

# Intercropping of African marigold (*Tagetes erecta* Linnaeus (Asteraceae)) Varieties at Different Plant Density with Tomato (*Solanum lycopersicum* Linnaeus (Solanaceae)) on Yield Related Traits and Yield of tomato at Wondo Genet, Southern Ethiopia

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## Abstract

Tomato is among the most important vegetable crops in Ethiopia. Planting marigolds between tomatoes protects the tomato plants from harmful root-knot nematodes in the soil and increase the marketable fruit yield of tomato by trapping different insects and pest attack and the like. Field experiment was conducted to assess effect of plant densities of intercropped African Marigold Varieties on yield related traits and yield of tomato and to evaluate the productivity and economic value of tomato and African marigold intercropping system, in southern parts of Ethiopia, at Wondo Genet Agricultural Research Center in 2017/18 cropping season. Three varieties of African marigold (AVT 001, AVT 540 and AVT 7063) at three population densities (PD) (25%, 50%, and 75%) were intercropped with tomato variety 'Melkashola'. The three varieties of African marigold (AFM) and tomato were included as a sole for comparison. Randomized complete block design in factorial with three replications was used. Plant height, days to 50% flowering, days to physiological maturity and days to first harvest of tomato were not significantly affected by varieties of African marigold, population densities, interaction and cropping system. Harvest duration of tomato was delayed (27.56 days) and hastened (25.78 days) by variety AVT 540 and AVT 001, respectively as compared to VAT 7063. The highest (7.56) number of primary branches was due to 50% PD African marigold (AFM). The 50% PD delayed harvest duration (29.56 days) as compared to other PD. The highest number of harvest (3.91), numbers of fruit per plant (45.89) and number of fruit per cluster (15.56) were also obtained due to 50% PD. The highest fruit weight (13.80 ton ha<sup>-1</sup>) and marketable fruit yield (13.11 ton ha<sup>-1</sup>) were also obtained from 50% PD, but the highest unmarketable fruit yield (3.24 ton ha<sup>-1</sup>) was obtained from 25%. Cropping system was showed non-significant effect except marketable and unmarketable fruit yield of tomato, the highest marketable (10.19 ton ha<sup>-1</sup>) and unmarketable (4.37 ton ha<sup>-1</sup>) fruit yield were obtained from intercropped and sole cropping of tomato respectively. The highest (0.84) partial land equivalent ratio (LER) of tomato and total LER (1.43) were due to 50% PD. The highest value of monetary advantage index (37,225 ETB ha<sup>-1</sup>) was due to 50% PD. Therefore, any of the three African marigold varieties at 50% PD could be recommended for intercropping with tomato.

**Keywords:** Cropping system, Marketable fruit yield, Population density and Unmarketable fruit yield.

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## INTRODUCTION

Tomato (*Solanum lycopersicum* Linnaeus (Solanaceae)) is one of the most widely grown vegetable crops in the world, next to potato. It originally came from tropical area from Mexico to Peru (Mazaher *et al.*, 2006; FAO, 2015). Its use as a food originated in Mexico and spread throughout the world following the Spanish colonization of the Americas (Cox, 2000). Tomato originated in the Andes mountain region of South America. Early domestication was undertaken by the Native Americans. The first encounter with tomato by Europeans appears to be during a voyage by Cortez in 1519, when he acquired some tomato plants in Mexico (Cox, 2000). The tomato was distributed throughout Europe in the years following. The tomato was actually taken by the Moors first through Spain, and then more widely distributed. The Moors' involvement resulted in one of the first European names for tomato (Moor's apple). However in Ethiopia, there is no exact information as to when tomato was first introduced; but, the crop is cultivated in different major growing areas of the country. In 1966 tomato was recognized as a commodity crop by Ethiopian Institute of Agricultural Research (EIAR) (Setotaw, 2006). The first record of commercial tomato cultivation is from 1980 with a production area of 80 ha in the upper Awash by Merti Agro-industry for both domestic as well as export markets (Lemma, 2002). The total area increased to 833 hectare by the year 1993 and later-on the cultivation spread towards other parts of the country. In Ethiopia, tomato ranks fifth in total production (3.76%) after Ethiopian cabbage, red peppers, green peppers and head cabbage; is also fifth in area coverage (2.51%) next to red peppers, Ethiopian cabbage, green peppers and Head cabbage from vegetable crops cultivated (CSA, 2018). Its national mean yield is 5.3 ton/ha (CSA, 2018). In 2017/18 Ethiopian *Meher* (rain

fed) cropping season tomato production was estimated with an area of 5,235.19 ha and a total production of 27,774.5 tons (CSA, 2018). The off season production is estimated to be higher than the *Meher* season.

Tomato is among the most important vegetable crops in Ethiopia. Both fresh and processed tomato varieties are popular and economically important vegetable crops produced in the country (Geleta *et al.*, 1995). The total production of this crop in the country has shown a marked increase since it became the most profitable crop providing a higher income to small scale farmers compared to other vegetable crops (Lemma *et al.*, 2003). It is used as canned vegetable having multiple uses and supplies an essential nutrient in human diets (Choudhury, 1979). It is mainly used for both commercial and home use purposes. The fresh produce is sliced and used as salad. It is also cooked for making local saucer ('*watt*'). The processed products like tomato paste, tomato juice, tomato catch-up and whole peel-tomato are produced in the country for local market and export. It was recognized as quality product for both local and export markets and providing a route out of poverty for small scale producers who live in developing countries in general and in Ethiopia in particular (Tewodros and Asfaw, 2013).

Tomato is one the most widely cultivated vegetable crops in our country and specifically around Wondo Genet area. Intercropping of African marigold within the row of tomato is the best way of introducing and increasing the production and productivity of African marigold in Ethiopia. Tomato was the main crop because it is mainly cultivated from vegetable crop around Wondo Genet area but, African marigold was the companion crop.

Marigold (*Tagetes erecta* Linnaeus (Asteraceae) is aromatic medicinal crop native of central and South America especially Mexico and belongs to the family Asteraceae (Compositae). There are 33 species of genus *Tagetes*. However the cultivated types of marigold are African marigold and French marigold (NHB 2013-14).

Members of the genus *Tagetes* have a long history of human use as beverages, condiments, ornamentals, and medicinal purpose such as analgesics, antiseptics, carminative, diuretic, antispasmodic, anthelmintic, stimulants, vermin repellents, and for treatment of stomach and intestinal diseases (Singh *et al.*, 2006). *Tagetes minuta* L., commonly known as African marigold, is a highly aromatic annual perennial herb growing. It is cultivated for '*Tagetes oil*' (Singh *et al.*, 2016).

Marigold and tomato companion planting is a tested and true technique used by gardeners for hundreds of years. Research studies have indicated that planting marigolds between tomatoes protects the tomato plants from harmful root-knot nematodes in the soil. Although scientists tend to be skeptical, many gardeners are convinced that the pungent scent of marigolds also discourages a variety of pests such tomato hornworms, whiteflies, thrips, and maybe even rabbits. Allow 45 to 60 cm between the marigold and the tomato plant, which is close enough for the marigold to benefit the tomato, but allows plenty of space for the tomato grow (<https://www.gardeningknowhow.com/ornamental/flowers/marigold/marigoldtomatocompanion.htm>).

