for the use of intercropping around the world is to produce more yield than a pure cropping of same land amount (Caballero and Goicoechea, 1995).The most common advantage of intercropping is the production of greater yield on a given piece of land by making more efficient use of the available growth resources using a mixture of crops of different rooting ability, canopy structure, height, and nutrient requirements based on the complementary utilization of growth resources by the companion crops (Lithourgidis *et al.,* 2011). Different authors reported that production significantly affected by intercropping. Ghanbari and Lee, (2002) reported that dry matter production in wheat and beans intercrops had been more than their pure cropping. According to Odhiambo and Ariga (2001) maize and beans intercrops in different ratios found that production increased due to reduced competition between species compared competition within species. Willey (1981) considers intercropping as an economic method for higher production with lower levels of external inputs. The increasing resource use efficiency is important, especially for small-scale farmers and also in areas where growing season is short (Altieri, 1995). Production more in intercropping can be attributed to the higher growth rate, reduction of weeds, reducing the pests and diseases and more effective use of resources due to differences in resource consumption (Eskandari, 2011). In addition, if there are complementary effects between the components of intercropping, production increases due to reducing the competition between them (Mahapatra, 2011). Bomford (2004) reported that tomato yield higher in intercropped with bean, cabbage and basil as compared to monocropped tomato. Similarly, de Carvalho *et al.* (2010) reported that number of marketable fruits was on average, 59% higher in tomato-basil intercrop than in the tomato monocrops.

A yield advantage of intercropping can be indicated by using different methods, among which Land Equivalent Ratio (LER) is the most commonly used to indicate the biological efficiency and yield per unit area of land as compared to mono-cropping system. An LER greater than 1.0 implies that for that particular crop combination, intercropping yielded more than growing the same number of stands of each crop as sole crops. An LER of less than 1.0 implies that intercropping was less beneficial than sole cropping (Onwueme and Sinha, 1991).

The intercropping practice could modify the microclimate by reducing light intensity, air temperature, desiccating wind and other climatic components. Study at Melkassa (in Ethiopia), wind protected tomato plants with strip intercropping of maize and sorghum plants gave higher yield (7.4 t/ha) compared to unprotected ones (5.7 t/ha) (Lemma, 2002). Intercropping modifies the extreme temperatures both in the air and in the soil, it can be used to improve the yield of tomato during the off season cultivation. Farrell and Altieri (1995) elaborated on the microclimate benefits of intercropping characteristics: micro climate within canopy can moderate temperature extremes, lower temperatures and reduce air movement lead to less evaporation and increase relative humidity versus open sites.

2.4.2 Improving microclimate of the soil and canopy

Inter cropping provides a good soil cover, soil temperature will stay relatively low. This prevents burning of the organic matter in the soil and loss of nutrients. It also provides a microclimate that can be favorable for associated crops. Studies on rhizosphere processes and nutrient use in intercropping systems have proved a lot of physiological indicator for interspecific facilitation among crops (Ghanbari and Lee, 2002). Furthermore, earlier studies reported that intercropping systems could improve light interception and increase shading as compared to mono cropping, lower water evaporation and conserve of soil water (Ghanbari and Lee, 2002).

Improvement of water use efficiency in intercropping leads to increase in the use of other resources (Hook and Gascho, 1988). Intercrops have been identified to conserve water largely because of early high leaf area (Ogindo *et al*., 2003). Kanton and Dennet (2004) pointed out that intercrops produced more dry matter than sole. Intercropping systems reduce wind speed, provide shade and increase infiltration, so conserving soil water and improving soil structure. The different root architects of intercrops influence water uptake and the capability of plants to reach for water resources. Poor foliage development, dropping of blossom, poor fruit set, breakage of leaves and branches, fall over of plants in irrigation furrow and high dust coverage on the leaves cause poor plant development and reduce fruit yield of tomato in the Rift Valley (Lemma, 2002). However, in a study at Melkassa (in Ethiopia), wind protected tomato plants with strip intercropping of maize and sorghum plants gave higher yield (7.4 t/ha) compared to unprotected ones (5.7 t/ha) (Lemma, 2002).

2.4.3 Reduction of pest and disease incidence

Vegetable crops failures are common under irrigated areas due to insect and disease infections or due to the prices that go up and down according to supply and demand. Therefore, it was recommended to practice intercropping, the agricultural practice of cultivating two or more crops simultaneously in the same piece of land. Tomato is susceptible to many pests and diseases. Intercropping promises to be a very promising cultural practice in the reduction and control of pests and diseases. One component crop of an intercropping system may act as a barrier against the spread of pest and diseases. Pino *et al*. (1994) also reported that pest and disease were less in maize-tomato intercropping compared to tomato alone. Mutisya *et al.* (2016) reported that agronet covers and companion cropping with a row of basil planted between adjacent tomato rows significantly lowered *B. tabaci* infestation in tomatoes by 68.7%. Intercropping mustard as a companion crop for collards has successfully been used to repel whitefly while tomato has successfully been used as a repellent for the diamondback moth on cabbage (Mutisya *et al.*, 2016).

2.4.4 Insurance against crop failure

One important reason for which intercropping is popular in the developing world is that it is more stable than mono-cropping (Lithourgidis *et al*., 2011). When two or more crops are grown on the same field, the risk or the crop failure is spread over the different crops as the different crops have different periods and patterns of growth, and are affected by different diseases (Tefera and Tana, 2002). Thus, If one of the crops fails (due to drought, flood, pests or diseases), there still is a harvest from the other crops (Hauggaard- Nielsen *et al*., 2008; Lithourgidis *et al*., 2011). Trupti *et al*. (2018) reported intercropping provide insurance against risk and give stable returns even under unfavorable weather conditions.

2.4.5 Efficient resource utilization

Intercropping is an excellent system of cropping which ensure better utilization of resources and inputs. Intercropping helps the farmers in better utilization of land by having more than one crop produced per unit area (Trupti *et al*., 2018). Ijoyah and Dzer (2012) also reported that intercropping gave greater combined yields and monetary returns than those obtained from either crop grown alone. Chaurasia *et al.* (1996) reported that maize intercropped with tomato increased total intercropped yields and gave greater monetary returns than those obtained from the component crops grown as sole cropping. Through intercropping, farmers can achieve the full production of the main crop and also an additional yield (bonus) associated with an increased plant population of the second component (Trupti *et al*., 2018).

2.5 Disadvantage of intercropping

There are some disadvantages in intercropping systems. These includes yield reduction of the main crop, loss of productivity during drought periods, and high labor inputs in regions where labor is scarce and expensive (Gebru, 2015). It is well documented that in most cases the main crop in an intercropping system will not reach as high a yield as in a monoculture, because there is competition among intercropped plants for light, soil nutrients and water (Lulie, 2017). This yield reduction may be economically significant if the main crop has a high market price than the other intercropped plants. Another disadvantage that is likely to be occurring is the higher cost of maintenance, in particular, weeding, which may have to be done by hand. This is not a serious problem in countries where excess farm labor is cheap, for example, Ethiopia; but for countries lacking such a labor force, intercropping will result in increased costs. Furthermore, harvesting of one crop may cause damage to the other (Gebru, 2015). Finally, the intercropped canopy cover may result in a microclimate with a higher relative humidity conducive to disease outbreak, especially of fungal pathogens (Maboko *et al*., 2017).

2.6 Effect of Plant Density and row arrangement in Intercropping System

Spatial arrangement is the systematic apportioning of the farm area or any growing surface for crop production. In multiple cropping by intercropping, the intercrop can be planted in any of the following ways: within the rows of the main crop, between the rows of the main crop and in replacement series (Bareja, 2011). When two or more crops are growing together, each must have adequate space to maximize cooperation and minimize competition between them. Improved resource utilization and hence, increased yield can be also achieved with proper manipulation of time of planting. For example, the study carried out by Amujoyegbe and Elemo (2013) revealed that staggering planting date takes advantage of peak resource demands and reducing competition between crops.

Identifying the optimal spatial and temporal arrangements and selection of effective, compatible and adaptable legume crops, depending on the natural endowments of localities could be an important prerequisite for successful intercropping. Reda *et al.* (2005) reported that one row of legume every two rows of sorghum was an optimum arrangement both in terms of reduction in parasitic weed incidence and increase in cereal yield. Similar study in another environment showed that alternate row planting of sorghum and legumes with staggered planting of the crops (planting legumes intercrops 3-4 weeks after the cereal) was found more productive and led to overall reduction in *Striga* infestation (Reda *et al.,* 2006). Similarly, an experiment conducted in the north western Ethiopia highlands indicated that highest LERs (2 at Motta and 1.5 at Adet), highest N use efficiency, and gross monetary advantage were obtained when a planting pattern of 1:1 maize: faba bean alternate rows were used (Tilahun, 2002). Another experiment done on different spatial arrangements of pearl millet - cowpea intercrop showed that one row of millet to one row of cowpea (with millet planted 2 weeks before cowpea) yielded better than the other spatial arrangements (Yirzagla *et al*., 2013). Therefore, spatial and temporal arrangement of crops is critical in determining the growth and yield of intercrops.

Plant density or plant spacing describes the space left between plants when planting a garden, field, and other landscaping plants. The more closely spaced plants are, the higher the density. The planting density of certain plants can be described by the number of plants within a given unit of area. In intercropping situation, total population (sum of population of the component crops) and component population (population of each component) have to be distinguished. The seeding rate of each crop in intercrop has to be adjusted to optimize plant density. Omae *et al.* (2014) reported that biomass and grain yield of cowpea increased at high density of cowpea on millet-cowpea intercropping but had no significant effect on biomass yield and grain yield of millet. It is evident from various workers that intercropping gives higher yield advantage when total population in the system is higher than that of sole crops (Willey, 1979). Similarly, Oroka (2012) reported that maximum density of intercrops resulted in maximum forage dry matter yield of rice and cowpea on rice-cowpea intercropping. Prasad and Brook (2005) reported that with increasing maize density at soybean-maize intercropping, rates of accumulation of dry matter and leaf area index also increased the latter, resulting in decreasing transmission of light to the intercropped soybean.

2.7 Evaluation of Productivity and Efficiency of Intercropping

Different indices have been suggested for evaluating productivity and efficiency per unit area of land of different crops intercropping systems. Among them, land equivalent ratio (LER) is the most widely used relative index to evaluate the efficiency and productivity of intercropping (Willey, 1991).

The LER could be used either as an index of biological efficiency to evaluate the effects of various agronomic variable (e.g. fertility levels, density and spacing, comparison of cultivars performance, relative time of sowing, and combinations) on an intercrop system in a locality or as an index of productivity across geographical locations to compare a variety of intercrop systems. It is defined as the area that a sole crop has to occupy in order to produce the same amount of yield as its component in the intercrop (Mead and Willey, 1980). The LER compares the yield of each part of the intercrop to the yield of that same species grown alone as a sole crop. The equation is as follows:

$$LER_T = LER_a + LER_b + \ldots\ldots\ldots.. + LER_n$$

Where LER_T is the total LER and the subscripts a, b, to n give partial LERs for each different species that is a component of the intercropping system. Each of these partial LERs can be calculated as follows:

$$LER_a = \frac{YIa}{YSa}$$

Where Y_{Ia} is the mass yield per unit area of the first species 'a' in the intercrop and Y_{Sa} is the mass yield per unit area of the same species when grown as a sole crop (Tsubo *et al.*, 2003). The LER_T value greater than one (LER>1) shows that intercropping has a yield advantage over the sole cropping of each crop individually. It also indicates that if the sole cropping was used a larger piece of land would be required to produce the same total yield that was produced under the intercropping system (Tsubo *et al.*, 2003).

2.8 Allelopathic Relationship between tomato and basil

Allelopathic is a trait within certain organisms that allows them to produce and secrete certain biochemical that has various effects on other organism's growth, survival, and reproduction processes (Jenkins, 2016). The creation of these chemicals can result in negative or positive interactions plants (Qasem, 2010). Mutualism is relationships defined as the symbiosis between two different species that is beneficial to both and help them improve their chances of survival (Qasem, 2010). While basically, any part of the plant can house these chemicals, most store the chemicals in their leaves and roots. When their leaves fall and decompose, the toxins that are released affect nearby organisms (Phipps, 2011). Other plants are able to release chemicals through the roots in order for it to be absorbed by other plants in the area. Prime example Allelopathic chemicals being released through soil is basil (Phipps, 2011).

Basil releases its Allelopathic oils into the soil in the surrounding areas (Jenkins, 2016). Basil's essential oils are linalool, citronellol, terpineol, and eucalyptol. All of these oils serve as pest repellents and insecticides for both basil and the plants around it (Simon *et al.,* 1999). Growing companion plants in close proximity to each other can improve the growth and overall health of the plants. When planted near a companion, plants will experience increased growth and improved health factors such as germination, biomass and fruit size (Jenkins, 2016). Also, the plants were less likely to be eaten by bugs, harmed by weeds. Certain plants can be used to fight off weeds and other harmful infestations by using the chemicals they produce through Allelopathy (Hage-Ahmed *et al.*, 2013). Jenkins (2016) studies indicate that the Allelopathic relationship seems to greatly benefit the root growth of tomato plants. With more massive, dense roots, the plants maintain greater water retentions which are likely to give a greater tomato production.

