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Evaluating Agronomic and Essential Oil of African Marigold (*Tagetes erecta* L.) Varieties Intercropping with Tomato by Its Population Density at Wondo Genet, Southern Ethiopia

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Abstract: Intercropping of African 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 the associated crops 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 'Melk shola'. 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. The varieties of AFM significantly affected plant (PH), essential oil content (EOC) and essential oil yield (EOY). The tallest plant (55.36 cm) of AFM was due to AVT 001 than other varieties. Variety AVT 540 gave the highest EOC (0.21) and EOY (7.55 kg ha^{-1}) than other two varieties. Sole planted African marigold produced significantly higher (55.73) number of fresh flowers per plant than the intercropped (50.04). Cropping system was significantly affected number of branch (NBPP) and number of fresh flowers per plant (NFFPP). The highest NBPP (24.91) and NFFPP (55.73) were obtained from sole planting of AFM. The highest NBPP (23.15) and NFFPP (50.07) were recorded from 50% PD. of AFM. The highest fresh flower yield (45,860 kg ha^{-1}), dry flower weight per hectare (5,360 kg ha^{-1}), EOC (0.17) and EOY (9.36 kg ha^{-1}) were due to 75% PD. 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^{-1}) was due to 50% PD. Therefore, any of the three African marigold varieties at 50% PD could be recommended for intercropping with tomato.

Keywords: African Marigold, Cropping System, Essential Oil Yield, Population Density

1. Introduction

African marigold, though its name suggests its origin from Africa, had its origin in Mexico and in British society. Marigold is native of central and South America especially Mexico it is also cultivated in Australia and Kenya [25] Marigolds belong to the family Asteraceae (Compositae) and the genus *Tagetes*. African marigold (*Tagetes erecta* L.) [42]. The common cultivated varieties are 'Guinea Gold', 'Apricot', 'Primrose', 'Sun Giant', 'Fiesta', 'Golden yellow', 'Glitters', Happiness', 'Hawai', 'Crown of Gold', 'Honeycomb' and 'Cerpid'. In India, marigold ranks first among the commercial loose flowers followed by Chrysanthemum, Jasmine, Tuberose, Crossanda and Barleria alone occupies 6725 hectares with an annual production of 64,025 tones [37]. African and French marigolds are more widely cultivated as compared to other species. Marigolds, in general, require a mild climate between elevations of 700 - 1500 m, but it can also grow up to 2500 meter above sea level. They perform well on well drained rich Loam or sandy loam soils [32]

Marigold is one of the easiest annual flowers to cultivate, having wide adaptability. Flowers are attractive, have good keeping quality with a wide spectrum of colour, shape and size. Marigold can be raised thrice a year- rainy, winter and summer seasons. They produce marketable flowers in a short time [22].

Tomato (*Solanum lycoperisicum* L.) 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 [32, 9]. Its use as a food originated in Mexico and spread throughout the world following the Spanish colonization of the Americas [10]. 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 [10]. 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) [41]. 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 [30]. The total area increased to 833 hectares 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 [11]. 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 [11]. 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 [19]. 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 [30]. It is used as canned vegetable having multiple uses and supplies an essential nutrient in human diets [9]. 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 [27].

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* L.*)* 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 marigolds are African marigold and French marigold [36].

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 [42]. *Tagetes minuta* L., commonly known as African marigold, is a highly aromatic annual perennial herb growing. It is cultivated for '*Tagetes* oil' [42]. *Tagetes minutia* s used in indigenous medicines as a natural source of raw material due to its anti-microbial, anti-inflammatory, anti-fungal and insecticidal and acaricidal activities [8, 43].

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. Marigold repels nematodes, tomato worm, slugs and general garden pests. [20] found that intercropping of tomato with African marigold (*Tagetes erecta* L.) reduced early blight (*Alternaria solani*) of tomato in three ways: (1) allelopathic effect on *Alternaria solani* development, (2) reduced humidity levels below those conducive to the pathogen requirement, and (3) behaved as a physical barrier against spore dispersal [20, 49]. Intercropping marigold for nematode management also appeared to reduce numbers of aphids and whiteflies, and resulted in lower levels of virus in tomato [49].