Marigold repels nematodes, tomato worm, slugs and general garden pests. Gomez Rodriguez *et al.* (2003) found that intercropping of tomato with African marigold (*T. erecta*) reduced early blight (*Alternaria solani* Sorauer, (Pleosporales: Pleosporaceae)) of tomato in three ways: (1) allelopathic effect on *A. solani* development, (2) reduced humidity levels below those conducive to the pathogen requirement, and (3) behaved as a physical barrier against spore dispersal (Gómez Rodriguez *et al.*, 2003; Zavaleta-Mejía and Gómez, 1995). Intercropping marigold for nematode management also appeared to reduce numbers of aphids and whiteflies, and resulted in lower levels of virus in tomato (Zavaleta-Mejía and Gómez, 1995).

There is a lack of information about the intercropping system and related planting density of African marigold with that of the component crops, due to recent information to the country and lack of awareness for the people about the economic importance of African marigold in Ethiopia. The importance of this crop was understood by WGARC and it was introduced to Ethiopia from Indian through Av Tomas (AVT) Natural Products PLC Company and the adaptations of the three African marigold varieties (AVT 001, AVT 540 and AVT 7063) were tested and registered.

Tomato is one of the high demanded vegetable crops by the growers. In the past, growth in food production was achieved by using more land but, more recently, the increase in productivity per unit area is the concern. Intercropping of tomato with African marigold is one of the methods of achieving high yield per unit area and harvesting more than one crop per season from a piece of land. Intercropping is receiving attention because it offers potential advantages for resource utilization, decreased inputs and increased sustainability in crop production, but our understanding of interactions and planting density among the intercropped species (like, tomato and African marigold) is still very limited (Egbe, 2010). Intercropping might positively impact on the future food problems in developing countries (Egbe, 2005). Also, optimization of land resource could be achieved when crops are grown under intercropping and plant population density increased.

The common goals of intercropping vegetable with other crops are to produce greater yield on a given piece of land, making use of resources that would otherwise not be utilized by a single crop. Since African marigold is recently introduced to the country, the farmers are reluctant to produce this crop as sole crop. Thus is a need of identifying different crops such as African marigold (*T. erecta* L.) to be intercropped with tomato.

Therefore, the general objective of this study is:

- ❖ to determine the tomato-African marigold intercropping.

The specific objectives of this study are:

- ❖ to assess effect of plant densities of intercropped African marigold varieties on yield related traits and yield of tomato; and
- ❖ to evaluate the productivity and economic value of tomato and African marigold intercropping system

## MATERIALS AND METHODS

### Description of the Study Area

The study was conducted at the experimental field of Wondo Genet Agricultural Research Center (WGARC) during the 2017/18 off cropping season (through irrigation) from end of October 2017 to mid of January 2018. Wondo Genet is located in South Nation Nationality and People's Regional State which is 274 km away from Addis Ababa. The geographical coordinate of the research site is 7°19'N and 38°38'E with an altitude of 1780 meters above sea level. The mean annual rainfall is 1390 mm. The site has mean maximum and minimum temperatures of 26°C and 12°C, respectively. Wondo Genet has a bimodal rainfall distribution with two rainy seasons. Short rains occur during March to May and the long rains occur from July to October. The dry season extends from November to February (Dawit and Afework, 2008). The soil type of the experimental area is *Nitosols* and it has a textural class of sandy clay loam with pH of 6.4 (Abayneh *et al.*, 2006). The center mainly has a national mandate to conduct researches on medicinal and aromatic plants (MAPs).

### Description of the Experimental Materials

**Tomato:** the available determinate improved type of tomatoes' variety 'Melkashola' was used. It was released by Melkassa Agricultural Research Center and adapted to altitude of 1000 to 1800 meter above sea level and matures in 144 days. It requires 1000 mm to 1200 mm annual rainfall and the potential yield of variety was 8-9.5-ton ha<sup>-1</sup> at research and 5.5-6.5-ton ha<sup>-1</sup> at farmer's field (Lemma, 2003).

**African marigold:** Three African marigold varieties namely AVT001, AVT540 and AVT7063 which were introduced from India through AVT Natural Products Plc to WGARC were used. It was first introduced to Ethiopia from Indian through Av Tomas (AVT) Natural Products PLc Company and the adaptations of the three African marigold varieties (AVT 001, AVT 540 and AVT 7063) were tested and registered. The varieties were well adapted and two of them gave better yield than in India (Beemnet, 2015).

### Treatments and Experimental Design

The experiment was consisting of two factors, the three African marigold varieties (AVT 001, AVT 540 and AVT 7063) and the plant population of tomato for both sole and intercropping was 33,333 plants ha<sup>-1</sup>, three plant densities of African marigold (*T. erecta*) 25% (20,833.333 plants ha<sup>-1</sup>), 50% (41,666.67 plants ha<sup>-1</sup>) and 75% (62,500 plants ha<sup>-1</sup>) and the sole planting of marigold was 83,333.333ha<sup>-1</sup>.

Table 1. Description of the Treatments

Trts.	A.mariglod spacing		Varieties of A.mariglod	A. marigold PD/ha	Remark
	Intra-row spacing(cm)	Inter-row spacing(cm)			
1	96	50	AVT 001	20,833.333	25% of AVT 001
2	48	50	AVT 001	41,666.67	50% of AVT 001
3	32	50	AVT 001	62500	75% of AVT 001
4	96	50	AVT 540	20,833.333	25% of AVT 540
5	48	50	AVT 540	41,666.67	50% of AVT 540
6	32	50	AVT 540	62500	75% of AVT 540
7	96	50	AVT 7063	20,833.333	25% of AVT 7063
8	48	50	AVT 7063	41,666.67	50% of AVT 7063
9	32	50	AVT 7063	62500	75% of AVT 7063
10	30	100	Melkashola	33,333.333	Sole tomato
11	30	40	AVT 001	83,333.333	Sole AVT 001
12	30	40	AVT 540	83,333.333	Sole AVT 540
13	30	40	AVT 7063	83,333.333	Sole AVT 7063

Where 100% population density throughout the treatments, Trts = treatments, PD = population density, A. marigold = African marigold.

Randomized complete block design with three replications in factorial arrangement was used. The detail of treatment is given in Table 1. The marigold was planted between the two tomato rows. Uniform populations of 33,333 plants ha<sup>-1</sup> was also maintained for tomatoes in both intercropping and sole cropping.

## **Experimental Procedures and Field Management**

### **Seedling preparation, planting and management**

The seedling of tomato variety 'Melkashola' was raised in nursery. Healthy and uniform seedlings with 3 to 4 leaf number were transplanted at the age of 30 days after sowing. The seedlings were irrigated after transplanting. Seedlings of African marigold varieties were raised in the nursery for 45 days until they are about 20 cm in length and then transplanted to the main experimental field. Marigold seedlings are easily transplanted and established in the main field without much mortality. The sole African marigold seedlings were transplanted to the main field with a spacing of 30 cm x 40 cm.

