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ORIGINAL ARTICLE

Effect of population density and spatial arrangements on the productivity of *Zea mays* L. and *Mentha spicata* L. in intercropping systems at wondo genet, rift valley of Ethiopia

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In Ethiopia, intercropping of medicinal and aromatic plants, like spearmint, with cereals is not well known and undertaken as a common practice. Intercropping spearmint (Sm) with major produced cereal crops such as maize (Mz) can give a chance for farmers to diversify their incomes. Therefore, the field experiment was conducted at Wondo Genet, Rift Valley of Ethiopia under rain-fed conditions during the 2020 cropping season to investigate the effect of spearmint population density and spatial arrangements on the productivity of the maize-spearmint intercropping. The experiment was laid out in a factorial arrangement based on a randomized complete block design with three replications. Treatments were made from a factorial combination of spearmint population density (100, 75, 50, and 25%), and spatial arrangements (1Mz:1Sm, and 1Mz:2Sm) ratio. Data on phenological, growth and yield-related crop parameters were collected following their respective standard methods and procedures and further subjected to analysis of variance (ANOVA) using SAS version 9.4. Whenever the ANOVA result showed a significant difference among treatments for a parameter mean separation was further done using the least significant difference (LSD). The analysis of variance showed that the main effect, their interaction, and cropping system didn't significant effect (P>0.05) on phenological, vegetative growth, and yield-related parameters of the main crop, maize. On the other hand, the spatial arrangement by population density interaction significantly affected the total fresh above ground-biomass, and leaf yield, and essential oil yield of spearmint where the maximum (22.70-ton, 12.72-ton, and 0.047-ton ha^{-1}) in their respective order were recorded at 100% spearmint population density with a double row arrangement respectively. The sole spearmint was superior to other intercropped treatments in each of the two-harvesting cycles for above-ground biomass, leaf, and essential oil yield. The LER values indicated that intercropping maize with a 100% spearmint population at the double row arrangement gave a 63% intercropping advantage with a monetary advantage index (MAI) of 71108 ETB followed by a 75% spearmint population at the same density with 58% advantage and MAI of 65275 ETB. Therefore, intercropping of 75% spearmint population density at double row arrangement with maize could be recommended for the study area.

Keywords: Intercropping, Maize, Population density, Spatial arrangement, Spearmint.

Introduction

Intercropping is the growing of two or more crops simultaneously on the same land to utilize resources such as water, nutrients, and solar radiation more efficiently and is an environmentally friendly method (Agegnehu G., et al., 2008; Maffei M., and Mucciarelli

M. 2003). It is a common agronomic practice in the tropics because it reduces losses caused by insect pests, diseases, and weeds, and ensures better yields. With growing pressures on agricultural land resulting from population growth, farmers must explore new ways including intensifying production per unit area and time (Usmanikhail M.U., et al., 2012).

Many studies have emphasized the use of medicinal plants in intercropping systems, such as cassava with okra, Okra with chili pepper, and saffron with chamomile (Muoneke C.O., and Mbah E.U. 2007). In addition, to maintaining biodiversity, the presence of medicinal plants in intercropping also improves their yield. Most of the intercropping system research in Ethiopia has concentrated on cereal-legume combinations (Bantie Y.B., et al., 2014). In Southern Ethiopia, maize ranks first in production and productivity (CSA, 2018). However, there is only limited information on intercropping with aromatic and medicinal plants though some earlier findings identified compatibility and profitability of intercropping aromatic and medicinal plants with major crops in Ethiopia (Helen D. 1980). As explained by Lulie B, et al., (2014) intercropping spearmint with maize is biologically efficient, economically feasible, and more profitable and provides more opportunities compared to sole planting.

However, the smallholder farmers in Southern Ethiopia are seriously constrained by limited land holding, where 40% of farmers have an average landholding of 0.1 to 0.5 ha with a further 30% having 0.51 to 1 ha (CSA, 2017). This limits the farmer's interest to expand their production horizontally by considering some more new crops like spearmint. In this regard, the practice of growing medicinal plants with existing field crops such as maize can give them a chance to diversify their incomes and improve their livelihoods. Thus, this study was initiated to generate useful information in terms of compatibility, agronomic management and economic feasibility of a maize-spearmint intercropping system. Therefore, this study aimed to evaluate the effect of spatial arrangement and planting density of spearmint under intercropping with maize and to assess the land-use efficiency and profitability of introducing the maize-spearmint intercropping system in the study area. We hypothesized that maize yield will not be affected when intercropping with spearmint at the optimum spatial arrangement and population density.

Materials and Methods

Description of study area

The experiment was conducted at Wondo Genet Agricultural Research Center (WGARC) southern Ethiopia under rain-fed conditions during the 2020 cropping season. The research center is located 270 km south of Addis Ababa and 14 km southeast of Shashemene. It exists within the Ethiopian Rift Valley of the Sidama Regional State. 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 of the area is 1069.2 mm. The site has a mean maximum and minimum temperature of 26°C and 12°C respectively. The soil of the study area is a clay loam with an average pH of 6.4 (Getachew A., et al., 2019). Wondo Genet has a bimodal rainfall distribution with two rainy seasons. Short rains occur in March-May and long rains in July-October. The dry season extends from November to February (Dawit Kassa and Afework Bekele, 2008). The site is suitable for maize and spearmint production.

Experimental materials

Hybrid maize variety BH-546 was used for the study. BH546 is an intermediate maturing variety released by Bako national maize research center (BNMRC) in 2013. The variety performs well in an agro-ecological range of 1000-2000 m.a.s.l with a rainfall range of 1,000-1,200 mm and gives 8.5-9.5 and 5.5-7.0-ton ha^{-1} grain yield on-station and on-farm experiments, respectively (Ministry of Agriculture, 2018). This hybrid has narrow and erected leaf architecture which makes it unique compared to the previously released hybrids. Its narrow semi-erect leaves make it desirable for high-density planting and inter-cropping with legumes, a common practice in most maize growing areas of the country (CIMMYT, 2013). For the companion crop, WGSM-3 spearmint variety was used as a planting material during the study, which was registered by WGARC in 2011 (Ministry of Agriculture, 2018) and well adapted to the study area. Fertilizers NPS and UREA were applied as per recommendations.