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. The varieties were well adapted and two of them gave better yield than in India [5].

African marigold cultivation has been become one of the priority aromatic medicinal crops under the program of aromatic and medicinal plants (AMPs). Related to this WGARC have been conducting research activities in agronomy and other fields to get better flower yield, essential oil content and essential oil yield on the three varieties of African marigold. The growing demand for vegetables of high quality and likely to be found year-round in the market has contributed to investments in new cropping systems that permit the production of the vegetables in different regions, as well as under adverse environmental conditions. However, is not the only concern with productivity and the quality of the desired product, but also with the way to achieve it [16]. 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 [17]. Intercropping might positively impact on the future food problems in developing countries [16]. 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 (*Tagetes 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:

1) to assess effect of plant densities of intercropped African marigold varieties on yield related traits and yield of the associated crops; and
2) to evaluate the productivity and economic value of tomato and African marigold intercropping system.

2. Materials and Methods

2.1. 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 [13]. The soil type of the experimental area is *Nitosols* and it has a textural class of sandy clay loam with pH of 6.4 [1]. The center has a national mandate to conduct researches on medicinal and aromatic plants (MAPs).

2.2. 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^{-1} at research and 5.5-6.5-ton ha^{-1} at farmer's field (Lemma, 2002).

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 [5].

2.3. 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^{-1}, three plant densities of African marigold (*Tagetes erecta* L.) 25% (20,833.333 plants ha^{-1}), 50% (41,666.67 plants ha^{-1}) and 75% (62,500 plants ha^{-1}) and the sole planting of marigold was 83,333.333ha^{-1}.

Table 1. *Description of the Treatments.*

Trts.	A. mariglod spacing		Varieties of A. mariglod	A. marigold	Remark
	Intra-row spacing (cm)	Inter-row spacing (cm)		PD/ha	
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

Trts.	A. mariglod spacing		Varieties of A. mariglod	A. marigold	Remark
	Intra-row spacing (cm)	Inter-row spacing (cm)		PD/ha	
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^{-1} were also maintained for tomatoes in both intercropping and sole cropping.

2.4. Experimental Procedures and Field Management

2.4.1. 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 filed. 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.

2.4.2. 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 both tomato and African marigold was 1.8 m; therefore, the gross plot of tomato was 10.8m^2 (1.8 m x 6 m). The gross plot area of sole African marigold was 6.84m^2 (4.8 m x 1.8 m). The net plot area for sole and intercrop tomato was 7.5 m^2 (1.5 m x 5 m) while, for sole and intercrop marigold were 6.6 m^2 (1.5 m x 4.4 m) and 6 m^2 (1.5 m x 4 m), respectively. This experiment field had a total area of 41.4 m x 21 m (869.4 m^2). The data was taken from the central rows for both tomato and marigold 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^{-1} African marigold was used. Uniform populations of 33,333 plants ha^{-1} were 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.

2.4.3. Fertilizer Application Rates and Other Agronomic Practices

A light irrigation or watering with rose cane was applied for both crops after transplanting. 150 kg N ha^{-1} fertilizer and 90 kg DAP ha^{-1} was applied. Of 150 kg N ha^{-1}, half of it was applied after 8 days of African marigold transplanting and the other half after 58 days after transplanting, but the whole amount of DAP applied after 8 days of African marigold transplanting [4]. Weeding was also done as necessary, one month after transplanting of the seedlings of African marigold and pinching was followed for bushy growth of the plant and development of lateral branches. Pinching is generally done within 40 days after transplanting.

Inorganic fertilizers, urea (in the form of N) and DAP fertilizer were applied at the rate of 100 kg ha^{-1} and 92 kgh^{-1}, respectively on tomato [15]. 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.

2.4.4. Harvesting of Flowers

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 field should be irrigated before plucking and the flowers were collected in polythene bags. Flowers were harvested in the morning hours. Irrigation before harvesting gives better flower quality. The fruit of tomato was also harvested after 3 months.

2.5. Data Collection and Measurements

2.5.1. African Marigold Component

Plant height (cm): measured from the soil surface to the tip of the start of flowering (flower excluded) of 5 randomly taken plants from the net plot area.

Branches number/plant: the number of branches per plant was counted at time of data collection (at the time of physiological maturity) of 5 random plants.