### **Land preparation, field layout and transplanting**

Both tomato and African marigold varieties were sown on nursery at the start September and October, respectively and transplanted to the main field at the end of October and middle of November, 2017 respectively.

The experimental field was ploughed and harrowed by a tractor to get a fine field. It was leveled by manually before the field layout was made. The distance between plot and block was 1 m and 1.5 m respectively. The sole and intercropped tomato consisted of six rows, while sole and intercrop African marigold consisted of twelve and five rows, respectively. Inter-row spacing of 100 cm and with the intra-row spacing of 30 cm was used for both sole and intercropped tomato. The inter-row and intra-row spacing for sole African marigold was 40 cm and 30 cm respectively. The row length of the experiment was 1.8 m; therefore the gross plot of was also 10.8m<sup>2</sup> (1.8 m x 6 m). The net plot area for sole and intercrop tomato was 7.5 m<sup>2</sup> (1.5 m x 5 m). This experiment field had a total area of 41.4 m x 21 m (869.4 m<sup>2</sup>). The data was taken from the central rows for tomato by taking the five randomly taken plants while in data collection. The African marigold were intercropped between two rows of tomato at 50 cm away from tomato row with intra-row 32 cm, 48 cm and 96 cm for 75%, 50% and 25% population density of the recommended sole population density, respectively. The sole population density of 83,333.333 plants ha<sup>-1</sup> African marigold was used. Uniform populations of 33,333 plants ha<sup>-1</sup> was maintained for sole and intercropped tomato. At the time of transplanting, seedling of African marigold should be stocky and bear 3-5 true leaves. Thin and long seedlings do not make a good plant. Very old seedlings are also not desirable and seedling of 4 and 5 weeks old for tomato and African marigold were transplanted, respectively.

### **Fertilizer application rates and other agronomic practices**

Inorganic fertilizers, urea (in the form of N) and DAP fertilizer were applied at the rate of 100 kg ha<sup>-1</sup> and 92 kg ha<sup>-1</sup>, respectively on tomato (Edossa *et al.*, 2013). The whole amount of DAP fertilizer was applied at the time of transplanting, whereas half rate of urea applied after well established and the remaining half was applied at vegetative stage of the plant. The component crops were irrigated once in a week through furrowing.

### **Harvesting of fruits**

Marigold flowers started to flower from 40-50 days and plucked when they have attained full size. Plucking of flowers was done in cool hours of the day. The fruit of tomato was also harvested after 3 months.

## **Data Collection and Measurements**

### **Tomato phenology, growth, yield component and yield**

#### **Phenological characters**

**Days to 50% flowering:** recorded when 50% plants flowered in a plots starting from the date of transplanting.

**Days to physiological maturity:** calculated as the number of days when 90% the plant in plot attained its maturity.

#### **Growth parameters**

**Plant height (cm):** measured at 90% physiological maturity from the soil surface to tips of the plant from 5 randomly taken plants.

**Number of primary branches per plant:** the number of primary emerging from the main stem was counted at 90% physiological maturity from 5 randomly taken plants.

**Days to first harvest:** counted as the number of days elapsed from the date of transplanting to first harvesting.

**Harvest duration (days):** calculated as number of days from the date of first harvest to last harvesting dates.

**Number of harvesting:** the number of harvest from first to last picking and recorded.

#### **Yield components and yields**

**Fruit cluster per plant:** the number of fruit cluster of 5 randomly taken plants and the average was noted.

**Number of fruits per plant:** the number of fruits from 5 randomly taken plants and the average fruit number were noted.

**Total fruit yield (ton ha<sup>-1</sup>):** the weight of an individual tomato fruit was calculated by dividing the number of fruits counted from 5 randomly taken plants, it converted in to ton per hectare (ton ha<sup>-1</sup>). It includes both

marketable and unmarketable fruit yield of tomato.

**Marketable fruit yield of tomato (ton ha<sup>-1</sup>):** Fruits of tomato free from damages, disease and defects were weighted (ton ha<sup>-1</sup>) at each harvest from total fruit yield as marketable yields and converted into ton ha<sup>-1</sup>.

**Unmarketable fruit yield of tomato (ton ha<sup>-1</sup>):** fruits with cracks, damaged by insects, diseases, birds, sunscald and blossom-end-rot...etc were considered at each harvest as unmarketable fruits and calculated kg plot<sup>-1</sup> and converted to ton ha<sup>-1</sup>. Unmarketable yield was calculated in percent, to know how much of it was not profitable or not had been sold, as follows:  $UY = (UY/TY) \times 100\%$  Where, UY is unmarketable yield and TY is total yield. Total fruit yield of tomato (t/ha): the fruit yield obtained at each harvest from the central rows was used for this parameter. It was also recorded at the time of each harvest then all the harvested fruit yield was summed and converted to ton ha<sup>-1</sup>.

### System productivity

#### Land equivalent ratio (LER)

**Partial land equivalent ratio:** is the ration of intercropped and sole cropped yield of the individual crop. For instance the partial land equivalent ratio of tomato was calculated as,

Partial LER of tomato =  $\frac{Y_{Ti}}{Y_{Ts}}$ ; where  $Y_{Ti}$  = intercropped yield of tomato and  $Y_{Ts}$  = fruit yield of sole cropped tomato. Similar to tomato the partial land equivalent ratio of African marigold was also calculated as; partial land equivalent ratio of African marigold =  $\frac{Y_{AFMi}}{Y_{AFMs}}$  where  $Y_{AFMi}$  = intercropped yield of African marigold and  $Y_{AFMs}$  = sole cropped of African marigold.

The LER was calculated using the formula  $LER = \sum (Y_{pi}/Y_{mi})$  (where  $Y_{pi}$  is the yield of each crop in the intercrop, and  $Y_{ms}$  is the yield of each crop in the sole crop).

So in this study the LER was calculated as,

$$LER = \frac{Y_{Ti}}{Y_{Ts}} + \frac{Y_{Ami}}{Y_{Ams}} \quad (\text{from the sole crop the actual yield was used from the three varieties})$$

#### Where

$Y_{Ti}$  = Yield per unit area of tomato intercrop (net plot area of intercropped tomato)

$Y_{Ts}$  = Yield per unit area of tomato sole (net plot area of sole tomato)

$Y_{Ami}$  = Yield per unit area of AFM in intercropping (net plot area of intercropped AFM)

$Y_{Ams}$  = Yield per unit area of African marigold sole (net plot area of sole AFM)

#### Monetary Advantage Index (MAI)

First the Gross monetary value (GMV) was calculated as; Yield of component crops  $\times$  respective market price; i.e., (yield of tomato  $\times$  price of tomato + yield of African marigold  $\times$  price of African marigold) (Willey (1979).