3. MATERIALS AND METHODS

3.1 Description of Experimental Site

The experiment was conducted in field at Wondo Genet Agricultural Research Center (WGARC), southern Ethiopia, under irrigated condition in 2017/2018 dry off season. The research center is located 264 km South of Addis Ababa and 14 km southeast of Shashemene town. It is located in Sidama Zone, Southern Nations Nationalities and People's Region (SNNPR), of Ethiopia at latitude $7^0$19'N and longitude $38^0$38'E an altitude of 1780 meters above sea level (m.a.s.l). The site has mean annual total rainfall 1121.8 mm with mean maximum and minimum temperatures of 26^{o}C and 12^{o}C, respectively. The soil of the study area has clay loam texture (sand=38, clay=37 and silt=25) with pH values of 6.92, (neutral in reaction) and is low in organic matter content, medium in total N, low in available P and high in CEC (Lulie *et al*., 2016). Wondo Genet has a bimodal rainfall distribution with two rainy seasons. Short rains occur from March to May and the long rains from July to October. The dry season extends from November to February (Appendix Table 5).

3.2 Treatments and Experimental Design

The experiment consisted of four population densities of basil (100%, 75%, 50%, 25%) and two row arrangements of intercropping tomato (T): basil (B) (1T:1B and 1T:2B), as well as sole plots of tomato and basil, making the total number of treatments 10.

Row arrangements

1. 1:1 row (1T:1B)
2. 1:2 rows(1T:2B)

Population density of basil

1. 100% of basil (66,666 plants ha^{-1})
2. 75% of basil (50,000 plants ha^{-1})
3. 50% of basil (33,333 plants ha^{-1})
4. 25% of basil (16,666 plants ha^{-1})

Therefore, field experiment was laid down in Randomized Complete Block Design (RCBD) with factorial arrangement in three replications, each with ten treatments (including sole plots of basil and tomato) (Table 1).

Table 1. Treatment Combinations of the experiment

No.	Treatment combinations	Plants spacing Inter row (cm)	Intra row(cm)	Basil Population plot $^{-1}$	Basil Population ha^{-1}
1	Sole tomato	100	30	___	
2	Sole basil	50	30	64	66666
3	1T:1B X 100%	100	15	64	66666
4	1T:1B X 75%	100	20	48	50000
5	1T:1B X 50%	100	30	32	33333
6	1T:1B X 25%	100	60	16	16666
7	1T:2B X 100%	50	30	64	66666
8	1T:2B X 75%	50	40	48	50000
9	1T:2B X 50%	50	60	32	33333
10	1T:2B X 25%	50	120	16	16666

A uniform population of 33,333 plants ha^{-1}with 100 cm by 30 cm inters and intra-row spacing, respectively, was maintained for tomato in both cropping systems (for sole and intercropped plots). A population of 66,666 plants ha^{-1} with 50 cm by 30 cm inters and intra row spacing, respectively, was considered as an optimum density for sole crop of basil. Besides, four different intercrop proportions of basil: (25% (16666 plants ha^{-1}), 50% (33333 plants ha^{-1}), 75% (50000 plants ha^{-1}) and 100% (66666 plants ha^{-1})) were also maintained in the experiment. The four levels of basil populations were inter-planted with tomato in a row arrangement of 1T:1B and 1T:2B tomato to basil row arrangements (Table 1).

3.3 Experimental Materials

Seeds of a tomato variety Melka Shola obtained from Melkassa Agricultural Research Center (MARC) and a promising genotype (B04) of basil from Wondo Genet Agricultural Research Center (WGARC) were used for the experiment. Tomato variety Melka Shola is determinate type and can be used for dual purposes and well adapted to Wondo Genet conditions. Melka Shola which was released by MARC in 1998, is still widely produced by small scale farmers and is high yielder (under farmers condition 30 t ha^{-1}) (Benti *et al*., 2017) and (43 t ha^{-1}in research plots) (Regassa *et al.,* 2012). Basil genotype B04 is also high yielder (herbage and essential oil yields) in Wondo Genet area (Abewoy, 2018).

3.4 Experimental Procedures

3.4.1 Land preparation

The land was prepared at Wondo Genet experimental site by removing crop residues and weeds and plowing by tractor (moldboards plow) to the depth of 40–50 cm followed by 10 to 15 cm deep disc harrowing and ridging. A plot size of 9.6 m^2 (4 m X 2.4 m) and a total area of 510m^2 (width: 15m, and length: 34m) was maintained for the experiment. The total number of rows per plot and number of plants per row for tomato were 4 and 8, respectively. However, the total number of rows per plot and number of plants per row for basil vary based on row arrangement and population. Path way between blocks and plots were 1.5 m and 1 m, respectively.

3.4.2 Seed sowing and raising of tomato seedlings

A seed bed having 1 m width and 5 m length was prepared a week prior to sowing. The soil was mixed with 100 g Urea and 200 g DAP per bed as recommended by Lemma (2002). Tomato seeds were sown on the nursery seedbed at 10cm spacing between rows and with very narrow spacing within rows. The seeds were drilled onto the seedbeds and covered with a soil layer of 0.2 cm and mulched for one week to maintain soil moisture and inhibit weed growth.

The mulch was removed and overhead shade was constructed at a height of 1.50 m seven days after sowing and maintained until 10 days prior to transplanting. Ridomil Gold (mefenoxam) fungicide was applied to the seedbed to control damping-off. After 30 days, the shade was removed for hardening-off the seedlings for ten days. Watering was applied at an interval of three days throughout the growth period of the seedlings in the nursery for both crops.

3.4.3 Rooting of basil cuttings

A seed bed with 1 m width and 5 m length was prepared a week before planting of basil cuttings at the nursery site of WGARC. The growing media was prepared from fine mixtures of top soil, sand and compost (3:1:2 ratio) and filled in standard polyethylene bags filled with basil cutting of two-month old fresh soft-wood, having 10-15 cm length, were taken from the top parts of disease-free plants. The cuttings were planted in the polyethylene bags and allowed to produce roots at the nursery for about 30 days.

3.4.4 Field transplanting of tomato seedling and rooted cutting of basil

Tomato seedlings were transplanted on November 02, 2017 G.C using furrow irrigation and, after two days, rooted cutting of basil were also transplanted to the field. Both crops were transplanted on a plot size of 4m x 2.4 m, a total area of 9.6 m^2, with four rows of tomato and eight rows basil each row having 8 plants for tomato and for sole basil. Tomato seedlings were planted at a spacing of 100cm x 30cm between rows and plants respectively, as recommended by Lemma, (2002). The basil seedlings were transplanted at different spacing between tomato rows in two arrangements (1T:1B and1T:2B). Irrigation water was applied by furrow system once a day to facilitate plant establishment and at three consecutive days interval after establishment. Hand weeding was done frequently depending on the emergence of weeds.

3.4.5 Fertilizer sources and application

Phosphorous fertilizer (150 kg ha^{-1}) was applied at the time of transplanting and Nitrogen (100 kg ha^{-1}) was applied in three equal splits, (one-third at transplanting, another one-third on 20 days after transplanting, and the remaining one-third was applied 40 days after transplanting)for each plots (Etissa, 2014). Urea and Triple Super Phosphate (TSP) fertilizers were used as sources of N and P, respectively. The fertilizers were placed alongside the ridge in the planting rows about 5 cm away from the transplants to ensure that there would be no direct contact with the soil particles below the plants.

3.4.6 Pesticides application

Most field-grown tomato plants require the use of pesticide spray to prevent the occurrence of pests and diseases. Thus, in this experiment, Ridomil Gold RZ was applied at the rate of 3 kg ha^{-1} based on the recommendation given by Syngenta Group Company UK to control down mildew fungal disease. Similarly, 0.5 L ha^{-1} Coragen 200 SC was applied to control tomato white fly and leaf miner (*Tuta absoluta*) using the recommendations given by the same company. It was sprayed twice at ten days interval at early vegetative growth stages.

3.4.7 Staking and other agronomical practices

Agronomic practices (weeding, cultivation, irrigation, staking, etc.) were applied during the growing season as per the recommendations for both tomato and basil. Determinate tomato varieties do not require stakes as the indeterminate varieties, however staking was required during the rainy seasons and on relatively fertile soil because the plant is very tall (Etissa *et al.*, 2013). During this study plant height increased up to 62.22 cm and highest number of fruits per plant was produced because of intercropping basil. This is one of the factors that made it necessary for staking of determinate tomato variety using stick and it was applied to avoid branch and fruit contact with moist soil and to improve fruit quality and also to make harvesting easier. According to Amina *et al*. (2012) staking was the easiest method reducing tomato disease incidence and favouring higher yields and good quality fruits than single post and non-staking.

3.5 Data Collection

Five plants were randomly selected from the central two rows and tagged for recording quantitative traits in each plot. Growth, yield and yield related parameters were measured for the tagged sample plants and averages values were computed per plot for both tomato and basil.

3.5.1 Data collected for tomato

3.5.1.1 Phenological parameters

Days to 50% flowering: When flowering was observed on 50% of the plants per plot, it was considered as 50 % flowering and number of days taken to this stage was converted for each plot.

Days to maturity (DM): It was recorded when approximately 90% of plants per plot attained their first crop harvest stage.

3.5.1.2 Growth parameters

Plant height (cm): Plant height was measured using measuring tape (Model No. Tape Measure-6201 and reading scale 5m) from the base of the plant to the tip points of the main stem when 50% of the first fruit has begun to mature. It was taken from the five randomly sampled plants and, the sum total was divided by number of sampled plants to get mean plant height, which was used, for data analysis.

Number of branches per plant (NBP): Each primary branch which was emerged from the main stem was counted and for the five sample plants in the middle two rows. The average value was taken for each plot and was used for data analysis.

3.5.1.3 Yield components and yield

Number of clusters per plant: It was recorded by counting the total number of clusters per plant for the five randomly selected plants at full maturity and the average was taken.

Number of fruits per cluster: It was measured by counting the total number of fruits per clusters for the five randomly selected plants at full maturity and the average value was considered for statistical analysis.

Number of fruits per plant: The total number of fruits produced per plant was counted at full maturity from the five sample plants and the average value was taken.

Number of marketable and unmarketable fruits per plant: Those fruits harvested from the five tagged plants were counted. Fruits were regarded as unmarketable when they exhibited cracking, zippering, rotting, blossom-end rot, rain-check, cat-face or fell into the extra small size category (less than 40 mm diameter). Marketable yield comprised of fruits that were larger than 40 mm diameter, whereas total yield was determined by adding marketable yield and unmarketable yield (Maboko *et al.*, 2017).

Total fruit weight per plant (g): All fruits produced by the five randomly tagged plants were weighed and the averaged was taken.

Marketable fruit weight per plant (kg): Those fruits from the five tagged plants, which were free from visible damage, insect pests, diseases, and not extra small sized, were weighed and the averaged value was computed.

Unmarketable fruit weight per plant (kg): Fruits with cracks, rotting, damaged by insects, diseases, birds and sunburn as well as extra small sized fruits (less than 40 mm diameter) which were collected from the five tagged plants were considered as unmarketable (Maboko *et al.,* 2017).

Fruit yield per hectare (kg): Fruit yield ha^{-1} was calculated on the basis of fruit yield per plant and converted to hectare and the average value was computed.

Fruit length (cm): Fruit length was measured using digital caliper (Model No. 4141 and reading scale 0-30 cm) from base to tipping point of each fruit immediately after harvest. The sum of fruit length of the five sampled plants was divided by to get the mean values for fruit length per plant.

Fruit diameter (cm): Fruit diameter was also measured using the same digital caliper (Model No. 4141 and reading scale 0-30cm) at the central point of each fruit immediately after harvest. The sum of fruit diameter for the five sampled plants was divided by five to get the mean fruit diameter per plant.

3.5.2 Data collected for Basil

3.5.2.1. Growth parameters

Growth, yield and yield related parameters were measured for five plants randomly selected from the middle two rows and the average values were computed for each plot.

Plant height (cm): Plant height was measured using a measuring tape (Model No. Tape Measure-6201 and reading scale 5m) from the base of a plant to the tip point of the main stem when 50% of the first fruit has begun to mature. It was taken from five randomly sampled plants using a ruler and, the sum total was divided by number of sampled plants to get mean plant height.

Number of primary branches per plant: Each primary branch which was emerged from the main stem was counted and recorded for the five plants the average value was taken.

3.5.2.2. Yield and yield components

The following yield and yield components traits were recorded for the five selected plants from each plot at harvesting stages. All yield and yield related traits were collected in the morning.

Fresh leaf weight per plant (g): Fresh leaf weight of the five randomly sampled plants was recorded immediately after the leaves were separated from the stem. All leaves and top tender parts of the plants were weighed by using sensitive balance (Model No. yt-1002 and reading scale 0.01).

Fresh herbal weight (kg/ha): The five sampled plants from each plot were harvested and fresh herbage yield per plant was weighed using sensitive balance (model no. yt-1002 and reading scale 0.01) and it was converted to kilogram per hectare depending on the population density.