Number of fresh flower ($plant^{-1}$): based on the number of flowers of five random plants per net plot was calculated. The number of fresh flowers per plant was counted at the time of harvesting the flower of African marigold.

Fresh flowers yield ($kg\ ha^{-1}$): weight of collected flowers by using sensitive balance, and then converted to hectare. It was calculated from flowers yield from net plot.

Dry flower weight ($kg\ ha^{-1}$); weight of flower was measured from the net plot after drying the fresh flower. Then it was converted in to kilo gram per hectare ($kg\ ha^{-1}$). The flower was dried in oven for 3 hours at the temperature of 105°C in the laboratory [12].

Essential oil (EO) content (%): was extracted from dry weight (w/w) basis from 200 g of dry flower yield, we used composite 200g sample of dried flower to extract the essential oil content [12]. The laboratory analysis for African marigold essential oil content was extracted by hydro-distillation as illustrated by [21] at WGARC. The essential oil content was just extracted and read by hydro-distillation (HPLC).

Essential oil yield ($kg\ ha^{-1}$): the essential oil yield was obtained by hydro-distillation, according to the procedure described by [21]. The flower of African marigold having biomass of 200 g/composite sample was charged in the Clevenger apparatus along with 700 ml of water trapped for 3 hours [12], then essential oil yield/hectare; was calculated from essential oil yield per plant and obtained from dry based and as;

$$\text{Essential oil yield (kg ha}^{-1}\text{)} = \frac{\text{Essential oil content (\%)x dry flower weight (kg ha}-1\text{)}}{100}$$

2.5.2. System Productivity

(i). 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 $= \frac{YTi}{YTs}$; where YTi= intercropped yield of tomato and YTs = 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 $= \frac{YAFMi}{YAFMs}$ where YAFMi = intercropped yield of African marigold and YAFMs = sole cropped of African marigold.

The LER was calculated using the formula LER= Σ (Ypi/Ymi) (where Ypi is the yield of each crop in the intercrop, and Yms is the yield of each crop in the sole crop.

So, in this study the LER was calculated as,

$$\text{LER} = \frac{YTi}{YTs} + \frac{YAmi}{YAms}$$ (from the sole crop the actual yield was used from the three varieties)

Where

YTi = Yield per unit area of tomato intercrop (net plot area of intercropped tomato)

YTs = Yield per unit area of tomato sole (net plot area of sole tomato)

YAmi = Yield per unit area of AFM in intercropping (net plot area of intercropped AFM)

YAms = Yield per unit area of African marigold sole (net plot area of sole AFM)

(ii). Monetary Advantage Index (MAI)

First the Gross monetary value (GMV) was calculated as; Yield of component crops × respective market price; i.e., (yield of tomato x price of tomato + yield of African marigold x price of African marigold) [47].

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 ($kg\ ha^{-1}$). 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. It was expressed as MAI= (Pab+Pba) * (LER-1)/LER Where, Pab = Pa ×Yab; Pba =Pb ×Yba; Pa = Price of tomato and Pb = 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^{-1}).

2.6. 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, Yijk = μ + αi + βj + ϒk + αϒik + εijk. Where, Yijk = the value of the response variable; μ = Common mean effect; αi = Effect of Population density; βj = Effect of block; ϒk = Effect of varieties; αϒik = Interaction effect of population density & varieties; and εijk = Experiment error.

For cropping system Yij=μ + αi + βj + ϒk + εij, where Yij= the value of the response variable; Common mean effect; αi = Effect of intercropped; βj = Effect of bock and ϒk = Effect of sole cropping.

3. Results and Discussion

3.1. The Result Data of African Marigold

3.1.1. Growth Response of African Marigold

(i). Plant Height

The variety showed significant (P≤0.05) effect on plant height of African marigold in marigold-tomato intercropping. However, population densities, interaction and cropping system were found non-significant (Table 5).

The tallest (55.36 cm) and shortest (44.80cm) plant height of African marigold was from AVT 001 and AVT 540, respectively. There was no significant difference between variety AVT 540 and AVT 7063 (Table 2). This might be due to AVT 001 affected by intteraspesfic competition, but the other two varieties (AVT 540 and AVT 7063) might be equally computing each other for resources like sun light. The interspesfic competition among tomato and two varieties of African marigold might be positive and no shading effect but, the one variety which gave tallest plant might have a shading effect due to tomato.