In order to access the economic advantage of intercropping as compared to sole cropping of tomato and African marigold varieties, the gross monetary value (GMV) and the Monetary Advantage index (MAI) were calculated from the yield of tomato and African marigold (kg ha<sup>-1</sup>). Gross monetary value and monetary advantages were calculated to measure the productivity and profitability of the intercropping as compared to sole cropping of the component crops.

**Monetary Advantage Index (MAI):** The most important part of recommending a cropping pattern was the cost: benefit ratio more specifically total profit, because farmers are mostly interested in the monetary value of return. The yield of all the crops in different intercropping systems and also in sole cropping system and their economic return in terms of monetary value were evaluated to find out whether tomato fruit yield and additional African marigold yield were profitable or not. This is calculated with monetary advantage index (MAI) which indicates more profitability of the cropping system with the higher the index value (Mahapatra, 2011). It was expressed as  $MAI = (P_{ab} + P_{ba}) * (LER - 1) / LER$  Where,  $P_{ab} = P_a \times Y_{ab}$ ;  $P_{ba} = P_b \times Y_{ba}$ ;  $P_a$  = Price of tomato and  $P_b$  = Price of African marigold. In this research we used the price of African marigold 30 Ethiopian birr per kilo gram of dry flower yield. It was determined by socio-economic and agricultural extension research process in Wondo Genet Agricultural Research Center. This price was calculated based on the inputs (fertilizers, labor, transportation cost and others) used while doing this research activity because, the flower yield of African marigold is not determined in our marketing system, but the price of tomato was just taken from the local market. The price of tomato was fluctuated and seasonal but we used the average of maximum and minimum price of tomato fruit twelve Ethiopian birr per kilogram (ETB 12 kg<sup>-1</sup>).

#### Statistical Data Analysis

All data were subjected to the analysis of variance (ANOVA) appropriate to the randomized complete block design using SAS (SAS, 2002). Least significant difference (LSD) test at 5% level of probability was also used for mean separation as procedure described by Gomez and Gomez, (1984). I used the linear model of RCBD while analyzed the data by SAS,  $Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_{ik} + \epsilon_{ijk}$ . Where,  $Y_{ijk}$  = the value of the response variable;

= Common mean effect;  $i$  = Effect of Population density;  $j$  = Effect of block;  $k$  = Effect of varieties;  $ik$  = Interaction effect of population density & varieties; and  $ijk$  = Experiment error. For cropping system  $Y_{ij} = \mu + i + j + k + ij$ , where  $Y_{ij}$  = the value of the response variable;  $\mu$  = Common mean effect;  $i$  = Effect of intercropped;  $j$  = Effect of block and  $k$  = Effect of sole cropping.

## RESULTS AND DISCUSSION

### Phenological and growth response of Tomato

#### Days to 50% flowering and days to physiological maturity of tomato

The analysis of variance showed that days to 50% flowering and days to physiological maturity of tomato were not significantly affected by varieties, their population density and interaction effect (Appendix Table 1). The result agreed with Ijoyah *et al.* (2015) who reported that population densities of okra did not significantly affect days to attain 50% flowering for okra in okra-egusi melon intercropping. Cropping system is not significantly affected days to 50% flowering and days to physiological maturity of tomato.

In contrast with this result Ijoyah (2012) who reported that the longer days to attain 50% flowering took more time for intercropped egusi melon in an egusi melon-maize intercrop as compared to sole egusi melon. The report of Hailu *et al.* (2015) disagreed with this result cropping system was significantly affected the days of 50% flowering and physiological maturity of tomato in intercropping of tomato with maize taken shortest time to reach physiological maturity than sole cropping. The findings of Abraha (2013) disagree with this result, revealed that in maize cowpea intercropping system the days of 50% flowering of cowpea was earlier in sole cropping than from cowpea-maize intercropping.

#### Plant height

The effects of varieties of African marigold, population densities, their interaction effect and cropping system were not significant effect on plant height (Table 2. and Appendix Table.1). The experimental result of Bilasvar and Salmasi (2016) demonstrated there was no significant difference in plant height between different population densities and between cultivars of sweet basil.

#### Number of primary branches

Population density had a highly significance ( $P < 0.01$ ) effect on primary branches number. There was no significance effect due to variety, interaction effect of population density and varieties of African marigold and cropping system (Appendix Table 1).

The highest (7.56) and lowest (5.31) number of primary branches was due to 50% and 25% population density respectively (Table 2). Intercropping of African marigold at 50% planting density gave the highest numbers of primary branches because of the interspecies competition at 50% which enables to use natural resources effectively like sun light, fertilizer, nutrients and soil moisture. The net assimilation rate at 50% plant population density might be higher and more biomass might be also produced. This study is similar to Hailu *et al.* (2015) and Hussain (2003) on maize-tomato intercropping at 50% population density gave the highest number of primary branches as compared to others, but Khorshidi *et al.* (2009) study showed that highest number of main branches per plant was recorded in lowest population density, while lowest number of main branches per plant was recorded in medium population density.

#### Days to first harvest

Population densities, varieties of African marigold, their interaction and cropping system had no significance effect on tomato (Appendix Table 2).

#### Harvest duration of tomato

Variety and population density showed significant ( $P \leq 0.05$ ) effect and highly significant ( $P < 0.01$ ) effect on harvest duration, respectively; while the effect of interaction and cropping system were not significant (Appendix Table 2).

The 50% population density significantly delayed (29.56) harvesting and the 75% population density hastened (25.11) (Table 3). This indicates that 50% population density gave more (extended) duration than population density as high as 75% and as low as 25% population. Variety AVT 001 was harvested earlier than the other two varieties. This variety might be more competent for light and other resources than the other two varieties.

Table 2. Mean effects of population density, varieties, cropping system and their interaction on plant height, primary branch number and days of first harvest of tomato

Population densities	Plant height (cm)	Number of primary branches per plant	Days to first harvest (days)
75%	60.89	5.67b	93.24
50%	65.00	7.56a	95.06
25%	61.56	5.31b	91.60
LSD (0.05)	NS	0.81	NS
Varieties			
AVT 001	66.44	6.20	95.46
AVT 540	62.00	6.19	93.08
AVT 7063	59.00	6.13	91.35
LSD (0.05)	NS	NS	NS
CV (%)	14.03	13.14	6.79
Cropping systems			
Intercropped	62.48	6.18	93.30
Sole	63.33	5.87	91.20
LSD (0.05)	NS	NS	NS
CV (%)	13.47	12.00	6.06

NS= not significant Means in a column followed by the same letters are not significantly different at  $p \leq 5\%$  level of significance

### Numbers of harvest of tomato fruit

The analysis of variance showed that population density had significant ( $P \leq 0.05$ ) effect on numbers of harvesting; however no significant effect due to varieties, cropping system and interaction effects (Appendix Table 2).

The 50% population density gave significantly highest (3.91) number of harvest than the 75% and 25% there was no significance difference between the two population densities, 75% and 25% (Table 3). This might be the interspecies competition at 50% population density was as low as 75% population density and the interspecies competition as high as 25% population density. At lower population density the inter-specific competition was less this might be presence of no effective utilization of available resources finally gave less fruit yield and numbers of harvesting frequency, at 75% population density the competition was higher as compared to 50%, and there might be scarcity of resources and shading effect. The present study was in line with Pal *et al.* (1993) revealed that the number of harvesting was increased with increasing population density, but it was up to certain population density and it starts to decline when population density increased beyond the available resources on a particular area. The absence of significant effect of varieties and cropping system indicates that any of the three varieties can be intercropped with tomato and intercropping does not affect number of harvest of tomato.