Research design and treatment

The experiment was laid out in a randomized complete block design (RCBD) in 2 × 4 factorial arrangements with ten treatments and three replications. The treatments consisted of combinations from four-population densities (P1=55556; P2=41667; P3=27778, and P4=13889 plants ha^{-1}), and two spatial arrangements (one row of maize with one row of spearmint (1Mz: 1Sm) and one row of maize with two rows of spearmint (1Mz: 2Sm). Population densities of spearmint for both 1:2 and 1:1 arrangement was 55556 plants ha^{-1}; 41667 plants ha^{-1}; 27778 plants ha^{-1} and 13889 plants ha^{-1} to maintain 100%; 75%; 50%, and 25% of the recommended population of sole spearmint (55556 plants ha^{-1}), respectively. Sole crops of maize and spearmint were used as a control treatment. Sole spearmint was planted using 60 cm by 30 cm (inter and intra-row spacing, respectively) with a total population density of 55556 plants ha^{-1}. Maize was planted using the recommended population density (30 cm × 80 cm=41667 plants ha^{-1}). The Gross plot size was 4.8 m × 3.6 m (17.28 m^2) and to avoid border effects, both ends of the rows (two hills on each side of rows) and the outermost rows were left out. Hence, 2.4 m × 2.4 m (5.76 m^2) of net plot size was used for the data collection for maize and spearmint. Two maize seeds were planted per hill and thinned after establishment to maintain a single healthy plant per hill. Maize and the companion crop were planted at the same time (Table 1).

Table 1. Descriptions of treatments.

Treatments	Mz-spacing		Sm-spacing		SA	Mz	Sm	Mz	Sm	Remark
	Inra-row (cm)	Inter-row (cm)	Inra-row (cm)	Inter -row (cm)	Mz: Sm	Row /Plot	Row /Plot	Population/ha	Population /ha	
T1	30	80	-	-	-	6	-	41667	-	Sole-Mz
T2	-	-	30	60	-	-	8	-	55556	Sole-Sm
T3	30	80	22.5	80	01:01	6	6	41667	55556	100%Sm
T4	30	80	30	80	01:01	6	6	41667	41667	75%Sm
T5	30	80	45	80	01:01	6	6	41667	27778	50%Sm
T6	30	80	90	80	01:01	6	6	41667	13889	25%Sm
T7	30	80	45	40	01:02	6	12	41667	55556	100%Sm
T8	30	80	60	40	01:02	6	12	41667	41667	75%Sm
T9	30	80	90	40	01:02	6	12	41667	27778	50%Sm
T10	30	80	180	40	01:02	6	12	41667	13889	25%Sm

SA=Spatial Arrangement; Sm=Spearmint; Mz=Maize; ha=hectar.

Data Collection

Soil sampling

Soil samples at a depth of 0-20 cm were taken from 13 random spots diagonally across the experimental field using an auger before planting. The collected soil samples were composited to one sample. The bulked soil sample was air-dried in a shade house to reduce contamination, thoroughly mixed, and ground to pass 2 mm sieve size before laboratory analysis. Then the sample was properly labeled, packed, and transported to the laboratory after which soil organic carbon, total N, soil pH, available P, cation exchangeable capacity (CEC), and texture were analyzed at Laboratories of Hawassa University, Wondogenet college of forestry and natural resources. The soil pH was measured in the supernatant suspension of a 1:2.5 soil to water ratio using a standard glass electrode pH meter. The Walkley and Black method was used to determine the organic carbon (%). Available P (mg kg^{-1}) was determined by employing the Olsen et al., (1954) method using ascorbic acid as the reducing agent. The cation exchange capacity (CEC) in cmol (+) kg^{-1} was measured using the 1M-neutral ammonium acetate method. The soil particle size distribution was determined using the Bouyoucos hydrometer method.

Maize

Crop phenology

Days to tasseling (days): Were counted and recorded from emergence to the period where 50% of maize plants in a plot produced tassel.

Days to silking (days): Were recorded as the number of days from emergence to the period where 50% of the plants in a plot produced silk.

Days to physiological maturity (days): It was recorded as the number of days from emergence to the period where 85% of the plants showed changes in their foliage color from green to yellow and black layer formation at the base of grains.

Growth parameters

Leaf area index: Leaf area per plant for leaf area index computation was recorded at the silking stage by measuring the leaf length and maximum leaf width of three leaves (top, middle, and bottom) per plant from five randomly taken plants from each net plot, the average of the three leaves were multiplied by the total number of leaves per plant and the area was adjusted by a correction factor of 0.75 (i.e., 0.75 × leaf length × maximum leaf width) as described by Francis C.A., (1986). The leaf area index was then calculated by dividing leaf area per plant to sampled ground area as suggested by Radford P.J., (1967).

Plant height (cm): The plant height of five randomly selected plants was measured from the ground to the base of the tassel at maturity. The mean of five plants was used for statistical analysis.

Above-ground biomass yields: Were collected from a net plot area. were collected from the net plot area of. Then sun-dried biomass was measured by sensitive balance.

Ear height (cm): The ear height of five randomly selected plants was measured from the ground to the first ear-bearing node and the mean of the five plants per plot was used for statistical analysis.

Yield and yield components

Ear length (cm): The ear length of five randomly selected plants was measured from the base to the tip of the ear and a mean of five plants was used for statistical analysis.