Dry leaf weight per plant (g): Leaf dry weight per plant was estimated by taking 100g of leaf and top tender parts of the plants from each sampled plant and was dried in an oven at 68 ^{o}C to a constant weight. Then, dried sample was weighed by sensitive balance (Model No. yt-1002 and reading scale 0.01). Finally, the sum of dry leaf weight was divided by the number of sampled plants to at the mean values.

Dry leaf yield (kg/ha): Dry leaf yield per hectare was obtained from the harvested per plant and converted in to yield kilogram per hectare. Five plants in the central rows of each plot were harvested and dry leaf yield per plot was estimated by taking a composite sample of the leaves and dried in on oven at 68°C to a constant weight. The dry leaf yield per hectare was estimated by dividing the dry leaf yield per net plot to the net area of the plot and converting the average value into hectare.

Essential oil content (%): Essential oil content was determined by hydro-distillation method, according to the procedure described by Bisrat *et al*. (2009). Dry leaves of basil (300g composite sample) were placed in round bottom flask and subjected to hydro-distillation in a Clevenger apparatus along with 700 ml of water and trapped for 3 hours. The water was poured into the flask until the plant part submersed completely. The round bottom flask was placed on the heating mantle and the water and plant sample was allowed to boil for 3 hours and the essential oil was collected and measured by using pipette reading. Essential oil content was determined according to the following formula (Rao, 2002).

$$\text{Essential Oil content (\%)} = \frac{\text{Amount of essential oil recovered (g)}}{\text{Amount of herbage biomass distilled (g)}} \text{X } 100$$

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

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

Total land equivalent ratio: was calculated as given below (Mead and Willey, 1980):

$$\text{Total LER} = \frac{\text{Yin tomato}}{\text{Ys tomato}} + \frac{\text{Yin basil}}{\text{Ys basil}}$$

Where, Yin= yield of intercropping

Ys=yield of sole planting

The economic advantage of intercropping system was estimated by the monetary advantage index (MAI) and calculated by multiplying the respective yields of the component crops by their market prices during the experiment and divided by the respective LER.

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

The price of tomato and herbal fresh of basil per kg in Ethiopian birr was taken from Shashemene Vegetable market during the cropping season. Accordingly, the prices were 12 and 25 birr kg^{-1} for tomato and basil, respectively. The higher the MAI value the more profitable is the cropping system (Ghosh, 2004).

3.6 Statistical Analysis

For each measured response variable, analysis of variance (ANOVA) was carried out using Statistical Analysis System (SAS) software version 9.3 (SAS, 2012). Means of treatments showing significant effects were further separated by the least significant difference (LSD) test at 5% probability level.

4. RESULTS AND DISCUSSION

4.1 Response of Tomato to Intercropping

4.1.1 Days to 50% flowering

The result of the present study revealed that the interaction of row arrangement and population density was of basil not statistically significant ($p>0.05$). However, the main effect of population density and cropping system significantly affected days to 50% flowering of tomato ($P<0.05$) (Appendix Table 1).

It was observed that intercropping tomato with different population densities of basil had an influence on time of flowering of tomato. As basil population density increases from 25% to 100%, days to 50% flowering of tomato decreased from 58.67 to 51.13 days (Table 2). In line with these results, Gerbu (2015) reported that tomato intercropped with maize at 100T:50M ratio flowered and matured earlier. This indicates that there was competition for light in higher populations which resulted in shorter time to reach reproductive stage than those with lower populations per unit area where competition was lower, resulting in the delay of flowering.

On the other hand, days to 50% flowering of tomato was significantly ($P<0.05$) influenced by cropping system (Appendix Table 1), where longer period (55.67 days) was required for sole than for the intercropped (52.92 days) plots (Table 2). The result of this study was agreement with the finding of Getahun (2015), who reported that tomato variety Melka Shola attained 50% flowering at 52.67 days after transplanting at Fogera Research Center.

4.1.2 Days to physiological maturity

The result of the present study revealed that the interaction of row arrangement and population density of basil was not significant for days to physiological maturity of tomato ($P>0.05$). However, the main effects of row arrangement, population density and cropping system were significant for days to physiological maturity of tomato plants (P<0.05) (Appendix Table 1).

Result of the present study indicated that row arrangement also affected days to physiological maturity of tomato. The maximum number of days to physiological maturity of tomato (96.17 days) was recorded for 1T: 1B row arrangement as compared to 1T:2B row arrangement (93.92 days) (Table 2), which revealed that double row of basil between tomato rows retards and has more adverse effect on physiological maturity of tomato. The present result was in line with the finding of Warner *et al.* (2002), who reported that fruit maturity was delayed slightly in single row arrangement as compared to the double row arrangements.

Delayed physiological maturity of intercropped tomato was observed at the minimum population density of basil. Hence, the maximum days to physiological maturity of tomato (99.00 days) were recorded at 25% basil population density, which was statistically not different from 50% basil population (97.75 days) (Table 2). This may be because of wider spacing, which minimized competition for light, nutrient and water as compared to narrow spacing and, thus delayed maturity in low population. Conversely, in higher population density of basil intercropped with tomato, physiological maturity was earlier because of higher competition for light. These results were in line with the findings of Tesfu and Charles (2010) as citied by Kitila *et al*. (2012), who reported that increasing planting density appeared to shorten days to maturity.

Cropping system also showed significant (P<0.05) variation for physiological maturity of tomato. Physiological maturity in sole planted tomato was delayed (99 days) as compared to the plot intercropped with basil (95.08 days) (Table 2), which indicated that intercropping basil with tomato has adverse effect on tomato physiological maturity. This may be because of temperature fluctuation during the study season (Appendix table 5) that affected the patterns of crop yield, as fruit maturation is determined largely by temperature and intercropping basil would modify fruit temperature, as result of which maturity was hastened.

4.1.3 Plant height

Plant height was significantly ($p<0.05$) influenced by row arrangement, population density, cropping system and by their interaction (Appendix Table 1).

The result of this study indicated that the maximum plant height (62.66 cm) was recorded for interaction of 100% basil population density with 1T:2B row arrangements, which was statistically similar to that of 100% population density by 1T:1B row arrangement (62.30 cm) (Figure 1). The possible reason for this might be more competition between tomato and basil plants for light at higher population densities. In line with the present study, El-Gaid *et al.* (2014) indicated that intercropping system of tomato with common bean significantly ($P<0.05$) affected tomato plant height. Similar result was also reported by Gebru *et al. (*2015), indicated that the denser the canopy under which tomato was grown, the greater was the struggle to enlarge its inter-nodal length and in lesser rates that the plant increase the number of nodes and branches. The findings of Hussain (2003) also confirmed that tomato plant was taller when intercropped with okra and maize as compared to sole planting. Similarly, cropping system showed significant ($P<0.05$) variation for tomato plant height (Appendix Table 1), where intercropped plants had maximum height (59.15cm) compared to these in sole plots (56.58cm) (Table 2). The maximum plant height of tomato in intercropped plots might be due to more struggles for light in high population density per unit area. In agreement with this result El-Gaid *et al*., (2014) reported the highest mean values of plant height for intercropping tomato with common bean.

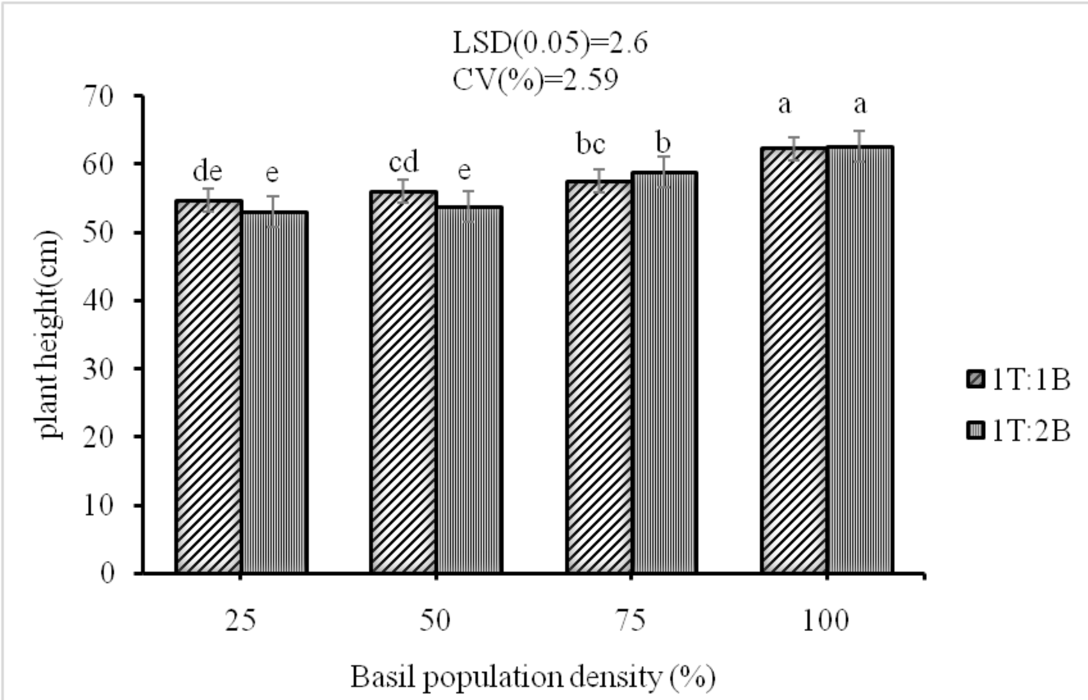

Figure 1. Interaction of population density and row arrangement of basil for plant height of intercropped tomato. Bars capped with same letter (s) are not significantly different at P≤0.05.

4.1.4 Number of primary branches

The result of the present study revealed that the interaction of row arrangement and population density had no significant (p>0.05) effect on primary branches of tomato plants. However, a main factor, population density significantly (P<0.05) affected number of primary branches (Appendix Table 1). Tomato intercropped with 25% basil population density had the highest number of primary branches (9.17), followed by 50% (8.92) while the least value was recorded for 100% basil population density (7.15) (Table 2). This might be due to low competition for light that occurred in low population density (least dense canopies) as compared to denser canopies and increased rates of lateral growth and, thus number of nodes and branches. This result was in agreement with the finding of Hussain (2003) who reported that number of branches of tomato decreased as plant density increased in maize okra intercropped system.

Table 2. Mean values for growth parameters of tomato as affected by row arrangement, population densities and cropping system under intercropping with basil at Wondo Genet during 2017/2018 season

Treatments	50% DF	DPM	PH (cm)	NPB	NCPP	NFPC	NCPP
Row arrangements							
1T:1B	57.00	96.17^{a}	59.15^{a}	8.58	9.80	7.21^{a}	9.80
1T:2B	56.08	93.92^{b}	56.58^{b}	8.13	9.88	5.88^{b}	9.88
$LSD_{0.05}$	Ns	1.31	1.27	ns	ns	0.47	ns
Population density							
100%	51.13^{b}	90.17^{c}	59.00^{a}	7.15^{c}	9.02^{b}	6.88^{a}	9.02^{b}
75%	56.50^{a}	93.67^{b}	58.15^{a}	8.17^{b}	10.25^{a}	6.10^{b}	9.68^{ab}
50%	59.67^{a}	97.33^{a}	57.95^{ab}	8.92^{a}	10.41^{a}	6.50^{ab}	10.25^{a}
25%	58.67^{a}	99.00^{a}	56.35^{b}	9.17^{a}	9.68^{ab}	6.70^{ab}	10.41^{a}
$LSD_{0.05}$	3.50	1.85	1.79	0.74	1.12	0.66	1.12
CV (%)	5.00	1.57	2.50	7.13	9.23	8.12	9.23
Cropping systems							
Sole	55.67^{a}	99.00^{a}	56.58^{b}	8.57	9.80	7.20^{a}	9.80
Intercropped	52.92^{b}	95.08^{b}	59.15^{a}	8.12	9.88	5.88^{b}	9.88
$LSD_{0.05}$	1.86	2.43	2.52	ns	0.97ns	0.78	ns
CV (%)	2.75	2.00	5.09	12.08	11.55	14.00	11.55

Means followed by the same letter with in column for a given treatment level are not significantly different at 5% level of probability. ns= not significant; DF=days to flowering, DPM=days to physiological maturity, PH=plant height, NPB=number of primary branches, LL=leaf length, LW=leaf width, NCPP=number of cluster per plant, NFPC=number of fruit per cluster, NFPP=number of fruit per plant, cm=centimeter, RA=row arrangement and PD=population density; 1T:1B= one tomato row alternating with one basil row, 1T:2B= one tomato row alternating with two basil rows

4.1.5 Number of clusters per plant

The analysis of variance showed that row arrangement didn't show significant effect on number of clusters per plant of tomato (Appendix Table 1). However, basil population density significantly affected number of cluster per plant of tomato ($P<0.05$), where high values (10.41 and 10.25) were recorded for 25% and 50% basil population density intercropped with tomato, respectively, while the minimum number of cluster per plant (9.02) was recorded for 100% basil population density (Table 2). The maximum cluster number for 25% basil population density could be due to the wider spacing, which had less competition for light and favored more flower bud formation. This implies that as with increase basil population the decrease in number of cluster per plant of tomato was in agreement with the findings of Benti *et al.* (2017) who reported that number of fruit clusters per plant may vary between seven (7) to 16 (sixteen). Cropping system was did not significantly ($P>0.05$) affected number of cluster per plant of tomato. Similarly, the interaction of row arrangement and population density of basil was not significant ($P>0.05$) for number of clusters per plant.