Population density and interaction effect of population density of taro variety had no significant effect on plant height. According to Ghanbari and Lee [31] claimed that plant height of mint was significantly affected by different plant density and according to Pareshbhai and Patel [37] which revealed that cropping system showed differences on plant height in jasmine-African marigold intercropping. This might be the presence of interspecies competition among the component crops.

(ii). Number of Branches Per plant

Branch number of African marigold was not significantly affected by variety and interaction effect. Population density and cropping system were significantly (P≤ 0.05) affected branch number of marigold (Table 5). The highest (23.16) and lowest (18.29) number of branches per plant was obtained from 50% and 75% population densities of African marigold (Table 2). Similar to tomato the interspesfic competition at 50% might be positive. This helps the component crops to use nutrients, applied fertilizers, soil moisture and solar radiation effectively. If the light interception capacity may be effective the net assimilation rate of the crops might be high and more biomass produced.

The cropping system showed a significant difference on branch number. According to the present study, branch number in sole cropping (24.91) higher than that of under intercropped one (21.13) (Table 2). This might be the presence of shading effect of tomato that might have reduced the light requirement of the intercropped marigold. This is confirmed by the reported result of Desalegn *et al* [14] that highest numbers of branches were recorded from sole of African marigold.

Table 2. *Mean effects of intercropping different population densities and varieties of African marigold on plant height, number of branches, and number of fresh flower per plant, Fresh flower yield of African marigold.*

Population densities	Plant height (cm)	Number of branches per plant	Number of fresh flower per plant	Fresh flower yield (kg ha^{-1})
75%	52.42	18.29b	42.35b	45,860a
50%	50.87	23.16a	50.07a	39,180b
25%	50.33	21.96ab	38.76b	19,040c
LSD (0.05)	NS	2.46	6.26	6.03
Varieties				
AVT001	55.36a	20.311	42.80	34,716
AVT540	47.80b	21.044	46.067	37,375
AVT7063	50.47b	22.044	42.327	31,982
LSD (0.05)	3.82	NS	NS	NS
CV (%)	7.5	11.01	14.33	17.38
Cropping system				
Intercropping	51.207	21.13b	50.04b	33,330
Sole	48.29	24.91a	55.73a	36,420
LSD (0.05)	NS	3.29	4.31	NS
CV (%)	8	17.05	10.21	12.56

Mean followed by the same letter with the same column are statistically non-significant at p<0.05 according to the least significant difference (LSD) test at P<0.05;

3.1.2. Yields Related Traits and Yield of African Marigold

(i). Number of Flowers Per Plant

Analysis of variance showed that population density highly (P<0.01) and cropping system significantly (P≤0.05) affected number of flowers per plant of African marigold. However varieties and interaction had no significant effect (Table 5).

The highest (50.07) and lowest (38.76) numbers of flower per plant were recorded at 50% and 25% population density, respectively. There was no significant different between 75% and 25% population density (Table 2). This indicates that the 50% population density higher yield as compared 75% and 25% population density. These might due to the highest number branches per plant was obtained due to 50% population density as we discussed in earlier. At this population density the interspesfic competition might enables to effective utilizations of resources and high net assimilation rate might be also produced. The sole planting produced significantly the higher (55.73) number of flowers per plant than intercropped (50.04) indicating the advantage of sole over intercropped (Table 2). The reason for low number of flowers due to intercropping might be due presence of interspesfic competition and the higher number of flowers per plant related high plant population. This also might be due to absence of interspesfic competition in sole cropping. Reduction in number of flowers due to intercropping was also reported by Pareshbhai and Patel [37] who found that the overall highest number of flowers/plants were remarkably greater in sole African marigold cropping system as compared to intercropped with jasmine and parsley.

(ii). Fresh Flower Weight Per Hectare

Fresh flower weight per hectare was highly (P≤0.01) affected by population density, but variety, interaction and cropping system was not significant (Table 6).