The number of kernels per ear: The number of kernels per plant of five randomly collected ears from the middle three rows of the plot was counted and the number of the mean kernel per ear was recorded.

Hundred kernel weight (g): The weight of 100 randomly samples grains from each plot was determined and expressed in grams.

Grain yield (ton ha^{-1}): Grain yield of a harvest from the net plot area was measured and adjusted to 12.5% moisture content and expressed in ton ha^{-1}.

Adjusted yield=Actual yield $\times \frac{100-M}{100-D}$

Where M is the measured moisture content in grain and D is the designated moisture content (12.5%).

Harvest index: The harvest index (HI) of each treatment from a net plot area was calculated using the following formula:

HI=$\frac{\text{Grain yield}}{\text{Biomass}} \times 10$

Spearmint component

The spearmint data collected included fresh leaf yield (g), dry leaf yield (g), fresh above-ground biomass yield (g), dry above-ground biomass yield (g), essential oil content (%), and essential oil yield (g). Essential oil content was determined on a fresh weight basis from 300g of composite leaves harvested from the three middle rows of a plot. Laboratory analyses were performed at Wondo Genet Agricultural Research Center. The essential oil was determined by hydro-distillation method. Oil content and yield were calculated by the following equation.

Essential oil content (%)=$\frac{\text{Extracted essential oil (g)}}{\text{spearmint sample (g)}} \times 100$

Essential oil yield (kg)=Spearmint biomass yield (kg) × essential oil content

Yield advantage and economic benefits in intercropping

The yield advantage and economic benefits of intercropping over sole cropping were determined in terms of land equivalent ratio and monetary advantage index.

Land Equivalent Ratio (LER)

The land equivalent ratio verifies the effectiveness of intercropping for using the resources of the environment compared to sole planting. The LER values were computed using the following formula described.

Total LER=$\frac{\mathrm{Yab}}{Yaa}+\frac{\mathrm{Yba}}{\mathrm{Ybb}}$

Partial LER of maize=$\frac{\mathrm{Yab}}{Yaa}$

Partial LER of spearmint=$\frac{\mathrm{Yab}}{Yaa}$

Where, Yab=Intercrop yield of maize

Yba=Intercrop yield of spearmint

Yaa=Pure stand crop yield of maize

Ybb=Pure stand crop yield of spearmint

Monetary Advantage Index (MAI)

The most important part of recommending a cropping pattern is the cost: benefit ratio more specifically total profit because farmers are mostly interested in the monetary value of the return. The yield of all the crops in different intercropping systems and also, in the sole cropping system and their economic return in terms of monetary value were evaluated to find out whether maize yield and additional spearmint yield are profitable or not. This was calculated with the monetary advantage index (MAI). It is expressed as

MAI=(Pab+pba) × $\frac{\mathrm{LER}-1}{\mathrm{LER}}$

Where, Pab=Pa × Yab; Pba=Pb × Yba; Where, Pa=Price of species 'a' and Pb=Price of species 'b'. The higher the index value, the more profitable is the cropping system. The current price of maize grain and spearmint fresh leaf yield per kg in Ethiopian birr were taken from the Wosha Wondogenet and Shashemene grain market in December 2020 cropping season. Accordingly, the prices were 11 and 7-ETB per kg for maize grain and spearmint fresh leaf yield respectively.

Data analyses

Data were subjected to analyses of variance (ANOVA) using the General Linear Model (GLM) of Statistical Analysis System (SAS) software version 9.4. The least significant difference (LSD) test at 5% probability was used for mean separation when the analysis of variance indicated the presence of significant differences.

Results and Discussion

Pre-experiment soil physical and chemical properties

Laboratory results of physical and chemical properties of soils of the experimental field analysis indicated that the proportion of sand, silt, and clay contents of the soil were 40, 24, and 36%, respectively at a depth of 0–20 cm. Thus, the soil textural classification system, the soil of the experimental field could be classified as clay loam with a slightly acid property (pH: 6.53) (Table 2). These properties are favorable for spearmint and maize production. The suitable pH range for most crops is between is 6.5 and 8.

The organic carbon content of the experimental soil (1.68%) is low, who classified the organic carbon content of the soil with <4%, 4-10%, and >10% as low, medium, and high respectively. The organic matter of the experimental site soil (2.9) was moderate in accordance. Classified total nitrogen content of <0.05, 0.05-0.12, 0.12- 0.25, and >0.25 as very low, low, medium, and high respectively. Thus, the total nitrogen content (0.44%) of the experimental soil was high (Table 2) indicating that the nitrogen nutrient was not a limiting factor for crop growth.

Table 2. Physico-chemical characteristics of the experimental soil.

Character	Value	Rating
pH	6.53	Slightly acidic
Available Phosphorus (mg/kg)	4.55	Low
Total Nitrogen (%)	0.44	High
Organic Matter (%)	2.9	Moderate
Organic Carbon Content (%)	1.68	Low
CEC (cmol/kg)	9.23	Low
Soil Texture		
Sand (%)	40	
Clay (%)	36	
Silt (%)	24	
Textural class		clay loam

Available P of the experimental site was 4.55 mg kg^{-1} and could be considered low in accordance, who classified available P of the soil with <5, 5-15, and >15 as low, medium, and high respectively. This indicated that P is a limiting nutrient for optimum crop growth and yield at the experimental site. The CEC of the soil was 9.23 cmol kg^{-1} soil (Table 2), which was low, where values <5, 5-15, 15-25, 25-40, and >40 are classified as very low, low, medium, high, and very high respectively.

Response of maize

Phenology

The analysis of variance revealed that days to tasseling, silking, and physiological maturity of maize were not significantly (P>0.05) affected due to spatial arrangements, population density, and their interaction. The cropping system also did not show (P>0.05) a significant effect on these parameters. However, relative different were observed on mean number of days required to attain tasseling, silking, and physiological maturity due to the treatments. The mean number of days required from planting to maturity was (160 to 162) for both sole and intercropped maize. The variation in mean days between sole and intercropped plots was less than two days in tasseling, silking, and physiological maturity.