### Yield components and yields of tomato

#### Number of fruit per cluster of tomato

Analysis of variance showed that population density had highly significant ( $P \leq 0.01$ ) effect on number of fruit per cluster. However, unlike population density the varieties of African marigold, interaction and cropping system did not show significant effect (Appendix Table 3).

The highest (15.56) and lowest (8.23) number of fruit per cluster were recorded at 50% and 25% population density, respectively (Table 3). This might be the interspecies competition in intercropped African marigold at 50% population density was very positive. When the number of plants was less the inter species competition became low and non effective resources and space utilization might be exist. When population density increased from 50% to 75% the number of fruits per cluster reduced, this might be due to over plant population density on a given area. This result is supported by Ijoyah *et al.* (2015) who revealed that population density of okra significantly increased the number of egusi melon fruits per cluster, number of egusi melon seeds per fruit, weight of seeds per fruit and yield of egusi melon in okra-egusi melon intercropping. Planting of okra at the population density of 40,000 plants  $ha^{-1}$  (50%) significantly increased yield of egusi melon, compared to when okra was sown at the population density of 50,000 (67%) and 20,000 (25%) plants  $ha^{-1}$ .

Table 3. Mean effects of population density, varieties and cropping system on Harvest duration, Number of harvest, number of per Fruit cluster and Number of Fruits per plant

Population densities	Harvest duration (days)	Number of harvest	Number of Fruit per cluster	Number of fruits per plant
75%	25.11b	3.33b	9.65b	38.63b
50%	29.56a	3.91a	15.56a	45.89a
25%	25.56b	3.28b	8.23c	32.38c
LSD (0.05)	1.09	0.35	3.74	5.67
<b>Varieties</b>				
AVT 001	25.78b	3.47	11.94	37.60
AVT 540	27.56a	3.53	14.03	41.06
AVT 7063	26.89a	3.51	11.46	38.24
LSD (0.05)	1.096	NS	NS	NS
CV (%)	8.40	10.04	16.67	14.57
<b>Cropping systems</b>				
Intercropped	26.74	3.50	11.81	38.97
Sole	28.00	3.48	8.07	39.13
LSD (0.05)	NS	NS	NS	NS
CV (%)	8.30	11.70	12.46	11.00

NS= not significant Means in a column followed by the same letters are not significantly different at  $p \leq 5\%$  level of significance.

### Number of fruit per plant

Population density had highly significant ( $P \leq 0.001$ ) effect on number of fruit per cluster. However, unlike population density the varieties of African marigold, interaction and cropping system did not show significant effect on number of fruit cluster per plant (Appendix Table 3). This is in agreement with the experimental result of Abd El-Gaid *et al.* (2014), revealed that number of fruits plant<sup>-1</sup> may not significantly affected by tomato-common bean intercropping.

The 50% and 25% population density produced significantly highest (45.89) and lowest (32.38) number of fruit per plant, respectively (Table 3). This might be due to the highest number of primary branches per plant is obtained due to 50% population density those branches forced to produce more number of fruits per plant when the net assimilation rate was higher. This is supported by the results of Ijoyah *et al.* (2015) that population density of okra significantly increased the number of egusi melon fruits per plant, number of egusi melon seeds per fruit, weight of seeds per fruit and yield of egusi melon in okra-egusi melon intercropping, Planting of okra at the population density of 40,000 plants ha<sup>-1</sup> significantly increased yield of egusi melon, compared to when okra was sown at the population density of 50,000 plants ha<sup>-1</sup>. This result disagree with the findings of Tuan and Mao (2015) and Tesfaye (2008) who reported that fruit number per plant was significantly influenced by plant density but the low plant density resulting in significantly more fruit number as compared to high plant density.

Cropping system does not have significant effect on number of fruits per plant. These might be due to intercropping of African marigold protect tomato from different external factors like insect pests, frost and other environmental factors that results more number of fruit was produced. The reported results of Ijoyah *et al.* (2015) not supported this of which intercropping of okra with egusi melon increased the number of egusi melon fruits per plant, number of egusi melon seeds per fruit, weight of seeds per fruit and yield of egusi melon as compared to sole planting of egusi melon.

### Total fruit yield

This study indicated that population density showed highly significant ( $P < 0.01$ ) effect on total fruit yield of tomato. However, there was no significant difference due to variety, interaction and cropping system on total fruit yield (Appendix Table 3).

The highest (13.8 ton ha<sup>-1</sup>) and lowest (10.80 ton ha<sup>-1</sup>) total fruit yield was obtained from 50% and 25% population density, respectively (Table 4). This may due to almost all growth, yield related and yield of tomato were better at 50% population density as compared to others population density. There was no significant difference between 75% and 25% population density, at 75% interspecies competition might be higher and due to this the component crops exposed for shading effect, scarcity of available nutrients and soil moisture. Compound canopies of component crops that occur due to the presence high plant densities can maintain relative humidity within the canopy which is important in avoiding desiccation and makes good growth condition even during moisture deficit periods. Therefore intercropping composed of different patterns of canopy development and different maturation times can display a greater amount of leaf area over the course of the growing season and



intercept more total light energy than less plant densities (monocultures). The reported result of Balasubramaniyan and Palaniappan (2001) showed that there is negative effect of very high population density particularly in branching crops due to competition for sun light under dense situation. On the other hand at 25% there might be loss of moisture, fertilizer, nutrient and light interception might be also less with associated to less interspecific competition. Intercropping African marigold at 50% population density significantly increased tomato total fruit yield by 0.27% as compared to 25% population density of African marigold by 0.22%. This result was supported by Yayock (1979) that showed fruit yield of tomato was increased as population density increased, but after certain point it starts to decline its yield because the increasing of interspecific competition among the component crops (the demand crops for moisture, nutrient and solar radiation might be beyond the available resources on a given area) so it is better to know the optimum planting density among the component crops. This might be due to the rise of interspecific competition among the component crops. Plant density significantly affected the interspecific dynamics of the component crops in intercropping (Rena *et al.*, 2016 and Pal *et al.* 1993) as it is a major factor affecting the intercropping system of the component crops in terms of yield. This related to interspecific competition for soil moisture, nutrients, light and other common resources. This experiment showed that yields of component crops in the intercropping system vary significantly with the components population density. This result was disagreed with the reported results of Tesfaye (2008); Law-Ogbomo and Egharevba (2009) they reported that highest total fruit yield per hectare of tomato was obtained from low plant density than at high plant density (fruit yield of tomato was decreased with increased population density).