The highest (45,860 kg ha^{-1}) and lowest (19,040 kg ha^{-1}) fresh flower weight per hectare were due to 75% and 25% population density respectively (Table 3). The weight increased as population density increased. This might be the presence high plant population density per area of land at 75% population density and less plant density at 25%, more flower yield obtained treatments which had plant population as compared others plant density. This is true if and only if the competition at the highest plant densities was positive and had no effect on flower yield reduction of African marigold. Rather enables for proper utilization of soil moisture, nutrients and solar radiation by the plants which resulted in more leaf growth per plant leading to higher flower yield, the highest flower yield was obtained from the highest population density [31, 46, 6]. They revealed that population density significantly influenced the fresh flower weight per hectare of *Calendula officinalis* L.

(iii). Dry Flower Weight

Dry flower weight was highly (P≤0.01) affected by the population density (Table 6) but variety, interaction and cropping system do not show significant effect on dry flower weight of African marigold (Table 6).

The highest (5,360 kg ha^{-1}) and lowest (2,340 kg ha^{-1}) dry flower weight was found at 75% and 25% population density, respectively (the dry flower weight significantly increased as population density increased) (Table 3). This may due to the highest total fresh flower yield was obtained due to 75% population density as we discussed in Table 2. This result agreed with that of [31, 2, 6] who reported that the highest dry biomass yield was obtained at higher plant population density of pepper mint. Sadeghi *et al* [40] claimed that dry flower of African marigold non significantly affected by population density African marigold in intercropping of marigold with maize.

(iv). Essential Oil Content

Essential oil content was significantly (P≤0.05) affected by population density and variety but not by cropping system and interaction (Table 6).

The highest (0.174) and lowest (0.156) oil content was obtained from 75% and 25% population density. Essential oil content was increased as population density increased from 25% to 75% respectively (Table 3). This indicates that like fresh flower yield and dry flower weight, essential oil content was also positively correlated with population density. This might be the absence of interspesfic competition due to higher population density and the highest plant population density results higher essential oil content per area of land [31, 27, 34, 26].

Table 3. *Mean effects of population density, varieties and cropping system on dry flower weight, essential oil content and essential oil yield African marigold.*

Population densities	**Dry flower Weight (kg ha^{-1})**	**Essential oil content (%)**	**Essential oil Yield (kg ha^{-1})**
75%	5,360a	0.174a	9.36a
50%	3,240b	0.169ab	5.48b
25%	2,340c	0.156b	3.65c
LSD (0.05)	630	0.013	0.082
Varieties			
AVT001	3,740	0.172a	6.43a
AVT540	3,580	0.211a	7.55a
AVT7063	3,530	0.127b	4.48b
LSD (0.05)	NS	0.044	1.27
CV (%)	7.26	6.96	10.74
Cropping system			
Intercropping	4.45	0.212	9.254
Sole	4.42	0.226	9.974
LSD (0.05)	NS	NS	NS
CV (%)	10.23	8.98	10.14

NS= not significant Means in a column followed by the same letters are not significantly different at p≤5% level of significance; Mean followed by the same letter with the same column are statistically non-significant at p<0.05 according to the least significant difference (LSD) test at p<0.05; where, SOV= source of variation.

The highest (0.211) and lowest (0.127) essential oil content was from variety AVT 540 and AVT 7063, respectively (Table 3). There is no significance difference between variety AVT 001 and AVT 540 (Table 3). The difference and similarity among the varieties might be due to their genetic factor.