The results of the study were in agreement with who worked on an intercropping system of hybrid maize with common bean varieties. The maize sole-crop has a growth period of 120 days and was not significantly different from maize intercropped with cowpea cultivars Glenda and Agrinaw which took 120 and 121 days to maturity. The absence of significant differences between sole and maize intercropped with fenugreek, field pea, and haricot bean for phenological parameters. However, this result contradicts with the findings who reported significant influence of maize-haricot bean intercropping on phonological performances of maize crop.

Growth analysis

The spatial arrangement, population density of spearmint, and their interaction had no significant (P>0.05) influence on plant height, ear height, and the number of ears per plant of the maize crop. These could be possibly due to no shedding effect, less competition of the companion crop, and better availability of moisture, nutrients, and favorability of the cropping season. The results conformed with the findings of Lulie B., et al., (2014) who reported the absence of significant difference in plant height and ear height of maize whether it was sole or intercropped with spearmint. Other growth parameters such as leaf area index (LAI) is an indication of leafiness per unit ground area and determine the rate of dry matter production, but like other growth parameters, the result of analysis of variance showed that the spearmint spatial arrangements, population density, and their interaction were not significantly (P>0.05) influencing the LAI of maize. The non-significant effects of the treatments on LAI may be due to complementary effects, i.e., enough soil moisture may be conserved by densely grown understory spearmint. This result is in line on sweet basil intercropped with maize (Fig. 1).

Fig. 1. Pictorial presentation of maize-spearmint intercropping system at field level.

Responses of yield and yield components

Yield attributes

Analysis of variance showed that the ear length, and the number of kernels per ear, did not show significant (P>0.05) variation due to the treatment main effects, their interaction, and cropping systems. Hundred kernel weight of maize was also not significantly (P>0.05) affected by the treatment main effects, their interaction, and cropping systems. The findings of this study were similar who reported non-significant effects of varietal, time of intercropping, and their interaction on thousand kernel weight. Also, consistent with thousand seed weight of maize didn't significantly vary whether the plant is intercropped or not under maize-spearmint intercropping. The 100 seed weights (g) were not significantly affected by either the main effects of the varieties and planting density of common bean or their interaction. Moreover, a non-significant effect of planting densities and planting patterns on maize 1000-kernel weight under fab bean intercropping.

Grain yield

Analysis of variance showed that the grain yield of maize was not significantly (P>0.05) affected by the main effect of spatial arrangement, population density, and their interaction. This absence of yield loss in maize because of spatial arrangement and population density of intercropped might be due to the compensation of spearmint aggressively spreading runners, which produce fine adventitious roots that allow roots to uptake excess water while contributing to less water runoff, increasing soil moisture retention and reduce soil nutrient loss. A similar finding by Prasad and Brook (2004) in Nepal observed that the maize yield was not significantly influenced by soybean population density under maize- soybean intercropping systems. A non-significant variation in grain yield of maize intercropped with spearmint. The spatial arrangement and population density did not show significant yield variation on maize intercropped with haricot bean.

Also, the cropping system did not show a significant (P>0.05) effect on the grain yield of maize, but numerically the highest value of 9.04 t ha^{-1} in sole treatment; while the lowest (8.62 t ha^{-1}) from 100% intercropped spearmint population density was recorded. The result of the study was in agreement with Balearic and Pathway (1981), who worked on maize intercropping with pigeon pea did not show a significant effect on maize yield whether it's intercropped or sole. Rather, intercropping pigeon pea in maize rows gave an additional 342 kg/ha of pigeon pea without causing a significant yield reduction in maize. Other studies also explained that the mean grain yield of maize was not significantly affected when intercropped with basil. Also, in line with the finding who reported that common bean intercropping didn't affect the grain yield of maize. But, contradicted on maize-haricot bean intercropping the sole cropped maize varieties had higher grain yield than those intercropped by an average of 855 kg/ha (16.4%). Due to the dual benefits obtained from this intercropping and non-significant yield variation of sole and intercropped treatments of the main crop, planting maize with spearmint intercropping is advisable than sole planting of maize.

Above ground biomass yield and harvest index

Analysis of the variance of the study showed that the above-ground biomass yield of maize was not (P>0.05) influenced by the main effects and their interaction. Also, the cropping systems did not vary significantly for above-ground biomass. The analysis of the variance of the result showed that the harvest index was not significantly (P>0.05) affected by the main effects, their interaction, and the cropping system. The physiological efficiency and ability of a crop for converting the total dry matter into economic yield is expressed with the harvest index (HI). A higher harvest index indicates a larger percentage of total dry matter transformed into final kernel yield. The absence of variation in harvest index might be due to non-significant variation of grain yield and above-ground biomass between each treatment. This agreed with Hirpa (2014) who found a non-significant effect on HI of maize under the maize-haricot bean intercropping system. Also, the harvest index of rice was non significantly affected by the main effect of common bean varieties, population, and their interaction.

Response of Spearmint

Fresh above ground biomass and leaf yield

The analysis of variance showed that the interaction effect of population density and spatial arrangement of intercropped spearmint was significant (P ≤ 0.001) for total fresh above-ground biomass and leaf yield of spearmint crop at the first, and the second harvest. Therefore, the interaction effects were large enough to cause substantial differences from the main effects.