4.1.6 Number of fruits per cluster

The analysis of variance showed that interaction of row arrangement and population density had significant ($P<0.05$) effect on the number of fruits per cluster of tomato (Appendix Table 1). Similarly, cropping system significantly ($P<0.05$) affected number of fruits per cluster. The maximum number of fruits per cluster (8.3) was recorded for 50% basil population density with 1T:1B row arrangement, while the minimum value (4.7) was recorded for 100% basil population density with 1T:2B row arrangement tomato to basil (Figure 2).This result was in line with the finding of Benti *et al*. (2017) who indicated that average number of fruits per cluster would lay between 2.27 and 5.89.

Number of fruits per cluster of tomato, on the other hand, was affected by cropping system where intercropped tomato with basil gave more numbers of fruits per cluster (7.20) as compared to the sole planted tomato (5.88) (Table 2).This might be due to tomato plants tended to benefit from polyculture, suggesting lower inter-specific competition than intra-specific competition for growth resources. The present result is in agreement with Bomford (2004) who reported that tomato plants grown in monoculture bore fewer fruits than those grown in bean, cabbage, or basil dicultures.

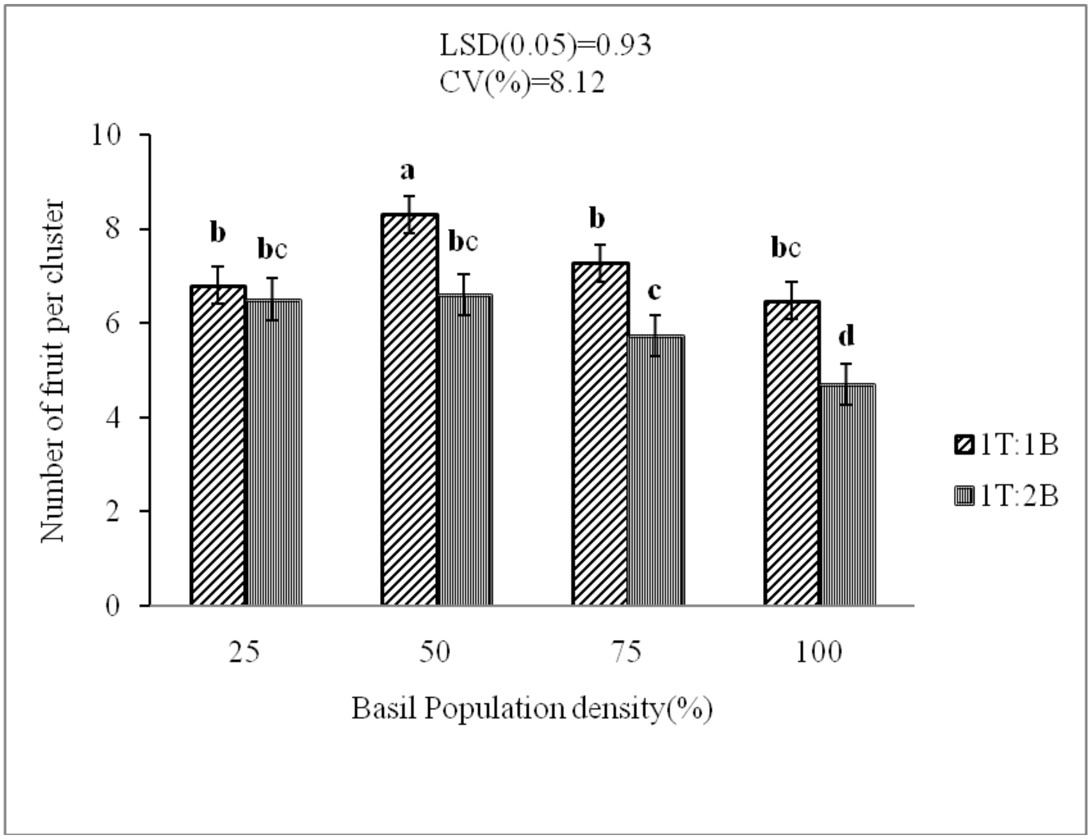

Figure 2. Interaction of population density and row arrangement of basil for number of fruits per cluster of intercropped tomato. Bars capped with same letter (s) are not significantly different at P≤0.05.

4.1.7 Number of fruits per plant

The analysis of variance showed that interaction of row arrangement and population density was highly significant for number of fruits per plant of tomato (Appendix Table 1). The maximum number of fruits per plant (71.73) was recorded for 50% basil population density with 1T:1B row arrangement, while the minimum value (55.6) was recorded for 100% basil population density with 1T:1B row arrangement, which was statically similar to those of 75% and 25% basil population with 1T:2B row arrangement (Figure 3). This might be because basil protects the surface of the soil against unfavorable factors and improve growing conditions for tomato. This result was in agreement with the findings of Benti *et al.* (2017) who reported that the maximum number of fruits per plant was obtained with variety Melka Shola (75.33) followed by Melka Salsa (64.33) and the minimum value for Fetan (15.0) andMira-1 (15.67). Maboko *et al.,* (2017) reported that number of fruits per plant decreased with increased plant density when tomato was grown in closed hydroponic system. Maboko and Du Plooy, (2018) have also reported that increased plant density resulted in fewer fruits and lower marketable and total yield per plant of tomato.

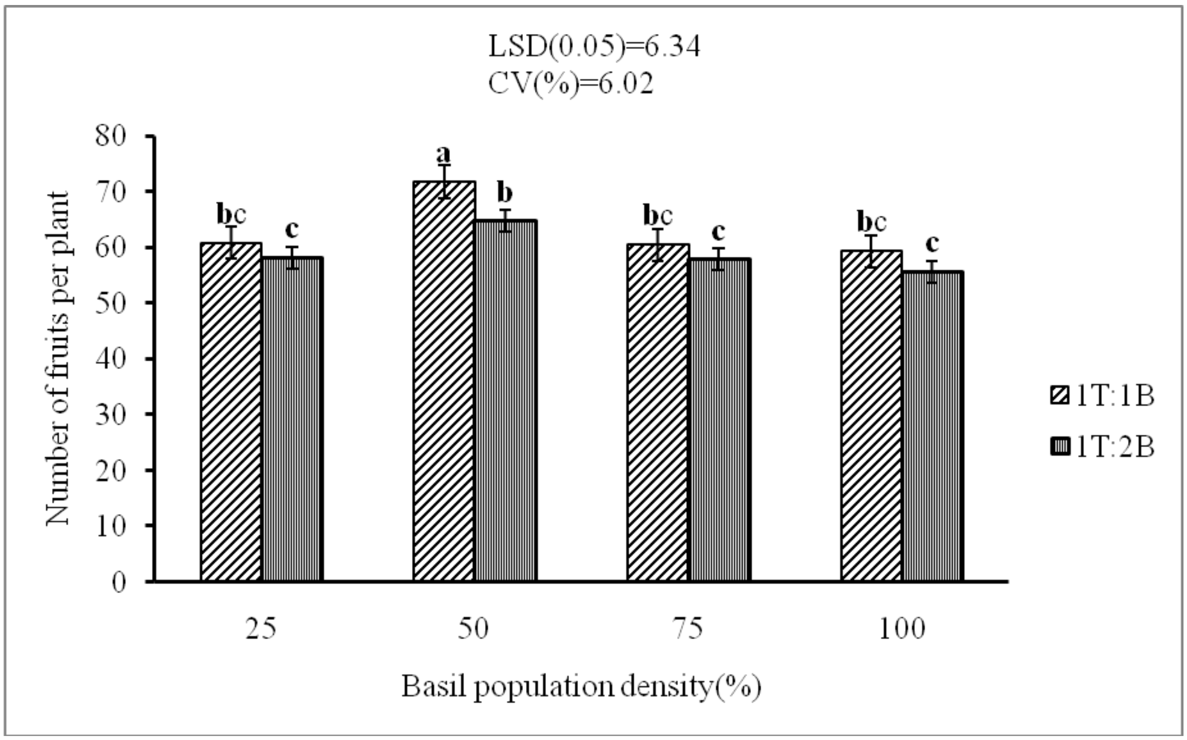

Figure 3. Interaction of population density and row arrangement for number of fruits per plant of tomato intercropped with basil. Bars capped with same letter (s) are not significantly different at P≤0.05.

4.1.8 Yield and quality of tomato fruit

Fruit diameter

The analysis of variance showed that row arrangement and basil population density significantly affected tomato fruit diameter. Similarly, cropping system also significantly affected tomato fruit diameter (Appendix Table 1).

The highest and lowest fruit diameter (4.61 cm and 4.12 cm) was recorded for 75% and 50% basil population intercropped with tomato, respectively. Higher tomato fruit diameter (4.47cm) was recorded for 1T:2B, as compared with 1T:1B tomato to basil row arrangement (4.21cm) (Table 3). This showed that population density of basil important factor influencing fruit size of intercropped tomato. In addition, when crops sown densely, competition among plants is more for growth factors resulting in reduction in size and yield of the plant. In line with the present result, Kirimi *et al*. (2011) reported that of the fruits was bigger and unit fruit weight was higher in wider spacing size.

The highest tomato fruit diameter was recorded from intercropped than sole planted tomato (4.46 cm and 4.21 cm), respectively (Table 3). This indicated that intercropping basil with tomato modifies soil micro climate and, thus helps attain potential fruit growth, which improves diameter of the fruits. On the other hand, Ahamd and Singh (2005) have reported that wider spacing minimizes competition for nutrients, water, and radiation which in turn favored fruit size.

Fruit length

The analysis of variance showed that row arrangement significantly affected tomato fruit length (Appendix Table 1). The highest fruit length (6.38 cm) was recorded for 1T:2B rows arrangement of tomato to basil and the lowest value (6.09 cm) was for 1T:1B row arrangement. On the other hand, Maboko *et al.* (2017) reported that tomato fruit size decreased with increased plant density which did not have an effect on overall yield per plot area. Unlike row arrangement, population density did not show significantly effected on fruit length (P>0.05). Similar result has been reported by Kirimi *et al*. (2011) indicating that fruit height and diameter were not affected the population density. However, cropping system significantly affected fruit length of tomato (P<0.05). Higher fruit length was recorded for tomato intercropped with basil as compare to sole planted tomato (Table 3). This might be because basil modifies the microclimate when intercropped with tomato and thus improves the growth condition for tomato.

Marketable fruit yield per plant

The result of the present study revealed that the interaction of row arrangement and population density was did not significantly affect marketable fruit yield per plant (P>0.05) (Appendix Table 2). However, the main effects of population density, row arrangement, and cropping system were significant for marketable fruit per yield plant (P<0.05). The current result is in line with the finding El-Gaid *et al.* (2014) who reported that number of fruits per plant was significantly (p<0.05) influenced by intercropping tomato with common bean at different plant densities. The maximum fruit yield per plant (1.1 kg) was recorded for 1T:1B row arrangement as compared to the value for 1T:2B row arrangements (0.95 kg) (Table 3). El-Gaid *et al.* (2014) have reported that one tomato plant with three common bean plants rows arrangement produced the highest mean number of fruits per plant (58.00), while the lowest mean value (48.20) was obtained from sole tomato.

The highest marketable fruit yield per plant (1.1kg) was obtained from 50% basil population density intercropped with tomato, followed by 75% basil population density (1.06 kg), while the least value was recorded for 100% basil population density (0.92 kg) (Table 3). The present result is in line with the finding Maboko and Du Plooy (2018), who reported that marketable yield and total yield per plant decreased with increasing plant density. Similarly, cropping system also affected fruit yield per plant of tomato, where intercropped tomato with basil exhibited higher value (1.1 kg) than the sole planted plot (0.95 kg) (Table 3). This might be due to the fact that intercropping modifies extreme temperatures both in the air and in the soil and, thus, improve the microclimate favoring yield of tomato during the offseason.

Similar result has also been reported by Gogo *et al.* (2015) were shading effect offered by intercropping basil with tomato modified air temperature and the diurnal temperature range, hence, providing ideal growth condition for tomato resulting in improve yield. Bomford (2004) has also reported that tomato plants grown in monoculture bore fewer fruits than those grown in bean, cabbage, or basil dicultures. Similarly, de Carvalho *et al* (2010) reported that number of marketable fruits was on average 59% higher in tomato-basil intercrop than in the tomato monocrop.

Unmarketable fruit yield per plant

The analysis of variance showed that the main factors (row arrangement and population density) had significant (P<0.05) effect on unmarketable fruit yield per plant (Appendix Table 2). It was observed that the highest unmarketable fruit yield per plant (0.089kg) was recorded for 1T:2B row arrangement as compared to 1T:1B row arrangement (0.082kg) (Table 3). The lower unmarketable fruit yield per plant in1T:1B row arrangement might be due to better air circulation around plants and lower relative humidity as compared to the 1T:2B row arrangement. Warner *et al.* (2002) reported that higher incidence of fruit disease symptoms with the closest row arrangement may be attributed to the more rapid plant canopy filling, providing a wetter environment for the microorganisms to spread and develop early in the season.