(v). Essential Oil Yield

Essential oil yield was highly (P≤0.001) and highly affected (P≤0.01) by population density and varieties of marigold, respectively but interaction and cropping system were not significantly affected essential oil yield (Table 6). The highest (9.36 kg ha^{-1}) and lowest (3.65 kg ha^{-1}) essential oil yield was obtained from 75% and 25% population density, respectively, essential oil yield significantly increase as population density increase from 25% to 75% (Table 3). Indicating that essential oil yield increased as population density increase. This may due to the highest and lowest fresh flower and dry flower weight was obtained due to 75% and 25% respectively, in table 5 and 6, respectively. The study of Bilasvar *et al* [7] also show that higher essential oil yield was recorded under high population density in intercropping of sweet basil with maize. According to Ijoyah et *al* [24] reported that the highest essential oil yield was recorded from highest population density in intercropping of African marigold with bean varieties. Similar finding has been reported by Mansoori [31] in pepper mint and Miguel *et al* [33] in *Thymus albicans* revealed that the highest essential oil yield was recorded from the highest planting density of pepper mint and *Thymus albicans* (essential oil was increased when plant density was increased). The result of Berimavandi *et al* [6] also revealed that population density was significantly influenced essential oil yield of *Calendula officianalis.* L and the highest oil yield were obtained from the highest population density. In the case of the three varieties of African marigold the highest and lowest essential oil yield were recorded from AVT 540 (7.07-ton ha^{-1}) and AVT 7063 (4.48 ton ha^{-1}) respectively (Table 3). This might be the distinguishable flower colors among the varieties of African marigold, the variety which has higher essential oil content and essential oil yield had a flower color of golden yellow and orange yellow for AVT 540 and AVT 001. But the one variety AVT 7063 which gave low essential oil content and oil yield has a flower color of light yellow. Because the flower determines the xanthophylls content and essential yield, that's why AVT 540 and AVT 001 had a highest both in essential oil content and essential yield. Similar result has been reported by Ijoyah *et al* [7] that highest plant dry weight and essential oil yield was recorded on both cultivars of sweet basil intercropped with maize.

3.2. Productivity of Tomato-African Marigold Intercropping

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

3.2.1. Partial Land Equivalent Ratio

The analysis of variance showed that partial LER of tomato highly (P≤0.01) affected by population density, but varieties and interaction were not significantly affected (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 4). 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. Intercropping of okra with egusi melon land equivalent ratio was increased as population density of okra increased up to a certain point [24]. The land equivalent ratio of tomato was significantly higher at 50% population density than 25% and 75% population densities in tomato -coriander intercropping [23]. The highest LER value of tomato was obtained due to 50% population density than 75% and 100% in tomato-lettuce intercropping [3].

The partial LER of African marigold was not significantly affected by population densities, the varieties and their interaction effects (Table 7). 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 complementarity 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 Mondal *et al* [35] and Verma *et al* [45] 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* [22] 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.

3.2.2. Total Land Equivalent Ratio

The analysis of variance showed that population density highly (P≤0.01) and variety and their interaction did not significantly affect LER (Table 7).

Total LER in all cases was more than unity (Table 4) 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 (Table 7). Though varieties of African marigold were statistically non-significant higher total LER (1.28) was obtained due to variety AVT 540 (Table 4). 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 4). These values indicated that intercropping gave a 43% and 13% yield advantages than sole planting. The highest total LER from 50% population density of marigold (Jasmine + French marigold) followed by (Jasmine + African marigold) [37, 18, 29, 38, 44]. 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 [48]. 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.

3.2.3. 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≤0.01) affected the MAI and had no significant effect by varieties of African marigold and interaction population density MAI (Table 7).

Table 4. *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^{-1})
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.

However, variety and interaction on the other hand did not show significant effect on MAI (Table 7). 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^{-1}) and lowest (ETB 16,011 ha^{-1}) 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. 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 [28, 45, 39].

4. Summary and Conclusions

African marigold is among the most important medicinal plants in the world. 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 been became 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. Plant height of African marigold was not significantly affected by population density. Population density were significantly affected number of branches per plant (NBP), number of fresh flowers per plant (NFFPP), fresh flower yield (FFY), dry flower weight per hectare (DFWPH) essential oil content (EOC) and essential oil yield (EOY). The highest (23.16) and lowest (18.29) NBP were due to 50% and 75% population density respectively, the highest (50.07) and lowest (38.76) of NFFPP were recorded from 50% population density. The highest (45,860 kg ha^{-1}) and lowest (19,040 kg ha^{-1}) of FFY were due to 50% and 25% population densities respectively. The highest (5,360 kg ha^{-1}) and lowest (2,340 kg ha^{-1}) of DFWPH, the highest (0.174 %) and lowest (0.156 %) of EOC and the highest (9.36 kg ha^{-1}) and lowest (3.65 kg ha^{-1}) of EOY were due to 75% and 25% population density of African marigold respectively. Cropping system was significantly affected number of branch and number of fresh flowers per plant. The variety of African marigold significantly affected plant (PH), essential oil content (EOC) and essential oil yield (EOY) of African marigold. The tallest (55.36 cm) and shortest plant (47.80 cm) of African marigold were due to AVT 001 and AVT 540 respectively. Variety AVT 540 gave the highest (0.21) and lowest (0.12) of EOC. The highest (7.55 kg ha^{-1}) and lowest (4.48 kg ha^{-1}) EOY were also obtained from AVT 504. Sole planted African marigold produced significantly higher (55.73) number of fresh flowers per plant than the intercropped (50.04). The highest (24.91) and lowest (21.13) of NBP was also obtained from sole planting. 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^{-1}) 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^{-1}. Therefore, African marigold with a density of 41,666.67 plants ha^{-1} 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. Generally intercropping of African marigold and other aromatic and medicinal plants with other known crops like tomato is one of the best options to increase the production of African marigold in Ethiopia.