The highest of 8.84 and 13.84-ton ha^{-1} at first and second harvest respectively, and a total of 22.10-ton ha^{-1} fresh above-ground biomass yield were recorded from 100% population density arranged with a 1Mz:2Sm row arrangement. The lowest 2.16-ton ha^{-1} at the first harvest, 4.54-ton ha^{-1} in the second harvest, and a total of 6.70-ton ha^{-1} from the two harvests were recorded from 25% population density at double row arrangement of spearmint (Table 3). With a similar trend to the above-ground biomass yield the highest (4.81-ton ha^{-1} at first harvest, 7.98-ton ha^{-1} at second harvest, and a total of 12.78-ton ha^{-1} fresh leaf yield) were recorded from 100% population density at 1:2 spatial arrangement; while the lowest (1.39-ton ha^{-1} at first harvest, 2.65-ton ha^{-1} at second harvest and 4.05 ton ha^{-1} of total fresh leaf yield of spearmint) were obtained from 25% population density at 1Mz:2Sm spatial arrangement of spearmint at each harvesting cycle. Moreover, the yield of the second harvest spearmint showed 22.04% more above-ground biomass and 24.78% higher leaf yield compared to the first harvest. This might be due to the spearmint spreads by runners and covering all ground area gradually. Similar results were pronounced and intercropping of maize with spearmint, at Wondogenet in Ethiopia. A related result in Iran described that the second harvest of peppermint had more fresh above ground and leaf yield and active substances than the first harvest when intercropped with Fenugreek.

Generally, an increase of fresh above-ground biomass and leaf yield of spearmint was more evident at 1:2 spatial arrangements when spearmint plants were closer to maize rows (Table 3). It seems that spearmints probably benefited from the inputs applied to maize rows as the plants got closer to maize rows and more intra-spaces between the spearmint planted at double row arrangement. The results showed that when the intercropped population density of spearmint increased from 25% to 100% the yield of fresh above-ground biomass and leaf yield were increased consecutively (Table 3). In each harvesting cycle, the highest fresh above-ground biomass and leaf yield was obtained from 100% population density; while the lowest yield was recorded from 25% population density of spearmint. This could be due to a greater number of plants per unit area, and more efficient utilization of applied inputs like fertilizers by the crop plants which otherwise could be over-utilized by the two intercropped plants. Therefore, the highest fresh above ground and leaf yield was recorded from 100% population density with a 1:2 arrangement of spearmint intercropped with maize. These results agreed and reported enhanced performance of medicinal and aromatic plants intercropped with teak.

Similarly, the cropping system had a significant effect on the first, and second harvests, and the total fresh above-ground biomass yield of spearmint. Leaf yield was significantly (P ≤ 0.05) affected by the cropping system at the first, and the second fresh leaf harvests, and total fresh leaf yield). Solely planted spearmint had 41.53%, 37.8%, and 40.29% advantage at first, second, and total fresh above-ground biomass yield respectively, compared to the intercropped one. Fresh leaf yields were greater by 41.56% at first harvest, 35.96% at second harvest and 38.18% of total fresh leaf yield compared to intercropped plots. Besides, the maximum fresh leaf yields of 7.68 ton/ha at first, and 11.38 ton/ha at second harvest obtained from sole spearmint were lower compared to the leaf yield of the crop.

Thus, sole cropping was superior to intercropping because, spearmint planted in association with maize faced competition for growth resources like sunlight and lack of enough space for root and canopy development, which consequently resulted in lower fresh above-ground biomass and leaf yield. A similar finding was indicating the superior performance of sole stevia compared with the intercropped treatments with haricot bean. Likewise, the intercropping maize with spearmint significantly depressed above ground biomass and leaf yield of spearmint. This finding is also in line with the previous similar findings in rose-scented geranium intercropped with vegetables. Other studies also showed that the highest aboveground biomass and leaf yield is obtained from a sole stand and 100% of rosemary intercropping with 100% carrot. The] menthol mint and spearmint intercropped with sugarcane suffered yield reduction (52% to 75%) as intercrops compared to their respective sole crop yields. However, the additional yield from spearmint gave extra yield and income to the farmer.

Table 3. Means for fresh above-ground biomass and leaf yield of spearmint under maize-spearmint intercropping as affected by the spatial arrangement, population densities, and cropping system of spearmint.

Treatments	**Fresh above-ground biomass (ton)**			**Fresh leaf yield (ton ha^{-1})**		
	1st harvest	**2nd harvest**	**Total**	**1stharvest**	**2nd harvest**	**Total**
Interactions						
1Mz:1Sm by 100%PD	8.00^{b}	11.30^{b}	19.30^{b}	4.04^{b}	6.80^{bc}	10.80^{b}
1Mz:1Sm by 75%PD	7.60^{c}	11.49^{b}	19.10^{b}	3.71^{c}	6.6^{c}	10.30^{c}
1Mz:1Sm by 50%PD	5.84^{d}	7.84^{c}	13.68^{c}	2.9^{d}	4.83^{d}	7.73^{d}
1Mz:1Sm by 25%PD	2.43^{f}	4.88^{d}	7.31^{e}	1.57^{e}	2.77^{e}	4.34^{e}
1Mz:2Sm by 100%PD	8.86^{a}	13.84^{a}	22.70^{a}	4.81^{a}	7.98^{a}	12.78^{a}
1Mz:2Sm by 75%PD	7.96^{b}	11.047^{b}	19.00^{b}	4.21^{b}	7.04^{b}	11.20^{b}
1Mz:2Sm by 50%PD	5.04^{e}	7.67^{c}	12.70^{d}	2.70^{d}	4.64^{d}	7.34^{d}
1Mz:2Sm by 25%PD	2.16^{f}	4.54^{d}	6.70^{e}	1.39^{e}	2.65^{e}	4.05^{e}
LSD @ 0.05	0.34	0.68	0.728	0.31	0.36	0.40
CV (%)	3.26	4.30	2.76	5.66	3.77	2.66
Cropping System						
Sole	15.30^{a}	19.91^{a}	35.20^{a}	7.68^{a}	11.38^{a}	19.07^{a}
Intercropped	6.32^{b}	8.97^{b}	14.98^{b}	3.17^{b}	5.36^{b}	8.53^{b}
LSD @ 0.05	2.90	5.31	5.03	2.64	2.59	3.36
CV (%)	7.64	10.46	5.70	13.82	8.81	6.94

MZ=Maize; SM=Spearmint; LSD=Least significance Difference; CV=Coefficient of Variation; *, **, ***, indicate significance at P ≤ 0.05, p ≤ 0.01 and p ≤ 0.001 probability levels respectively; ns=not significant; Means in a column followed by the same letters are not significantly different at p≤ 5% level of significance; PD=population density.