The maximum unmarketable fruit yield per plant was obtained from 25% basil population density (0.093kg) and, as basil population density increases the unmarketable fruit yield per plant decreases (Table 3). This might be due to intercropping basil with tomato might have decreased disease severity and the volatiles oil odor of basil masked or degrested the insect pests. In line with this, Carvalho *et al.* (2017) reported that intercropping tomato with basil reduced the incidence of whitefly in an open field.

Unmarketable fruit yield per plant was not significantly (P>0.05) affected by interaction of the main factors (Appendix Table 2). However, it was significantly (P<0.05) affected by cropping system. The maximum unmarketable fruit yield per plant (0.099 kg) was recorded for sole planted tomato, while the plot intercropped with basil had the lowest value (0.085 kg) (Table 3). In agreement with this result, Mutisya *et al.* (2016) have reported that intercropping tomato with a row of basil in between adjacent rows of tomato result the lowest number of non-marketable fruits compared to the sole cropped tomato. The result of this study was also in agreement with the findings of Carvalho *et al*. (2017), who reported that percentage of damaged fruits of tomato was higher for sole planted (43.64 %) than for intercropped tomato with basil (29.37 %). This could be due to the releases of Allelopathic oils of basil into the soil in the surrounding areas (Jenkins, 2016). Simon *et al. (*1999) have also reported that basil's essential oils like linalool, citronellol, terpineol, and eucalyptol serve as pest repellents and insecticides for both basil and the plants around it.

Marketable fruit yield per hectare

Analysis of variance showed that, the main factors (row arrangement and population density) and cropping system significantly ($P<0.05$) affected marketable fruit yield per hectare. However, interaction of row arrangement and population density was not significantly ($P>0.05$) (Appendix Table 2). The highest marketable fruit yield per hectare was obtained for 50% basil population (36691.3 kg ha^{-1}) and the least was recorded for 100% basil population density (30736.9 kg ha^{-1}) intercropped with tomato (Table 3). The result of this study was in agreement with the findings of Carvalho *et al.* (2017), who reported that the highest number of marketable tomatoes yield was obtained in tomato-basil intercrop in the field with the optimum planting density. Gebru *et al.* (2015) also reported that marketable fruit yield increased with increasing population density due to efficient utilization of resources such as light and nutrients as a result of total ground coverage by higher plant populations per unit area of land.

Single row arrangement (1T:1B) gave maximum marketable fruit yield per hectare of tomato (36657.8 kg ha^{-1}) (Table 3). The increase in marketable yield of tomato when intercropped with basil in single (1T:1B) row arrangement could be due to wider spacing between rows of basil that makes less competition for resources as compared to double rows of basil (1T:2B). Sharaiha and Gliessman (1992) reported that lettuce intercropped with faba bean at 2:1 and

2:2 row arrangements gave less production as compared to 1:1 row arrangement and lettuce sole crop.

Higher marketable fruit yield of tomato per hectare was obtained (34862 kg ha^{-1}) from tomato intercropped with basil as compared to sole planted tomato (30737 kg ha^{-1}) (Table 3). In agreement with this result, Mutisya *et al*. (2016) reported that companion planting tomato with basil significantly increased tomato fruit weight per hectare. Miyazawa *et al.* (2010) also reported that better yields of intercrops compared to the yield sum of the component species grown alone and attributed the good performance to better use of available growth resources such as nutrients, water, and light. Basil has on the other hand been reported to be a poor resource (water, nutrient, space, and light) competitor when grown together with tomatoes in the open field (Bomford, 2004). Moreno *et al*. (2002) reported that tomato requires adequate soil moisture for its growth and development, and thus, intercropping basil with tomato may have enhanced the shading effect on the soil through the provision of living mulch (Banik *et al.*, 2006), leading to a reduction in the rate of evapotranspiration and improved soil moisture status (Gurr *et al.*, 2003), which in turn, encouraged better growth and development, and higher yields of tomato, as observed in the current study.

Unmarketable fruit yield per hectare

It was observed that unmarketable fruit yield per hectare was not significantly ($P>0.05$) affected by interaction of row arrangement and population density (Appendix Table 2), but independent effect of row arrangement and population density was significant ($P<0.05$). Mean result revealed that the highest unmarketable fruit yield per hectare (2970.66 kg ha^{-1}) was recorded from 1T:2B row arrangement as compared to 1T:1B tomato basil row arrangement (2738.86 kg ha^{-1}) (Table 3). This might be due to higher incidence of fruit symptoms with the closest row arrangement that attributed to plant canopy filling more quickly, providing a wetter environment for the microorganisms to spread and develop early in the season. Yarou *et al.* (2017) reported that single row-intercropping of cabbage with basil seems to be the best arrangement of plants for reducing pest damage.

The maximum unmarketable fruit yield per hectare was obtained from tomato plots intercropped with 25% basil population density (3089.97 kg ha^{-1}), while the minimum value recorded for 100% basil population density (2622.20 kg ha^{-1}). Unmarketable fruit yield per hectare was decreased as basil population density from 25% to 100% (Table 3). This might be due the release of more amount of essential oils by basil plants with increasing population density of basil would lower level of fruit damage by insects and disease Yarou *et al.* (2017) also reported that unmarketable cabbages in intercropped plot with tropical basil was significantly low compared to the sole cabbages and cabbage plots surrounded by tropical basil.

Similarly, unmarketable fruit yield per hectare was significantly ($P<0.05$) affected by cropping system. The maximum unmarketable tomato fruit yield per hectare (3312.2 kg ha^{-1}) was recorded for sole planted plots as compared to tomato intercropped with basil (2854.8 kg ha^{-1}) (Table 3). This might be due to intercropping tomato with basil provides alternate food as intermediate hosts for predators, thus increasing natural enemies' population in an intercropped system better growth and more flowers on basil translates to a higher concentration of volatile compounds, leading to more insect pests and beneficial insect attraction. This result is in line with that of Mutisya *et al.* (2016) who reported that tomato basil intercropping causes higher attraction of *B. tabaci* onto the basil, deterring them from feeding on tomato plants and for this reason, the reduction in non-marketable tomato fruits. Hordofa (2000) also reported that tomato- bean intercropping gave higher marketable fruit yield and lower fruit worm damage as compared to sole planted tomato.

Table 3. Fruit size and yield of tomato intercropped with basil as affected by row arrangement, population density and cropping system at Wondo Genet during 2017/2018 cropping season

Treatments	FD(cm)	FL(cm)	MFPP(kg)	UMFPP(kg)	MF(kg ha^{-1})	UMF(kg ha^{-1})
Row arrangements						
1T:1B	4.210^{b}	6.090^{b}	1.100^{a}	0.082^{b}	36657.800^{a}	2738.860^{b}
1T:2B	4.470^{a}	6.380^{a}	0.950^{b}	0.089^{a}	31004.300^{b}	2970.660^{a}
$LSD_{0.05}$	0.180	0.270	0.050	0.003	1313.200	93.520
Population densities						
100%	4.300^{b}	6.280	0.922^{c}	0.079^{d}	30736.900^{b}	2622.200^{d}
75%	4.610^{a}	6.070	1.064a^{b}	0.083^{c}	35498.800^{a}	2781.640^{c}
50%	4.120^{b}	6.210	1.101^{a}	0.088^{b}	36691.300^{a}	2925.250^{b}
25%	4.310^{b}	6.370	1.009^{b}	0.093^{a}	32397.200^{b}	3089.970^{a}
$LSD_{0.05}$	0.260	ns	0.067	0.004	1857.100	132.260
CV (%)	4.87	4.90	5.30	3.74	4.43	3.74
Cropping systems						
Sole	4.210^{b}	6.080^{b}	0.949^{b}	0.099^{a}	30737.000^{b}	3312.200^{a}
Intercropped	4.460^{a}	6.370^{a}	1.099^{a}	0.085^{b}	34862.000^{a}	2854.800^{b}
$LSD_{0.05}$	0.244	0.259	0.050	0.008	2130.100	257.460
CV (%)	6.57	4.85	5.70	6.97	6.36	6.97

Means followed by the same letter with in a column for a given treatment are not significantly different at 5% level of probability; ns=not significant; FD=Fruit diameter; FL=fruit length, MFPP=marketable fruit yield per plant, UMFPP=unmarketable fruit yield per plant, MF=marketable fruit yield per hectare, UMF=unmarketable fruityield per hectare, LSD= Least significant difference, CV= Coefficient of variation; 1T:1B= one tomato row alternating with one basil row, 1T:2B= one tomato row alternating with two basil rows

4.2 Response of Basil to Intercropping

4.2.1 Plant height

The difference in plant height due to different treatment combinations (row arrangement and population density) was not significant (p>0.05) (Appendix Table 3). Similarly, row arrangement had no significant (P>0.05) influence on plant height. However, population density significantly (P<0.05) influenced plant height, where the tallest plant (37.93cm) was observed 100% basil population density, while the shortest (31.66cm) was for 25 % basil (Table 4). The basil population density decreases from 100% to 25% plant height also decreases. It was observed that, as from37.93cm to 31.66cm) the increase in plant height with increasing plant population could be due to increased competition for light. The present study was in line with the work of Alemu (2017) who reported that as basil population density increases, the competition for sunlight and nutrient increased and, thus, stems length increased. Pereira *et al*. (2015) also reported that increased density increases stem length of the plant due to increased competition between the plants for absorbing light to cause growth in their height.

Unlike main effects, cropping system did not show significant (P>0.05) variation for basil plant height (Appendix Table 3). This could be due to less competition for light between basil and tomato. In line with the present result, Bomford (2004) has reported that basil is a poor resource (water, nutrient, space, and light) competitor when grown together with tomatoes in the open field.

4.2.2 Number of primary branches per plant

Results of the analysis of variance revealed that row arrangement had significant (P<0.05) effect on number of primary branches per plant (Appendix Table 3). The highest number of primary branches (9.52) was recorded for 1T:1B row arrangement while the minimum value (8.03) was recorded 1T:2B row arrangement of tomato to basil (Table 4). This might be due to closer inter-row spacing which could have more favored plant competition to nutrition, air and other growth factors, there by reduced vegetative growth of plants. Decrease of plant density in a unit area may cause increased light absorption by plants and provide more space for plant development, Therefore, 1T:1B row arrangement has enough space for light absorption, as a result more branches grow when compare with 1T:2B row arrangement. Similar results have also been reported by Ibrahim (2000) who observed more branches at wider spacing because of enough space among plants to produce more branches.

The effect of population density was not significant (P>0.05) for number of primary branches per plant (Appendix Table 3). Similarly, the interaction of main factors was not significant (P>0.05). However, cropping system had significant (P<0.05) influence on number of branches. The highest number of primary branches of basil was counted from sole planted tomato (11.39) as compared to tomato intercropped with basil (8.03). This might be due to the presence of enough space for absorption of photosynthetically active radiation (PAR) and availability of nutrient and water (Atghaei *et al.*, 2015).

4.2.3 Fresh herbal yield per plant

The analysis of variance showed that, population density had significant (p<0.05) effect on fresh herbal yield per plant (Appendix Table 3). The maximum fresh herbal yield per plant (30.76g) was recorded at 50% basil population density (Table 4). This might be due to the fact that yields per plant decrease gradually as plant population per unit area increased. However, the yield per unit area increased due to efficient utilization of growth factors. Maximum yield per unit area can be obtained when individual plants are subjected to severe competition. Sadeghi *et al*. (2009) reported that basil is sensitive to plant density and lower densities do not produce sufficient fresh herbal yield per unit area.

However, row arrangement, cropping system and interaction of main factors were not significant (p>0.05) for fresh herbal weight per plant of basil (Appendix Table 3). This result showed that intercropping as compared to sole planting did not affected fresh herbal per plants of basil. This indicated also that basil plant can be tolerating tomato plants without adverse effect on individual fresh herbal yield under intercropped condition. Similar results were reported by Rao (2002) indicating that intercropping of cornmint did not affect biomass yield of rose-scented geranium.

4.2.4 Fresh stem weight per plant

Population density significantly ($P<0.05$) affected, but row arrangement and cropping system did not significantly ($P>0.05$) influence fresh stem weight per plant of basil (Appendix Table 3).

The maximum fresh stem weight per plant (33.05g) was recorded for 50% basil population density, while the least value (24.84g) was recorded for 25% basil population density, which was statistically similar to the value obtained from 75 % and 100% basil population density (26.64g and 27.73g, respectively) (Table 4). Decrease in the weight of individual plants at higher plant density might be due to reduction in growth and development of the plants. The present result was in agreement with the finding of Bomford (2004), who reported that basil benefited from the reduced of size of its companions and, with more access to light, it accumulated more chlorophyll and produced more aboveground biomass. Nigussie *et al.* (2017) reported that the highest and lowest stem fresh weights were observed at 80% and 20% population density of rosemary intercropped with onion.