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.

Appendix

Table 5. *Mean square values of ANOVA on the agronomic and yield components of African marigold (Tagetes erecta L.) under intercropping with tomato.*

SOV	DF	Plant height	Branch number	Number of fresh flowers per plant	Weight of Fresh flower per plant
Rep	2	54.197	75.004	32.78	8055.86
PD	2	10.60ns	57.85ns	300.907**	58053.30ns
VAR	2	132.148**	6.81ns	32.49ns	11820.80ns
PD*VAR	4	6.54ns	5.83ns	16.193ns	3053.33ns
Error	16	14.614	19.913	39.27	6186.62
CV %		7.50	11.12	14.33	14.38
Rep	2	44.14	57.14	617.65	17378.88
CS	1	57.50ns	96.33ns	218.45*	5076.68ns
Error	2	19.32	17.61	131.93	10330.03
CV (%)		8.00	17.05	10.21	14.38

*, **, significant at $P \leq 0.05$ and $p \leq 0.01$ probability levels respectively; Rep=Replication; VAR=Varieties PD=Population density; CS=cropping system.

Table 6. *Mean square values of ANOVA on fresh yield per hectare, dry flower yield per hectare, essential oil content and essential oil yield by population density, varieties and cropping system of tomato African marigold intercropping.*

SOV	DF	Fresh flower weight per hectare	Dry flower weight	Essential oil content	Essential oil yield
Rep	2	80.127	0.0559	0.0036	2.65
VAR	2	65.45ns	0.11148ns	0.0123*	40.075**
PD	2	1753.24***	21.62***	0.00084*	14.65***
PD*VAR	4	35.42ns	0.086ns	0.0021ns	2.20ns
Error	16	36.37	0.40	0.00201	1.503
CV (%)		7.38	7.26	6.96	10.74
Rep	2	131.42	0.0034	0.009	21.37
CS	1	65.55ns	0.0047ns	0.0013ns	3.503ns
Error	2	121.105	0.632	0.00143	2.65
CV (%)		12.56	10.23	8.98	10.14

*, **, *** significant at P≤0.05, p≤0.01 and p≤0.001 probability levels respectively; ns= non significant difference; Rep=Replication; VAR= Varieties, PD=Population density; SOV= source of variation, DF= degree of freedom.

Table 7. *Mean square values of ANOVA on productivity of intercropping of tomato as affected by population densities and varieties of African marigold at Wondo Genet during 2017/2018 cropping season.*

SOV	DF.	Partial LER of tomato	Partial LER of African marigold	Total LER	Monitory advantage index
Rep	2	0.0072	0.161	0.23	346241729570
PD	2	0.24**	0.0087ns	0.24**	645054017163**
VAR	2	0.009ns	0.0243ns	0.0192	102847510272ns
PD*VAR	4	0.011ns	0.038ns	0.0574ns	30384652662ns
Error	16	0.0129	0.0189	0.023	45063508813
CV (%)		7.31	14.47	13.23	12.05

*, ** and ns significant at P≤0.05 and p≤0.01 probability levels respectively; ns= not significant; DF= degree of Freedom; SOV= source of variation; Rep=Replication; VAR= Varieties PD=Population density; LER = land equivalent ratio; CV=coefficient of variation.

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