Dry above ground biomass and leaf yield

The interaction effect of row arrangement and population density significantly (P ≤ 0.05) influenced dry above-ground biomass yield at first and second harvests and the total dry above-ground biomass yield of spearmint. The dry leaf yield of spearmint at first and second harvests and total dry leaf yield were significantly (P ≤ 0.05) affected by the interaction. The main effect of spatial arrangement did not show a significant (p>0.05) effect on dry above-ground yield at first harvest, and second harvest, and on total dry above-ground biomass yield of spearmint crop. Quite the reverse, population density had a (p ≤ 0.001) significant effect on dry above-ground biomass yield of spearmint.

The maximum dry above-ground biomass (1.52-ton ha^{-1} at first harvest, 3.23-ton ha^{-1} at second harvest), and total above-ground biomass (4.76-ton ha^{-1}) yield were obtained from 100% population density arranged in a double row arrangement of spearmint.

Whereas, the least (0.4-ton ha^{-1} at first harvest, 1.07-ton ha^{-1} at second harvest, and the total of 1.47-ton ha^{-1}) were recorded from 25% population density at 1:2 spatial arrangement of spearmint though statistically at par, with single row arrangement (Table 4). Also, like dry above-ground biomass yield, higher dry leaf yield of spearmint was higher (0.87-ton ha^{-1} at first harvest, and 1.91-ton ha^{-1} at second harvest) and total dry leaf yield (2.78-ton ha^{-1}) was recorded from 100% population density at double row arrangement as compere to single row arrangement in each harvesting cycle. Whereas, the least yields were obtained from 25% spearmint planting density (Table 4). These might be due to the direct relationship of dry yield with fresh above-ground biomass and leaf yield of spearmint. These findings were consistent with the results who reported that the higher sweet basil dry herbage yield is recorded from 100% population density at double row arrangement. The higher dry herbage yield at 100% population density of basil treatment attributed to competition free and the accommodation of the high number of basil per unit area contributes to producing high biomass and leaf yield.

On the other hand, the cropping system showed a significant ($P \leq 0.05$) effect on aboveground biomass and leaf yield of spearmint at each harvesting cycle. The maximum dry above-ground biomass yield of 2.7-ton ha^{-1} at the first harvest, 4.79-ton ha^{-1} at the second harvest, and a total above-ground biomass yield of 7.55-ton ha^{-1} were obtained under the sole crop (Table 4). Similarly, greater leaf dry weights of 1.3-ton ha^{-1} at first harvest, 2.82-ton ha^{-1} at second harvest, and a total of 4.15-ton ha^{-1} were obtained from the sole cropping system of spearmint (Table 4). The amounts of dry above-ground biomass yield reduction over intercropped crop were 35.29% at first harvest, 39.045% at second harvest, and a total of 40.85% compared to the sole crop. Reductions for dry leaf yield were 28.07% for the first harvest, 37.56% for the second harvest, and 37.87% for the total, for the same comparison (Table 4). These findings were in line with the result who reported maximum above ground and leaf yield from sole planting of stevia than intercropped treatments under haricot bean intercropped with stevia.

Table 4. Means for dry above-ground biomass and leaf yield of spearmint under maize-spearmint intercropping as affected by the spatial arrangement, population densities, and cropping system of spearmint.

Treatments	Dry above-ground biomass			Dry leaf yield (ton/ha)		
	1st harvest	2nd harvest	total	1st harvest	2nd harvest	total
Interactions						
1Mz:1Sm+100%PD	1.39^{b}	2.67^{b}	4.06^{b}	0.73^{bc}	1.66^{b}	2.40^{bc}
1Mz:1Sm+75%PD	1.36^{b}	2.71^{b}	4.07^{b}	0.69^{c}	1.60^{b}	2.29^{c}
1Mz:1Sm+50%PD	1.03^{c}	1.79^{c}	2.82^{c}	0.54^{d}	1.13^{c}	1.67^{d}
1Mz:1Sm+25%PD	0.44^{e}	1.16^{d}	1.60^{d}	0.29^{e}	0.66^{d}	0.95^{e}
1Mz:2Sm+100%PD	1.52^{a}	3.23^{a}	4.76^{a}	0.87^{a}	1.91^{a}	2.78^{a}
1Mz:2Sm+75%PD	1.39^{b}	2.63^{b}	4.02^{b}	0.79^{b}	1.68^{b}	2.47^{b}
1Mz:2Sm+50%PD	0.91^{d}	1.80^{c}	2.71^{c}	0.50^{d}	1.10^{c}	1.6^{d}
1Mz:2Sm+25%PD	0.4^{e}	1.07^{d}	1.47^{d}	0.26^{e}	0.65^{d}	0.91^{e}
LSD @0.05	0.10	0.26	0.29	0.07	0.14	0.164
CV (%)	5.60	7.05	5.22	7.29	6.14	4.97
Cropping System						
Sole	2.76^{a}	4.79^{a}	7.55^{a}	1.3^{a}	2.82^{a}	4.15^{a}
Intercropped	1.32^{b}	2.10^{b}	3.17^{b}	0.73^{b}	1.28^{b}	1.87^{b}
LSD @0.05	1.02	1.54	1.41	0.52	0.72	0.69
CV (%)	14.22	12.76	7.47	14.37	10.02	6.48

MZ=Maize; SM=Spearmint; LSD=Least Significance Difference; CV=Coefficient of Variation; PD=Population Density *, **, ***, indicate significance at P≤ 0.05, p≤ 0.01 and p≤ 0.001 probability levels respectively; ns=not significant; Means in a column followed by the same letters are not significantly different at p≤ 5% level of significance.