Table 4. Means for plant height, number of primary branches, fresh herbal and stem weight per plant of basil as affected by row arrangement, population density and cropping system intercropped with tomato at Wondo Genet during 2017/2018 cropping system

Treatments	PH (cm)	NPB	FHPP (g)	FSPP (g)
Row arrangements				
1T:1B	34.56	9.52 [a]	27.68	26.46
1T:2B	35.42	8.03 [b]	27.30	26.93
$LSD_{0.05}$	ns	1.18	ns	ns
Population densities				
100%	37.93 [a]	9.28	27.73 [b]	25.89 [b]
75%	36.25 [b]	8.93	26.64 [b]	25.13 [b]
50%	34.13 [c]	8.76	30.76 [a]	33.05 [a]
25%	31.66 [d]	8.13	24.84 [b]	22.71 [b]
$LSD_{0.05}$	1.40	ns	3.83	5.02
CV (%)	3.24	15.39	11.26	15.2
Cropping systems				
Sole	34.41	11.39 [a]	27.14	22.29
Intercropped	35.42	8.03 [b]	27.30	26.93
$LSD_{0.05}$	ns	1.96	ns	ns
CV (%)	3.38	9.73	5.55	10.89

Means followed by the same letter with same column for a given treatment are not significantly different at 5% level of probability. ns= not significant; PH=plant height; NPB=number of primary branches per plant; FHPP=fresh herbal yield per plant; FSPP=fresh stem weight per plant; LSD= least significant difference, CV= coefficient of variation, 1T:1B= one tomato row alternating with one basil row, 1T:2B= one tomato row alternating with two basil rows.

4.2.5 Herbal fresh weight per hectare

Herbage fresh weight of basil was significantly ($P<0.05$) influenced by the interaction of row arrangement and basil population density. However, the independent effects of row arrangement and cropping system didn't significantly influenced fresh herbal weight per hectare (Appendix Table 3). The maximum fresh herbal yield (2116.8 kg ha^{-1}) was obtained from 1T:2B row arrangement of tomato to basil combined with 100% basil population density, while the lowest value was obtained from the interaction of 1T:2B row arrangement with 25% basil population density (Figure 4). The increase in herbal fresh weight 1T:2B row arrangement and 100% basil population density could be due to optimum radiation, nutrient, and water supply which allow basil to bear a large number of leaves and inflorescence thereby to increase herbage yield. Similar finding was reported by Carvalho *et al*. (2017), indicating that highest herbal yield of basil was recorded when in intercropped with tomato plants. Omae *et al.* (2014) also reported that the biomass and grain yield of cowpea increased at a high density of cowpea on millet-cowpea intercropping system.

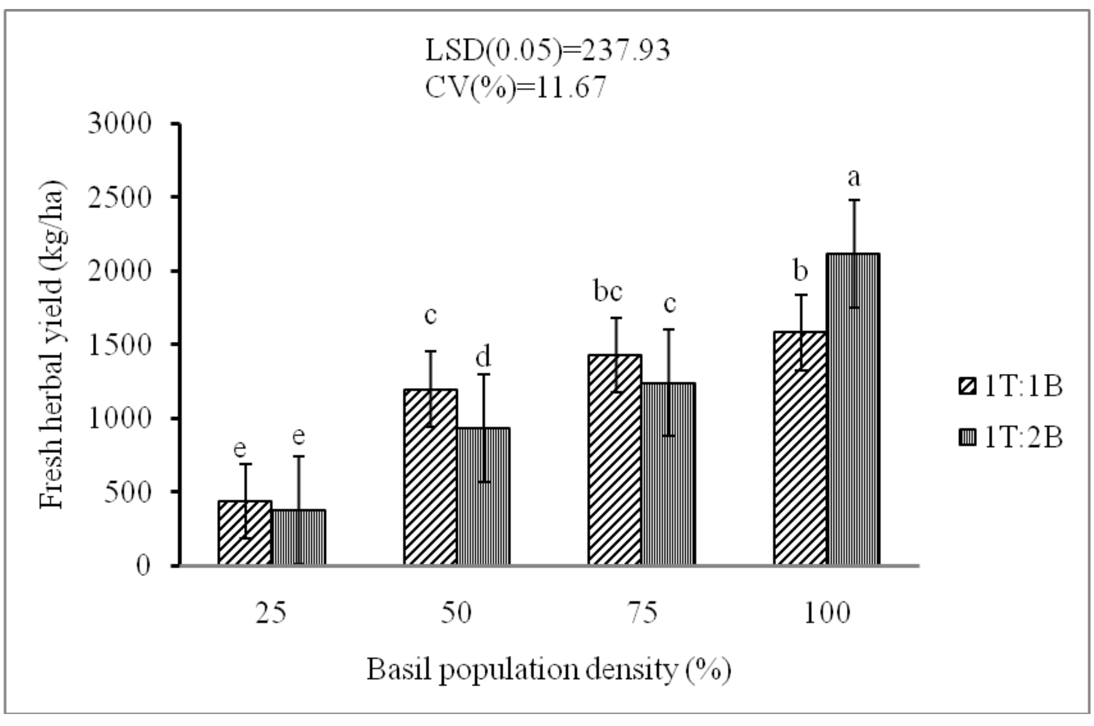

Figure 4. The interaction effect of population density and row arrangement of basil in tomato basil intercropping on basil fresh herbal yield. Bars capped with same letter (s) are not significantly different at P≤0.05.

4.2.6 Dry Herbal yield per hectare

It was observed that both the main factors and their interaction had significant (P<0.05) influence on dry herbal yield per hectare (Appendix Table 3). The maximum dry herbal yield (341.49 kg ha^{-1}) was recorded for 1T:2B row arrangement with 100% basil density, whereas the lowest value was obtained from 1T:1B row arrangement with 25% basil population density (Figure 5). Dry herbal yield followed the same trend as fresh herbal yield. In line with this Nigussie *et al*. (2017) reported that maximum herbal yield of rosemary was obtained with 80% rosemary intercropped with onion. Oroka (2012) has also reported that maximum density of intercrops resulted in maximum forage dry matter yield of rice intercropped with cowpea.

Herbage dry yield of basil, on the other hand, was not significantly (P>0.05) affected by cropping system (Appendix Table 3). In line with this result Girma (2015) reported that herbal yield of basil was not significantly varied with sole planting and 1:1 row arrangement in maize-basil intercropping. This might be due to the presence of less competition between basil and tomato when intercropped. In agreement with the present study, Carvalho *et al*. (2017) reported that in the highest herbal yield in of basil was recorded for both mono-cropping and intercropping with tomato plants. Gill *et al.* (2007) also reported that fresh herb yield was highest for sole Japanese mint plot, which was statistically on par with intercropping Japanese mint plus one row of onion.

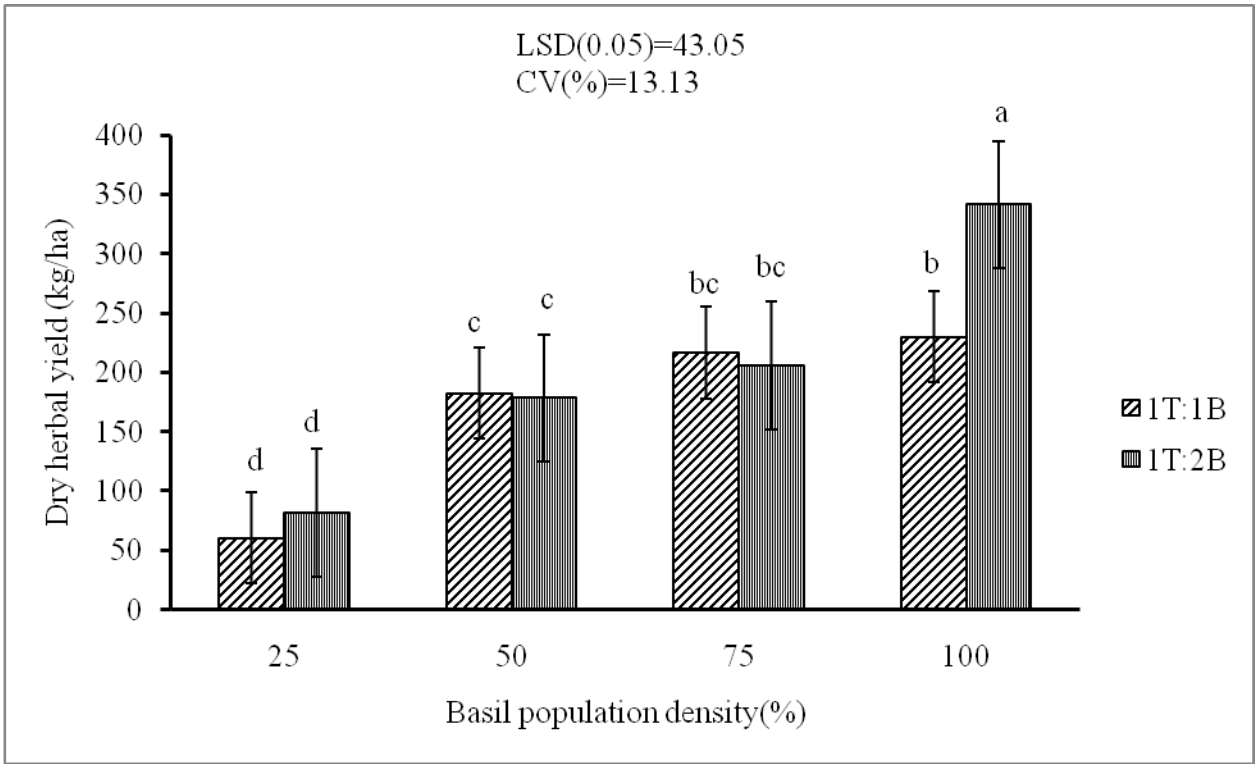

Figure 5. The interaction effect of population density and row arrangement of basil on herbal dry yield basil yield. Bars capped with same letter (s) are not significantly different at P≤0.05.

4.2.7 Essential oil content

Essential oil content was not significantly (P>0.05) affected by the interaction of main factors, but, row arrangement and population density had significant (p<0.05) effect (Appendix Table 3). Similar result has been reported by Mirjalili and Poorazizi (2014) indicating that plant density significantly affected essential oil content of basil. Higher essential oil content (1.17%) was obtained from 1T:1B row arrangement as compared with 1T:2B row arrangement (0.95%) (Table 5). This could be due to the fact that at wider row spacing, the competition between the plants reduces and hence, each plant has more space and produces more leaves. In addition the essential oil content of plants under high light was more than that of plants grown with low light as biosynthesis of essential oil is highly dependent on light conditions (Rao, 2002). In line with this, Mirjalili and Poorazizi (2014) reported that two-row cultivation of basil, with low density resulted in higher yield of essential oil.

The highest essential oil content (1.13%) was obtained from 100%, followed by 75% (1.12%) and 50% basil population density (1.1%), while 25% basil population density had the least value (0.88%) (Table 5). This result indicates that as population density increases the essential oil content of basil also increases. In line with this, it has been reported that plant population densities affected plant growth by subsequently influencing the absorption of nutrients and exposure of plants to the light, which has a direct effect on photosynthesis and production of essential oil (Khorshidi, 2009 as cited by Alemu, 2017). Atghaei *et al.* (2015) also reported that as basil population density increases, the essential oil content also increased.

Cropping system had significant ($p<0.05$) influence on essential oil content of basil, which was higher in sole planted basil (1.26%) when compared with basil intercropped with tomato (0.96%) (Table 5). This might be due to the case that sole planted basil didn’t suffer from competition with tomato plants and, thus had higher production of essential oil than did the intercropped plot. However, intercropping basil with tomato affected the amount of sunlight that passes through the canopies, which could influence the photosynthetic rates of the leaves within the canopy. In line with this result, Lulie *et al.* (2014) reported that higher essential oil content of spearmint was obtained from sole planting as compared to the intercropped spearmint with maize.

Table 5. Fresh herbal weight, fresh stem weight, dry herbal weight and essential oil content of basil as affected by row arrangement, population density and cropping system under intercropping with tomato at Wondo genet during 2017/2018 season

Treatments	FHW($kgha^{-1}$)	FSW($kg\ ha^{-1}$)	DHW ($kg\ ha^{-1}$)	EOC (%)
Row arrangements				
1T:1B	1160.59	1067.68	172.53[b]	1.17[a]
1T:2B	1167.14	1156.89	201.90[a]	0.95[b]
$LSD_{0.05}$	ns	ns	21.53	0.13
Population densities				
100%	1848.54[a]	1726.00 [a]	285.77 [a]	1.14 [a]
75%	1332.07[b]	1256.40 [b]	211.31 [b]	1.12 [a]
50%	1064.93[c]	1101.90 [b]	180.63 [c]	1.11 [a]
25%	409.94[d]	364.90 [c]	71.14[d]	0.88 [b]
$LSD_{0.05}$	168.24	225.52	30.44	0.18
CV (%)	11.67	16.37	13.13	13.63
Cropping systems				
Sole	1607.60	1573.56	228.88	1.26[a]
Intercropped	1581.90	1346.17	226.89	0.96[b]
$LSD_{0.05}$	ns	ns	ns	0.22
CV (%)	9.32	9.48	5.99	9.80

Means followed by the same letter with in a column for a given treatment are not significantly different at 5% level of probability. ns= not significant; FHW=fresh herbal weight, FSW=fresh stem weight, DHY= dry herbal yield (kg/ha); EOC=essential oil content; EOY=essential oil yield; LSD= Least significant difference, CV= Coefficient of variation

4.2.8 Essential oil yield

The result of this study revealed that the interaction of row arrangement and population density of basil significantly ($P<0.05$) influenced essential oil yield of basil (Appendix Table 3). Similar result has been reported by Gill *et al*. (2007) where different intercropping patterns significantly affected essential oil content of Japanese mint.