The cropping system showed no significant difference on fruit yield of tomato. This is in close agreement with Amin and Limbani (2007) that no significance difference was observed in cropping system of okra-cucumber intercropping. Though intercropping practices is done with the purpose of creating a system with higher combined yield that could benefit the farmers and enhance crop diversity as well as reduce total crop failure due to pest, disease. Intercropping of African marigold under tomato is better for farmers because they can be obtained a good fruit yield of tomato than planting alone. Because it protects tomato from different external environmental factors, it also activates and helps for efficient utilization of resources, it became more productive. The smaller yield loss of tomato under intercropping of African marigold could be due presence of African marigold.

Table 4. Mean effects of population density and varieties of African marigold intercropping on fruit weight, marketable fruit yield and unmarketable of tomato

Population density	Total fruit yield (ton ha <sup>-1</sup> )	Marketable fruit yield (ton ha <sup>-1</sup> )	Unmarketable fruit yield (ton ha <sup>-1</sup> )
75%	11.75b	9.90b	1.85b
50%	13.80a	13.11a	0.69c
25%	10.80b	7.56c	3.24a
LSD P (0.05)	1.79	1.49	0.34
Varieties			
AVT 001	11.41	10.39	1.02
AVT 540	12.00	10.33	1.67
AVT 7063	12.19	9.83	2.36
LSD P (0.05)	NS	NS	NS
CV (%)	7.38	11.18	10.51
Cropping system			
Intercropped	11.99	10.19a	1.80b
Sole	10.93	6.56b	4.37a
LSD (0.05)	NS	3.38	1.49
CV (%)	12.27	7.54	8.11

LSD (0.05) =least significance difference at probability level of 5%, AVT=AV Tomas the name of the company, NS= non significance difference, Means in a column followed by the same letters are not significantly different at p≤5% level of significance; Where, CV= coefficient of variation,

### Marketable fruit yield

The marketable fruit yield of tomato was highly ( $P \leq 0.001$ ) affected by population densities and significantly by cropping system ( $P \leq 0.05$ ) but not by African marigold varieties and interaction effect (Appendix Table 4). The 50% and 25% population density gave significantly the highest (13.11 ton ha<sup>-1</sup>) and lowest 7.56ton ha<sup>-1</sup>) marketable fruit yield, respectively. The yield of tomato increased with African marigold population increased from 25% to 50% and then decreased to 75% of population densities (Table 4). This indicates that the 50% population density gave best marketable fruit yield than 25% and 75% population densities. This may due to almost all yields related parameter and yield of tomato were best and highest at 50% population density as compared to other population densities of African marigold.

The highest marketable fruit yield of tomato was due to intercropping (10.19 ton ha<sup>-1</sup>) than sole cropping

system (6.56 ton ha<sup>-1</sup>) (Table 4). This might be the presence and absence of African marigold in intercropped and sole cropping tomato. Because intercropping of African marigold serves as a trap crop and act as a physical barrier against different environmental factors and insect pest that attacks tomato fruits. It is supported by the experimental results of Hussain and Bilal (2007) reported the highest and lowest marketable fruit yield was observed in tomato-marigold intercropping and sole of tomato, respectively. The research of Wozniak and Wach (2011) is not similar with this experimental result in which intercropping carrot and parsley with marigold reduced the yield of both crops. The current study is also supported by (Koocheki *et al.*, 2008 ; Gomez Rodriguez *et al.*, 2003 ; Zavaleta-Mejía and Gomez, 1995) they reported that, intercropped tomato with African marigold, marigold plants serves as a physical barrier and promoted reductions in the maximum relative humidity surrounding the canopy, but to a lesser extent than marigold, it also altering the microclimatic conditions around the canopy, particularly by reducing the number of hours per day with relative humidity > 92%, thus diminishing conidial development. The most common advantage of intercropping is to produce a higher yield from a given piece of land by achieving more efficient use of the available natural resources for crop growth that would otherwise not be utilized by each single crop grown alone (Lithourgidis *et al.*, 2011). Therefore, in terms of land use efficiency intercropping is regarded as more productive than sole cropping (Andrews and Kassam, 1976). Higher nutrient uptake and better water use efficiency have also been present. Better use of solar radiation by intercrops was attributed to increased interception of photo synthetically active radiation resulting in higher radiation use efficiency.

### **Unmarketable fruit yield**

Unmarketable fruit yield of tomato was highly ( $P \leq 0.01$ ) affected by the population densities of African marigold and cropping system, but not by the varieties of African marigold and interaction effects (Appendix Table 4). The highest (3.24 ton ha<sup>-1</sup>) unmarketable fruit yield was obtained at 25% population density while the lowest (0.69 ton ha<sup>-1</sup>) was recorded from 50% population density (Table 4). The increased population density from 25% to 50%, decreased the unmarketable fruit yield of tomato. This might be the ornamental nature of African marigold enables to prevent the yield loss of tomato fruit from extraneous factor like insect pests when intercropped it with 50% population density of African marigold.

In cropping system the highest (4.37 ton ha<sup>-1</sup>) and lowest (1.80 ton ha<sup>-1</sup>) unmarketable fruit yield was obtained from sole cropping and intercropping of tomato, respectively. This indicates that intercropping of marigold might have reduced the unmarketable fruit yield of tomato by serving as a trap crop for different pests that affect the marketable value of tomato. Improved productivity per unit incident radiation could be also achieved by the adoption of an intercropping system that either increase the interception of solar radiation and/or had greater radiation use efficiency. The findings of Francis (1986) and Ramakrishna and Ong (1994) they stated that the ability of intercrops to intensify resource use both in space and time dimension makes greater total use of available growth resources than mono cropping. Intercropping increased the amount of solar radiation intercepted due to faster canopy cover, which lead to efficient utilization of light resources. Keating and Carberry (1993) also stated that intercropping offers the advantage of efficient interception and utilization of solar radiation than mono cropping. This study agreed with that of Hussain and Bilal (2007) that the highest fruit damaged was from sole cropping of tomato as compared to tomato-marigold intercropping. Similar Jankowska *et al.* (2012) that the highest unmarketable yield of carrot was obtained from sole cropping but the lowest from carrot-marigold intercropping. Because intercropping of marigold with carrot enables to protect insect pests and other soil born nematodes by its flower and root system, respectively.

### **Productivity of Tomato-African marigold Intercropping**

The productivity of intercropping was evaluated using the partial and total LERs as induces.

#### **Partial land equivalent ratio**

The analysis of variance showed that partial LER of tomato highly ( $P \leq 0.01$ ) affected by population density, but varieties and interaction were not significantly affected (Appendix Table 7). The highest partial LER (0.84) of tomato was due to 50% population density, but no significant in between 75% and 25% population density (Table.7). Over all, partial LER of tomato increased as African marigold population density increased from 25% to 50% population density then decreased to 75% and 25% population density. This was probably the highest and lowest of inter-species competition due to 75% and 25% population density, respectively. Similarly Ijoyah *et al.* (2015) revealed that intercropping of okra with egusi melon land equivalent ratio was increased as population density of okra increased up to a certain point. The findings of Ram and Singh (2010) showed that the land equivalent ratio of tomato was significantly higher at 50% population density than 25% and 75% population densities in tomato -coriander intercropping. The reported result of Abidin *et al.* (1989) agree to the current study who reported that the highest LER value of tomato was obtained due to 50% population density than 75% and 100% in tomato-lettuce intercropping.