Essential oil content and yield

The essential oil content of spearmint was not significantly (P>0.05) affected by the spatial arrangement, spearmint population density, and their interaction. The cropping system effect was also non-significant (P>0.05) on the spearmint essential oil content whether it was solely planted or intercropped in each harvesting cycle. This might be due to genetic factors, environment, and cropping season compatibility. In agreement with the result of this study, the essential oil content of basil was not significantly affected by different planting densities whether it was solely planted or intercropped with hot paper. Similarly findings in the first and second harvesting cycle and total essential oil content is not showed a significant variation on spearmint intercropped with maize. But, contrary have reported that essential oil content linearly decreased with an increasing population density of basil intercropped with maize.

The treatment interactions significantly (P ≤ 0.001) influenced essential oil yield at first, and second harvest, and the total essential oil yield of spearmint. The maximum essential oil yield 18.15 kg ha^{-1} at first harvest, 28.69 kg ha^{-1} at second harvest, and the total of 46.85 kg ha^{-1} were attained from 100% population density at double row arrangement. The lowest (5.43 kg ha^{-1} at first harvest, 9.75 kg ha^{-1} at second harvest, and a total of 15.18 kg ha^{-1}) were recorded from 25% population density and double row arrangement (Table 5). This might be due to the proportional relationship of essential oil yield to the number of plants per unit area of land and also, may be due to higher leaf yield and also as it has a positive influence on moisture conservation and water use efficiency. This finding was in line with previous similar findings in onion intercropped with rosemary. A similar result was also reported who showed a reduction of oil yield of rosemary at 25% as compared to 100% of its intercropping with carrot. In line with the study, the maximum essential oil yield for densely populated basil. This could probably be due to the efficient utilization of growth resources eventually increased the oil yield of basil in higher population densities.

Table 5. Means for essential oil content (w/w, wet based (%) and essential oil yield of spearmint under maize-spearmint intercropping as affected by the spatial arrangement, population densities, and cropping system of spearmint.

Treatments	Essential oil yield (kg ha^{-1})		
	1st harvest	**2nd harvest**	**Total**
Interactions			
1Mz:1Sm+100%PD	14.98^{b}	23.11^{b}	38.09^{b}
1Mz:1Sm+75%PD	14.28^{b}	24.09^{b}	38.38^{b}
1Mz:1Sm+50%PD	11.15^{c}	16.41^{c}	27.56^{c}
1Mz:1Sm+25%PD	6.06^{d}	9.82^{d}	15.87^{d}
1Mz:2Sm+100%PD	18.15^{a}	28.69^{a}	46.85^{a}
1Mz:2Sm+75%PD	16.32^{ab}	23.94^{b}	40.26^{b}
1Mz:2Sm+50%PD	10.26^{c}	16.27^{c}	26.53^{b}
1Mz:2Sm+25%PD	5.43^{d}	9.75^{d}	15.18^{d}
LSD @0.05	2.88	1.97	3.005
CV (%)	13.62	5.92	5.51
Cropping System			
Sole	29.64^{a}	42.16^{a}	71.79^{a}
Intercropped	11.87^{b}	18.89^{b}	30.85^{b}
LSD @0.05	7.30	10.80	13.54
CV (%)	10.00	10.06	7.50

MZ=Maize; SM=Spearmint; LSD=Least Significance Difference; CV=Coefficient of Variation; *, **, ***, indicate significance at P ≤ 0.05, p ≤ 0.01 and p ≤ 0.001 probability levels respectively; ns=not significant; Means in a column followed by the same letters are not significantly different at p ≤ 5% level of significance; PD=Population Density.

Correspondingly, the cropping system also revealed a highly ($P \leq 0.01$) significant effect on first and second harvests and the total essential oil yield of spearmint. According to the present finding, essential oil yield at solitary cropping was greater by 42.80% at first harvest, by 38.11% at second harvest, and by 39.88% for total yield compared to those obtained under intercropping (Table 5). These reductions in essential oil yield of spearmint may be associated with the reduction of fresh leaf yields in the intercropped treatments. Similar results are obtained in maize spearmint intercropping where more than 40% yield reduction in intercropped was observed compared with the sole plots at each harvesting cycle. They noticed that the highest essential oil yield is obtained in solely planted rosemary than the one intercropped with onion. A similar result also reported that sole planted sweet basil essential oil yield was superior to intercropped with maize.

Productivity Indices of Maize-Spearmint Intercropping

Land Equivalent Ratio (LER)

Partial land equivalent ratio

ANOVA results revealed that the spatial arrangement, population density, and interaction of main factors were not significant ($P>0.05$) for maize partial land equivalent ratio, but numerically the higher (1.00) and lower (0.96) partial land equivalent ratio of maize were obtained from 25% and 100% population density at single or double row arrangements respectively. However, the partial land equivalent ratio of the intercropped spearmint was significantly ($P \leq 0.001$) affected by the interaction of spatial arrangement and spearmint planting density. The maximum (0.67) partial land equivalent ratio of spearmint was obtained from 100% population density arranged at a 1Mz:2Sm spatial arrangement. Whereas the minimum (0.21) from 25% population density at double row arrangement; was statically similar to the value of 0.23 recorded at single row arrangement from 25% population density. Overall, the partial land equivalent ratio of spearmint increased as spearmint population density increased in all maize spearmint combinations probably due to efficient utilization of resources and the higher population per unit area. A similar increment in partial LER of haricot bean with increases in planting density has been reported for intercropping haricot bean with maize.