The highest essential oil yield (22.86 kg ha^{-1}) was obtained from 1T:2B row arrangement combined with 100% population density of basil, while the lowest value was obtained from 1T:2B row arrangement with 25 % population density (4.26 kg ha^{-1}) of basil (Figure 6). The reduction in essential oil yield of basil with decreasing basil population density might be probably due to decreased herbal biomass yield. The result of the present study was in agreement with the findings of El-Gandi *et al.* (2001) who reported higher essential oil yield for higher plant density for sweet basil. Solomon and Beemnet (2011) also reported higher EO yield under narrow (30 cm) inter-row spacing for Japanese mint. The highest essential oil yield was obtained from sole planted basil (21.82 kg ha^{-1}) as compared with the intercropped basil (15.36kg ha^{-1}). This result was in line with the finding of Daneshnia *et al*. (2016) indicating increased basil essential oil yield during sole cropping in comparison with mixed cropping system. Similar results have been reported by Nigussie *et al*. (2017) for rosemary-onion intercropping, where rosemary essential oil yield was higher in sole as compared to the intercropped plot.

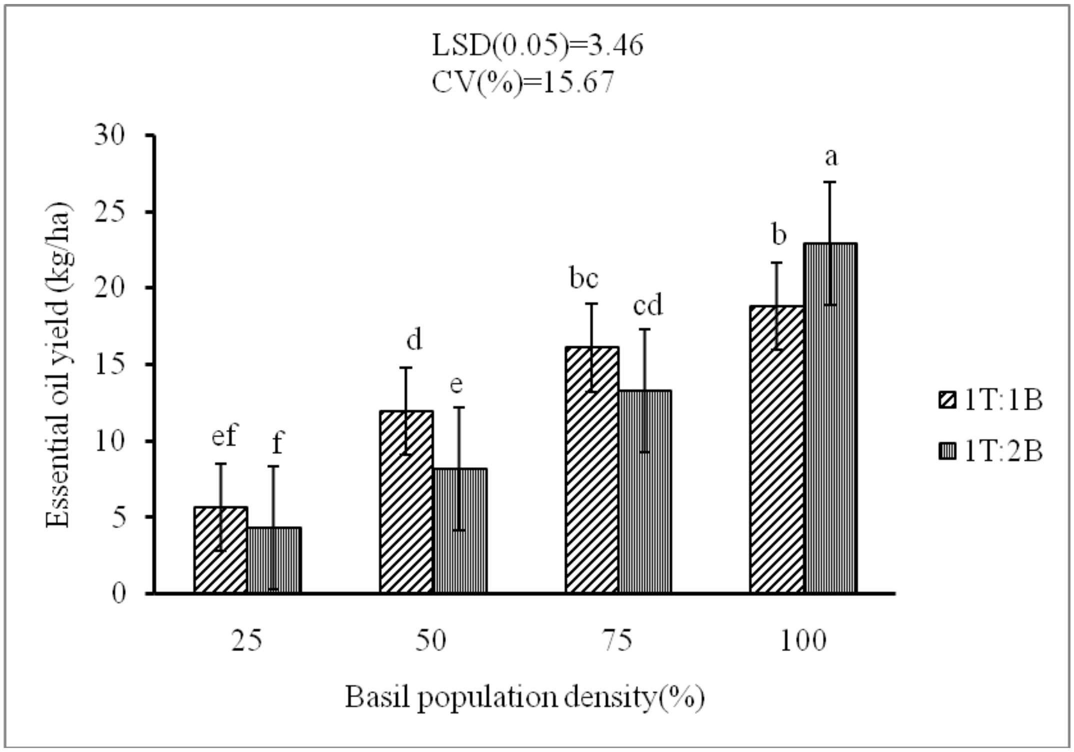

Figure 6. The interaction of population density and row arrangement of basil intercropped with tomato on basil essential oil yield. Bars capped with same letter (s) are not significantly different at P≤0.05.

4.3 Productivity of Tomato-Basil Intercropping

4.3.1 Land equivalent ratio

The analysis of variance revealed that, the interaction of row arrangement and plant population density of basil had significant ($P<0.05$) influence on partial land equivalent ratio of tomato (Appendix Table 4). It was observed that the highest partial LER of tomato (0.99) was obtained from 50% basil population density with 1T:1B row arrangement, while the least value (0.70) was recorded for 25% basil population density with 1T:2B row arrangement (Figure 7). This indicated that inter-specific competition between tomato and basil plants was lower than the intra-specific competition within basil plants. In line with this, De Carvalho *et al.* (2010) reported that the tomato relative yield was higher than 1.0 when intercropped with fennel and rue plants.

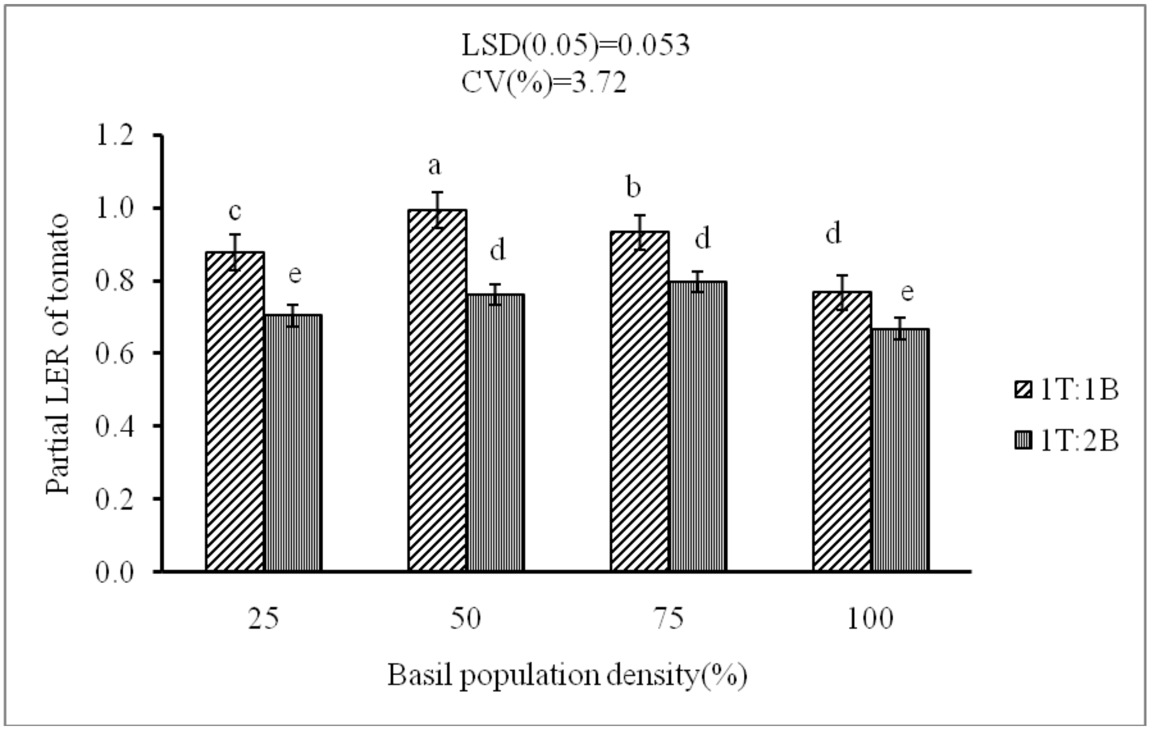

Figure 7. The interaction effect of population density and row arrangement of basil intercropped with tomato on tomato partial land equivalent ratio (LER). Bars capped with same letter (s) are not significantly different at P≤0.05.

The maximum partial LER of tomato was obtained from 1T:1B row arrangement (0.89) as compared to 1T:2B row arrangement (0.73) (Table 6). This result is in agreement with the finding of Prakash *et al.* (2004), who reported that intercropping of tomato in maize in a row ratio of 1:1 resulted in the highest land-equivalent ratio (1.86), followed by intercropping of 1 row of tomato within paired rows of maize and 1 row of tomato between 2 paired rows (1.79). Similarly, population density showed significant ($p<0.05$) effect on partial land equivalent ratio of basil. However, partial land equivalent ratio of basil was not significantly ($p>0.05$) affected by row arrangement and by the interaction of main factors (Appendix Table 4). It was observed that 100% basil population density had the highest value of partial LER of basil (1.17) while 25% had the least (0.26) (Table 6). This result showed that partial LER of basil increased as basil population density increased in all treatment combinations due to efficient utilization of resources. This result was in agreement with the finding of Lulie *et al*. (2017) who reported that partial LER of haricot bean increased as haricot bean population density increased from 25% to 100% (0.44-0.76) in maize haricot bean intercropping. Nigussie *et al*.

(2017) also reported that as population densities of rosemary decrease from 80% to 20%; to partial land equivalent ration also decreased from 0.89 to 0.29 in onion-rosemary intercropping system.

There was no significant interaction effect of population density, row arrangement alone on total LER; however, population density significantly affected total LER (Appendix Table 4). The highest and lowest LER (1.90 and 1.03) was recorded for 100% and 25% basil population intercropped with tomato, respectively (Table 6). hence, it was observed that as basil population density increased in all treatments combinations, total LER also increased and its value in all cases was more than one (1.90, 1.69, 1.54 and 1.03), showing that intercropping of basil with tomato is more advantageous than sole cropping of both crops. It also indicated that monocultures would need 90 %, 69 %, 54% and 3 % more land, respectively, than the area required for intercropping of the two crops to produce the same combined yields. Result of the present study were in agreement with the finding El-Gaid *et al.* (2014) who reported that highest value of LER was obtained from 1 tomato: 3 common bean plants (1.26) and the lowest values were obtained from 1 tomato: 1 common bean plants (1.08). Lulie *et al*. (2014) also reported higher LER for intercropping maize with spearmint compared to mono-cropping of maize. Similar result was also reported by Nigussie *et al*. (2017) indicating that highest total LER (1.68) was obtained when onion was intercropped with 80% rosemary.

4.3.2 Monetary advantage index (MAI)

Row arrangement did not showed significant ($P>0.05$) variation (Appendix Table 4), while population density had significant ($P<0.05$) effect on MAI. In line with this result, Gill *et al.* (2007) reported that row arrangement of Japanese mint had no significant effect on gross return during Japanese mint intercropping with onion and maize.

Intercropping tomato with basil at 100% gave the maximum MAI (194600 ETB), which was not statistically different from the MAI obtained from 75% and 50% population density of basil (185828and 163131 ETB, respectively) (Table 6). Therefore, this value indicated that tomato grower can maximize the land use efficiency and profit by intercropping tomato with basil on limited land area. Higher returns under intercropping systems also explain the suitability of intercropping tomato with basil and suggest that the system has to be adopted at a profitable scale. The result of the present study was in agreement with that of Ijoyah and Dzer (2012) who reported that intercropping gave greater combined yields and monetary returns than those obtained from either crop grown alone. El-Gaid *et al.* (2014) also reported that intercropping of 1 tomato plant with 3 common bean plants could provide economically profitable options for farmers. Lulie *et al.* (2014) have also reported that maize intercrop with spearmint at 42cm inter row spacing of spearmint gave higher monetary advantage index followed by 36cm inter row spacing of spearmint intercropped with maize than planted as sole. According to Nigussie *et al*. (2017) the highest monetary advantage index was obtained when onion was intercropped with 80 % rosemary population density.

On the other hand, MAI was not significantly ($P>0.05$) affected by row arrangement, though 1T:1B tomato to basil gave the maximum marketable yield, low unmarketable yield, higher partial LER of tomato and appeared to be more suitable from practical point of view than 1T:2B row arrangement. Therefore, intercropping of basil with tomato at 1T:1B row arrangement increased yield advantage of tomato more than the 1T:2B row arrangement as revealed by the highest total LER and monetary advantage index. In agreement with this, Girma (2015) reported that the highest monetary value index was obtained from 1:1 row arrangement as compared to 1:2 and 1:3 row arrangements during intercropping maize with basil.