The partial LER of African marigold was not significantly affected by population densities, the varieties and their interaction effects (Appendix Table 4). The intercropped tomato yielded the 61% to 69% and 54% to 84% of its sole crop yield in terms of African marigold varieties and population densities, respectively. This showed that intercropping was an advantageous as compared to sole cropping of either of the component crops as depicted by total LER values above one indicated complementarily in resource utilization by the component crops. In addition, African marigold varieties yielded the 55% to 64% of their sole crop yield, while 55% to 61% of their sole crop yield was obtained due to African marigold population densities. This study is not similar with the finding of Modal *et al.* (2018) and Verma *et al.* (2011) that the partial land equivalent ratio of balsam and rose-scented geranium (*Pelargonium geraviolence* L.) were significantly affected by population density of cauliflower in cauliflower-balsam and geranium-cauliflower intercropping system respectively. Furthermore, the partial LER of tomato and African marigold were higher than 0.5 in all varieties and population density indicating that there was an advantage for both crops in these intercropping systems. But comparing the two partial LER values of the two combined crops, partial LER of tomato was higher than partial LER of African marigold in all cropping systems. Thus, the results ascertain that tomato were the major contributor to the mixture yield which also confirms the presence of greater competitive capacity of tomato against African marigold. This study was similar with Hailu *et al.* (2015) reported that the partial land equivalent ratio of tomato was higher than the partial land equivalent of maize in tomato/maize intercropping. Besides, tomato had a relatively larger upper canopy structures and the roots grow into larger area compared to African marigold.

### Total land equivalent ratio

The analysis of variance showed that population density highly ( $P \leq 0.01$ ) and variety and their interaction did not significantly affect LER (Appendix Table 4).

Total LER in all cases was more than unity (Table 5) indicating that intercropping of African marigold with tomato is advantageous than sole cropping of tomato. However, varieties and the interaction effect did not show significant variation on total LER (Appendix Table.4). Though varieties of African marigold were statistically no significant higher total LER (1.28) was obtained due to variety AVT 540 (Table 5). The highest total LER (1.43) was recorded when African marigold was planted at 50% population density of its sole and the lowest LER (1.13) due to 75%. There was no significant difference between 75% and 25% population density (Table 5). These values indicated that intercropping gave a 43% and 13% yield advantages than sole planting. These experiment was similar with result of Pareshbal and Patel (2016) reported that the highest total LER from 50% population density of marigold (Jasmine + French marigold) followed by (Jasmine + African marigold). It is also supported by Gawade *et al.* (2003); Lakshminarayanan *et al.* (2005); Rahman *et al.* 2006 and Thankamani *et al.* (2011). The yield advantage could be due to a possible efficient utilization of growth resources by the intercropped crops or the intercropping advantages of weed reduction and increased light use efficiency (Willey, 1985). However, it is obvious that the optimum plant density could be achieved at certain points; to this effect optimum plant density was achieved at 50% of the sole population density of African marigold.

Table 5. Mean effects of population density, variety of African marigold and interaction effects on partial land equivalent ratio of tomato and African marigold, total land equivalent ratio and monetary advantage index of the component crops.

Population densities	Partial LER of Tomato	Partial LER of African marigold	Total LER	Monitory advantage index (ETB ha <sup>-1</sup> )
75%	0.58b	0.55	1.13b	28,732b
50%	0.84a	0.58	1.43a	37,225a
25%	0.54b	0.52	1.15b	16,011c
LSD (0.05)	0.11	NS	0.15	8,140
Varieties				
AVT 001	0.69	0.55	1.25	22,056
AVT 540	0.63	0.64	1.28	24,304
AVT 7063	0.61	0.52	1.19	17,608
LSD (0.05)	NS	NS	NS	NS
CV (%)	7.31	14.47	13.23	12.05

Where, MAI= monitory advantage index, LER= land equivalent ratio, AVT= Av Tomas (the name of the company), CV= coefficient of variation, LSD= least significance differences among treatments, NS= non significance difference.

### Monetary advantage index

Monetary advantage index (MAI) was used to evaluate economic feasibility of intercropping in terms of increased value per unit area of land. The analysis of variance showed that the population density highly ( $P \leq 0.01$ ) affected the MAI and had no significant effect by varieties of African marigold and interaction population density MAI

(Appendix Table 5). However variety and interaction on the other hand did not show significant effect on MAI (Appendix Table 4). Monetary advantage of intercropping was indicated that there is no different between population density and varieties of African marigold.

The highest (ETB 37,225 ha<sup>-1</sup>) and lowest (ETB 16,011ha<sup>-1</sup>) MAI was obtained due to 50% and 25% population density, respectively (Table 4). The 75% and 50% population density gave significantly the equally monetary advantage; this indicates that either of them can be used. Similarly, Kumar and Patra (2000) and Rao *et al.* (2000); Chellaiah *et al.* (2002); Verma *et al.* (2009) and Rao Rajeswara (2002) they reported that intercropping of vegetables with medicinal aromatic crops based cropping systems with their highest population density in north and south India has shown that farmers gain significantly higher profit from their lands.

## SUMMARY AND CONCLUSION

Tomato is among the most important vegetable crops in Ethiopia. Its production in intercropping with African marigold in Ethiopia has not been reported as compared to other crops before in our country. Intercropping of African marigold within the row of tomato is the best way of introducing and increasing the production and productivity of African marigold in Ethiopia. Different researchers have indicated that planting marigolds between tomatoes protects the tomato plants from harmful root-knot nematodes in the soil, fruit borers and insect pests. African marigold cultivation has become one of the priority aromatic medicinal crop under the program of aromatic and medicinal plants (AMPs) at Wondo Genet Agricultural Research Center (WGARC). Tomato and African marigold intercropping could increase income of smallholder farmers and promote production of African marigold at Wondo Genet area of Southern Ethiopia, through enhancing efficient utilization of land.

Field experiment was conducted at WGARC in 2017/18 cropping season, to assess effect of plant densities of intercropped African marigold varieties on yield related traits and yield of the associated crops and to evaluate the productivity and economic value of tomato and African marigold intercropping system.

The experiment consists of tomato variety “Melkashola”, three African marigold varieties (AVT 001, AVT 540 and AVT 7063), three population densities of African marigold (25%, 50% and 75%) and sole of the three African marigold varieties and tomato. Randomize complete block design in factorial arrangement with three replications was used.

Data collected for tomato were: on phenology and growth parameters of tomato, fruit cluster per plant, number of harvest, fruit yield, marketable fruit yield and unmarketable fruit yield of tomato. Plant height, days to 50% flowering, days to physiological maturity and days to first harvest of tomato were not significantly affected by varieties of African marigold, population densities, interaction. Variety AVT 540 significantly delayed (27.56 days) harvest duration of tomato to as compared to other varieties.