Table 6. Productivity measurement of intercropping of tomato with basil as affected by population density of basil and row arrangement at Wondo Genet during 2017/2018 cropping season

Treatments	Partial LER of Tomato	Partial LER of basil	Total LER	MAI
Row arrangements				
1T:1B	0.89[a]	0.69	1.57	158906.00
1T:2B	0.73[b]	0.77	1.51	135115.00
$LSD_{0.05}$	0.026	ns	ns	ns
Population densities				
100%	0.71[c]	1.17[a]	1.90[a]	194600.00[a]
75%	0.86[a]	0.88[b]	1.69[b]	185828.00[a]
50%	0.87[a]	0.66[c]	1.54[b]	163131.00[a]
25%	0.79[b]	0.26[d]	1.03[c]	44484.00[b]
$LSD_{0.05}$	0.37	0.17	0.18	49382.00
CV (%)	3.72	18.68	9.45	27.13

Means followed by the same letter with in column for a given are not significantly different at 5% level of probability. ns= not significant; LER=land equivalent ratio; MAI= Monetary Advantage Index; 1T:1B= one tomato row alternating with one basil row, 1T:2B= one tomato row alternating with two basil rows; LSD= Least significant difference, CV= Coefficient of variation

5. SUMMARY AND CONCLUSIONS

The present experiment was conducted at Wondo Genet Agricultural Research Center, southern Ethiopia under irrigated condition in 2017/2018 to determine the optimum planting density and row arrangements of basil for intercropping with tomato.

Plant height, number of fruits per cluster and number of fruits per plant of tomato were significantly affected by the interaction of basil population density and row arrangement. As a result, the tallest plant (62.30cm) was obtained at 1T:1B tomato to basil row arrangement with 100% basil population density. The highest number of fruits per cluster and number of fruits per plant (8.3 and 71.73) were recorded at 1T:1B row arrangement with 50% basil population density. On the hand, population density, row arrangement, and cropping system showed a significant effect on tomato yields. The highest marketable fruit yield per plant and marketable fruit yield per hectare (1.1kg plant $^{-1}$ and 36691.3kg ha^{-1}) were obtained from tomato plot intercropped with 50% basil population density and from 1T:1B tomato to basil row arrangement (1.1kg plant $^{-1}$ and 36657.8 kg ha^{-1}).

Moreover, basil population density and row arrangement showed a highly significant variation in different growth and yield parameters of basil. Fresh and dry herbal yield per hectare and essential oil yield of basil were affected by the interaction of basil population density and row arrangement of tomato and basil. As a result, the maximum fresh and dry herbal yield per hectare and essential oil yield of basil (2116.8 kg ha $^{-1}$, 341.49 kg ha $^{-1}$ and 22.86 kg ha $^{-1}$respectively) were obtained from 100% basil population density intercropped at 1T:2B tomato to basil row arrangement.

On the other hand, the efficiency of intercropping tomato with basil was significantly affected by basil population density and row arrangement. The highest partial LER of tomato (0.89) was obtained from the interaction of 1T: 1B row arrangement with 50% basil population density, followed by 75% basil population density (0.86). Partial LER of basil increased as basil population density increased from 25% to 100% in all treatment combinations, probably due to efficient utilization of resources. Generally, the highest total LER (1.90) was recorded at 100% basil population intercropped with tomato. Similarly, population density of basil had significant effect on monetary advantage index where 100% basil population gave the maximum MAI (194600ETB), which was not statistically different from the MAI obtained from 75% and 50% population density (185828 and 163131 ETB, respectively).

In general, it could be concluded that different intercropping systems compared to sole planting did not affect yield and some yield components of tomato. Therefore, from the practical perspective tomato producer around the study area can maximize land use efficiency and profit by intercropping tomato with basil at 1T:1B row arrangements with 50% basil population density. The advantage of intercropping tomato with basil can also be affected by different varieties of both and basil, soil conditions, and climate and hence, it is advisable to further study on the following:

- The effect of Population density and row arrangement of basil and tomato intercropping with different varieties of both crops and under different climate conditions and soil
- Evaluation of tomato-basil intercropping under rain fed conditions
- Assessment of pests and diseases incidence on intercropping aromatic and medicinal plants with tomato under both irrigation and rain fed condition

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7. APPENDICES

Appendix Table 1. Analysis of variance for growth and yield parameters of tomato as affected by row arrangement, population densities and cropping system under tomato-basil intercropping at Wondo Genet during 2017/18 cropping season

Source of variations	Df	50% DF	DPM	PH (cm)	NPB	LL (cm)	LW (cm)	NCPP	NFPC	NFPP	FL (cm)	FD (cm)
Mean squares												
Replication	2	1.29^{ns}	4.04^{ns}	3.98^{ns}	0.06^{ns}	0.28^{ns}	0.73^{ns}	1.27^{ns}	0.87^{ns}	35.54^{ns}	0.10^{ns}	0.104^{ns}
RA	1	5.04^{ns}	30.38**	39.78**	1.21^{ns}	0.13^{ns}	0.09^{ns}	0.04^{ns}	10.53***	95.6**	0.49*	0.41**
PD	3	82.82***	93.15***	7.34*	4.92***	1.57^{ns}	0.73^{ns}	2.38*	0.67^{ns}	35.86**	0.10^{ns}	0.25**
RA*PD	3	18.60^{ns}	11.26^{ns}	49.25***	0.91^{ns}	0.43^{ns}	0.03^{ns}	3.99^{ns}	3.55***	111.69*	0.026^{ns}	0.078^{ns}
Error	14	8	2.23	2.1	0.35	0.277	0.30	0.82	0.28	13.50	0.093	0.044
CV (%)		5.00	1.57	2.5	7.13	5.74	11.44	9.23	8.12	6.01	4.90	4.87
Cropping systems												
Replication	2	0.33^{ns}	0.26^{ns}	3.89^{ns}	0.06^{ns}	0.28^{ns}	0.74^{ns}	1.27^{ns}	0.87^{ns}	35.55^{ns}	0.10^{ns}	0.10^{ns}
CS	1	14.02**	50.42**	10.35*	2.57^{ns}	0.20^{ns}	1.53^{ns}	5.36^{ns}	0.91^{ns}	51.51^{ns}	0.02*	0.012*
Error	2	2.14	3.66	8.69	1.02	0.299	0.288	1.29	0.84	31.52	0.09	0.08
CV (%)		2.75	2.00	5.09	5.09	5.96	10.96	11.55	14.00	9.19	4.85	6.57

*, **, and *** significant at $P \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$ probability levels respectively; ns= not significant CV = coefficient of variation; df = degrees of freedom; CS=cropping system RA=row arrangement; PD=population density; DF=days to flowering, DPM=days to physiological maturity, PH= plant height; NB = number of branches plant; LL = leaf length; LW = leaf width; NCPP=number of cluster per plant; NFPC=number of fruit per cluster; NFPP=number of per plant; FL=fruit length; FD=Fruit diameter. NS, *, and ** = non-significant, significantly different at 5%, and 1% respectively.

Appendix Table 2. Analysis of variance for growth and yield parameters of tomato as affected by row arrangement, population densities and cropping system under tomato-basil intercropping at Wondo Genet during 2017/18 cropping season

Mean squares						
Source of variation	Df	MFP (kg plant $^{-1}$)	UMFPP (kg plant $^{-1}$)	MFKG (kg ha $^{-1}$)	MFKGH (kg ha $^{-1}$)	UMFKGH (kg ha $^{-1}$)
Replication	2	6827.01 ^{ns}	22.79 ^{ns}	0.008 ^{ns}	4989336.60 ^{ns}	25322.76 ^{ns}
RA	1	176696.52***	290.16***	0.136***	191776500.00**	322396.44**
PD	3	44615.65***	215.51***	0.036***	45184320.80**	239449.34***
RA*PD	3	3584.78 ^{ns}	0.85 ^{ns}	0.003 ^{ns}	1789633.20 ^{ns}	946.08 ^{ns}
Error	14	3291.84	143.74 ^{ns}	0.003	2249187.6	159703.98 ^{ns}
CV (%)		5.61	3.74	5.30	4.43	3.74
Cropping system						
Replication	2	1450.38 ^{ns}	16.93 ^{ns}	0.15 ^{ns}	11261207.2 ^{ns}	18816.39 ^{ns}
CS	1	80120.04**	710.02***	0.083***	76589252.4***	788890.88***
Error	2	5287.56	813.77	0.003	4625831.0	904176.85
CV (%)		7.11	9.96	5.7	6.36	9.96

*, **, and *** significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= not significant CV = coefficient of variation; df = degrees of freedom; RA=row arrangement; CS=cropping system; PD=population density; MFP=marketable fruit per plant; UMFPP=unmarketable fruit per plant; MFKGH=Marketable fruit kilogram per hectare; UMFKGH=unmarketable fruit kilogram per plant

Appendix Table 3. Analysis of variance for growth and yield parameters of basil as affected by row arrangement, population densities and cropping system under tomato-basil intercropping at Wondo Genet during 2017/18 cropping season

Source of variation	df	PH(cm)	NPB	FHPP(g)	FSPP(g)	FHB(kg ha^{-1})	FSB(kg ha^{-1})	DHB(kg ha^{-1})	EOC (%)	EOY(kg ha^{-1})
Mean squares										
Replication	2	6.24^{ns}	1.28^{ns}	24.61^{ns}	11.46^{ns}	8686.371^{ns}	22248.28^{ns}	1253.97^{ns}	0.04^{ns}	3.4^{ns}
RA	1	4.46^{ns}	13.35*	0.88^{ns}	1.33^{ns}	257.519^{ns}	47751.73^{ns}	5175.67*	0.28**	5.5^{ns}
PD	3	44.17***	1.39^{ns}	36.91*	118.87**	2150512.23***	1912247.83***	47617.77***	0.09*	274.35***
RA*PD	3	5.02^{ns}	1.33^{ns}	54.44^{ns}	61.63^{ns}	197811.82**	197200.18^{ns}	4778.34**	0.03^{ns}	18.35*
Error	14	1.28	1.82	9.58	16.47	18459.25	33167.47	604.44	0.021	3.9
CV (%)		3.24	15.39	11.26	15.2	11.67	16.37	13.13	13.63	15.67
Cropping systems										
Replication	2	2.85^{ns}	1.49^{ns}	9.15^{ns}	0.93	288.96^{ns}	7194.02^{ns}	216.80^{ns}	0.022^{ns}	2.29^{ns}
CS	1	0.038^{ns}	21.00*	0.49^{ns}	16.71^{ns}	292203.03^{ns}	4868.59*	5900.60**	0.05*	237.27***
Error	2	1.38	1.00	2.27	6.74	22200.83	18159.39	186.91	0.013	0.76
CV (%)		3.38	9.73	5.55	10.89	9.32	9.48	5.99	9.80	4.42

*, **, and *** significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= not significant CV = coefficient of variation; df = degrees of freedom; RA=row arrangement; CS=cropping system PD=population density; PH=plant height; NPB=number of primary branch; FHPP=fresh herbal per plant, FSPP=fresh stem per plant, FHB=fresh herbal biomass, FSB=fresh stem biomass, DHB=dry herbal biomass, EOC=essential oil content, EOY=essential oil yield, kg ha^{-1}=kilogram per hectare, g=gram and cm=centimeter

Appendix Table 4. Analysis of variance for Productivity measurement of intercropping of tomato as affected by population densities and row arrangement of basil at Wondo Genet during 2017/2018 cropping season

Mean squares					
Source of variation	df	Partial LER of Tomato	Partial LER of basil	Total LER	MAI
Replication	2	0.0003^{ns}	0.060 ^{ns}	0.042 ^{ns}	1962304019 ^{ns}
RA	1	0.15***	0.031 ^{ns}	0.024 ^{ns}	3396033578 ^{ns}
PD	3	0.032***	0.870***	0.831***	29086146604***
RA*PD	3	0.0048*	0.039 ^{ns}	0.044 ^{ns}	3191366653 ^{ns}
Error	14	0.009	0.019	0.021	11590311082.9
CV (%)		3.72	18.68	9.45	27.13

*, **, and *** significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= not significant CV = coefficient of variation; df= degrees of freedom; RA=row arrangement; PD=population density; LER=land equivalent ratio; MAI=monetary Advantage Index

Appendix Table 5. Means monthly climate data during 2017/2018 season at Wondo Genet.

Months	**T_{min} (^{O}C)**	**T_{max} (^{O}C)**	**RH (kpa)**	**Wind speed (m/s)**	**Sunshine hours (%)**	**RF (mm)**
January	9.68	27.97	1.27	1.26	75	29.42
February	11.15	28.22	1.29	1.27	71	55.53
March	11.97	28.38	1.44	1.50	66	91.00
April	12.49	26.98	1.55	1.31	60	121.76
May	12.48	26.21	1.69	1.30	60	135.74
June	12.37	24.81	1.64	1.54	54	107.50
July	12.77	23.32	1.14	1.12	38	158.38
August	12.85	23.75	1.57	1.11	42	151.96
September	12.24	24.69	1.66	0.92	46	135.55
October	11.15	25.99	1.52	0.91	78	80.42
November	9.32	27.34	1.29	1.06	77	38.61
December	9.76	26.89	1.64	1.21	62	15.93

Source: Wondo Genet College of Forestry and Natural Resources Meteorological Station

^{0}C= degree centigrade, T_{max}= maximum temperature, T_{min}= minimum temperature, RH= relative humidity, RF=rainfall, m/s= meter per second, mm= millimeter