Population densities of African marigold significantly affected harvest duration (HD), numbers of harvest (NH), number of fruit per cluster (NFPC), numbers of fruit per plant (NFPP), and total fruit yield (TFY), marketable fruit yield (MFY) and unmarketable fruit yield (UFY) of tomato. The 50% Population density delayed HD (29.56 days) as compared to other population densities. The highest (3.91) and lowest (3.28) NH were due to 50% and 25% population density respectively. Highest (45.89) and lowest (32.38) NFPP were obtained from 50% and 25% population density respectively, and highest (15.56) and lowest (8.23) NFPC were also obtained from 50% and 25% population density of African marigold respectively. The highest TFY (13.80 ton ha<sup>-1</sup>) and lowest (10.80 ton ha<sup>-1</sup>) of TFY, the highest (13.11 ton ha<sup>-1</sup>) and lowest (7.56 ton ha<sup>-1</sup>) MFY were obtained from 50% and 25% population density of African marigold respectively, but the highest (3.24 ton ha<sup>-1</sup>) and lowest (0.69) UFY were obtained from 25% and 50% population densities respectively. Cropping system was showed non significant effect except marketable and unmarketable fruit yield of tomato, the highest (10.19 ton ha<sup>-1</sup>) and lowest (6.56 ton ha<sup>-1</sup>) MFY and the lowest (1.67 ton ha<sup>-1</sup>) and highest (4.37 ton ha<sup>-1</sup>) of UFY were due to intercropped and sole of tomato respectively.

Varieties of African marigold had non-significant effect on partial land equivalent ratio (LER) of both tomato and African marigold, and total LER. Population density was non-significantly affected the partial LER of African marigold. The highest (0.84) partial LER of tomato and total LER (1.43) were recorded from 50% population density. Intercropping of tomato with African marigold had a total LER value greater than 1 this showed the advantage of intercropping over sole cropping. Partial LER of tomato, total LER and monetary advantage index were significantly affected by population densities. The varieties were also non-significantly affected the monetary advantage index (MAI). The highest value of MAI (37,225 ton ha<sup>-1</sup>) was due to 50% population density. Intercropping of the two component crops at 50% population density of African marigold gave LER values of 1.43 and MAI of 37,225 ETB ha<sup>-1</sup>. Therefore, African marigold with a density of 41,666.67 plants ha<sup>-1</sup> and at a spacing of 48 cm x 50 cm could be recommended for intercropping with tomato 45 days after tomato planting in the target area, based on its better compatibility, productivity and economic benefit.

Therefore, intercropping of African marigold varieties at 50% population density with tomato gave effective land utilization efficiency and more profitability. Since intercropping adds extra income and warrants insurance against a risk to the farmers, intercropping of tomato component was found to be advantageous than single

cropping of tomato as there is a scarcity of land and a need to diversify production. Therefore, the inclusion of any of the three varieties of African marigold under tomato intercropping scheme raised yield advantage of intercropping over the single crop per year as revealed by the highest total LER and monetary advantage index.

Farmers can achieve greater benefit from their land by growing the main crop (Tomato) and in association with an increased plant population of the African marigold, which maintains at least 50% of the sole stand. Hence, Tomato/African marigold intercropping could increase incomes obtained by smallholder farmers at Wondo Genet area of Southern Ethiopia, through enhancing efficient utilization of land. Therefore, any of the three African marigold varieties at 50% population density could be recommended for intercropping with tomato

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## APPENDICES

Appendix Table 1. Mean square values of ANOVA for Phenology and growth parameter as affected by population density, varieties and cropping system

Sources of variation	DF	Plant height	Number of primary branches	Days to 50% flowering	Days to physiological maturity
Rep	2	12.48	0.06	70.78	169.44
VAR	2	126.259ns	0.0123ns	33.33ns	69.44ns
PD	2	43.81ns	13.141***	10.33ns	175.00ns
PD*VAR	4	67.81ns	0.403ns	22.67ns	177.78ns
Error	16	76.90	0.66	38.69ns	129.86ns
CV (%)		14.03	13.14	12.67	12.98
Rep	2	22.53ns	0.27ns	55.23ns	130.33ns
CS	1	63.56ns	0.90ns	116.03	213.33ns
Error	2	71.94	0.42	33.11	131.60
CV (%)		13.47	12.00	11.56	12.94

\*, \*\*, \*\*\* significant at  $P \leq 0.05$ ,  $p \leq 0.01$  and  $p \leq 0.001$  probability levels respectively; ns= not significant difference; Rep= replication; VAR= variety; PD= population density; CS= cropping system; CV= coefficient of variation; SOV= Source of variations; DF= degree of freedom.

Appendix Table 2. Mean square values of ANOVA for days to first harvest, Number of harvest and Harvest duration as affected by population density, varieties and cropping system

SOV	DF	Days to first harvest	Number of harvest	Harvest duration
Rep	2	152.29	0.11	1.037
VAR	2	38.339ns	0.0133ns	7.259*
PD	2	27.064ns	1.0844*	53.93**
PD*VAR	4	8.593ns	0.1244ns	2.37ns
Error	16	40.182	0.1244	5.35
CV (%)		6.79	10.04	8.40
Rep	2	142.085ns	0.028ns	2.53ns
CS	1	11.95ns	2.225ns	0.73ns
Error	2	31.90	0.18	5.22
CV (%)		6.06	11.70	8.30

Appendix Table 3. Mean square values of ANOVA for number of per fruit cluster, number of fruit per plant, fruit weight ton per hectare by population density, varieties and cropping system on tomato

Source of variation	Degree of freedom	Number of Fruit cluster	Number of fruit per plant	Fruit weight ton per hectare
Rep	2	18.98	124.448	2.574
VAR	2	16.69ns	30.388ns	1.48ns
PD	2	453.38***	411.488**	25.32**
PD*VAR	4	24.814ns	85.342ns	2.55ns
Error	16	14.04	12.21	3.24
CV (%)		16.67	14.57	10.16
Rep	2	16.208ns	64.83	0.97
CS	1	51.00ns	204.02ns	2.35ns
Error	2	16.63	66.54	4.87
CV (%)		12.46	11.00	8.74

Appendix Table 4. Mean square values of ANOVA on Marketable fruit yield and Unmarketable fruit yield by population density, varieties and cropping system on tomato

SOV	Degree of freedom	Marketable fruit yield	Unmarketable fruit yield
Rep	2	3.00	0.016
VAR	2	0.84ns	0.1085ns
PD	2	69.93***	16.86***
PD*VAR	4	360.99ns	0.076ns
Error	16	2.25	0.118
CV (%)		11.18	10.51
Rep	2	1.71ns	11.90ns
CS	1	35.59*	105.76***
Error	2	7.32	1.428
CV (%)		7.54	8.11

\*, \*\*, \*\*\* significant at  $P \leq 0.05$ ,  $p \leq 0.01$  and  $p \leq 0.001$  probability levels respectively; ns= not significant difference; Rep= replication; VAR= variety; PD= population density; CS= cropping system; CV= coefficient of variation; SOV= Source of variations; DF= degree of freedom.