Furthermore, when the two partial LER values were compared the partial land equivalent ratio of maize was higher than the partial LER of spearmint. Thus, the results indicate that maize was the major contributor to the mixture yield which also confirms the presence of greater competitive capacity of maize against spearmint and farmers' justification of growing the spearmint as an intercrop. During intercropping C4 plant (maize) with C3 plants, those species that have a C4 photosynthetic pathway derives more resource use efficiently than C3. Besides, maize had relatively larger upper canopy structures and the roots grow into a depth and explored larger areas compared to spearmint.

Total land equivalent ratio

The result of this experiment showed that the interaction effect of spatial arrangement and planting density of spearmint significantly ($P \leq 0.05$) influenced the total land equivalent ratio (LER). The total LER in all cases was more than unity showing that intercropping of spearmint with maize is more advantageous than the conventional monoculture crop (Table 6). Land equivalent ratio values greater than one indicates yield advantages of intercropping over monoculture. A land equivalent ratio of less than one indicates that more land is needed in the intercrop to equal the productivity of the monoculture in Nigeria reported that the total LER values were above 1.0 in all intercrop combinations of maize varieties with sweet basil.

The highest total LER (1.63) was recorded when spearmint was a double row arrangement at 100% population density followed by 75% population density at double row arrangement (1.58) (Table 6). These values indicated that intercropping gave 63 and 58% yield advantages and land-use efficiency respectively than planting sole crops. The higher LER in intercropping was attributed to better utilization of natural (land, CO_2, and light) and added (fertilizer and water) resources and intercropping advantages of weed reduction. This result is in agreement with the reports who observed an increment in total LER as haricot bean planting density increased from 25% to 100%. A similar finding was also reported by Lulie and Bogale (2014) who observed that haricot bean intercropped with medicinal crop (stevia) yield advantages of 63% and 54% were obtained at 80% and 60% stevia mix proportion. Also, stated that the maximum total LER (1.64) was reported from 75% of basil intercropping with maize.

Monetary Advantage Index (MAI)

The monetary advantage index was significantly (P ≤ 0.05) influenced by the spatial arrangement, population density, and their interaction. The MAI was significantly higher (71108 ETB ha^{-1}) at 100% population density followed by 75% (65257 ETB ha^{-1}) intercropped spearmint proportion at double row arrangement with maize without a significant difference; while the lowest (22360 ETB ha^{-1}) was obtained from 1:2 spatial arrangement and 25% population density, which was statistically like that observed under 1:1 spatial arrangement and 25% population density of spearmint (Table 6).

These results suggest that intercropping adds extra income and warrants insurance against the risk to the farmers. Therefore, the inclusion of spearmint under intercropping with maize in an intercropping scheme raised the yield advantage of intercropping over the sole crop as revealed by the highest total LER, and monetary advantage index. Supportive results were reported and intercropping of common bean at 100% planting density with roselle resulted in 39% yield advantage as well as giving 21,410 ETB monetary value. Also recommended that the population density of 100 and 75% of haricot beans in an intercropping gives the maximum monetary advantage to farmers, especially those with limited landholding. Another study involving interplanting spearmint with sugarcane gave a maximum of 44% to 63% profits. However, this result was contrary to that intercropping of haricot beans with stevia has given a negative MAI value at 40% and 20% stevia proportion due to LER values less than unity. This could be attributed to differences in the nature and performance of both the main and subsidiary component crops associated with the cropping system.

Table 6. Productivity measurement of intercropping of maize-spearmint as affected by population densities and spatial arrangement of spearmint.

Treatments	Partial LER of maize	Partial LER of spearmint	Total LER	MAI (ETB ha^{-1})
1Mz:1Sm+100%PD	0.96	0.57^{b}	$1.53b^{c}$	59054^{bc}
1Mz:1Sm+75%PD	0.97	0.54^{c}	1.51^{c}	56885^{c}
1Mz:1Sm+50%PD	0.96	0.41^{d}	1.37^{d}	39965^{d}
1Mz:1Sm+25%PD	1.00	0.23^{e}	1.23^{e}	24117^{e}
1Mz:2Sm+100%PD	0.96	0.67^{a}	1.63^{a}	71108^{a}
1Mz:2Sm+75%PD	0.99	0.59^{b}	1.58^{ab}	65257^{ab}
1Mz:2Sm+50%PD	0.98	0.38^{d}	1.36^{d}	39412^{d}
1Mz:2Sm+25%PD	1.00	0.21^{e}	1.21^{e}	22360^{e}
LSD @0.05	Ns	0.025	0.064	6668.4
CV (%)	3.36	3.20	2.57	8.06

*, **, *** significant at P ≤ 0.05, p ≤ 0.01 and p ≤ 0.001 probability levels respectively; ns=Not Significant Means in a column followed by the same letters are not significantly different at p ≤ 5% level of significance; SA=spatial arrangement; PD=Population Density; LER=Land Equivalent Ratio; LSD=Least Significance Difference; CV=Coefficient of Variation;%=percentage; ETB=Ethiopian birr; ha^{-1}=per hectare; Mz=maize; Sm=spearmint; MAI=monetary advantage index.

Conclusions and Recommendation

According to the result of the present study, there is no adverse effect of spearmint spatial arrangement, and population density on yield and all other parameters of maize when intercropped with spearmint. This might be due to the compatibility effect of component crops. Sole spearmint gave significantly higher fresh and dry above-ground biomass, leaf yield, and essential oil yield at each harvesting cycle than the intercropped mint. This might be attributed to the highly competitive nature and shading effect of maize on spearmint. But, the essential oil content of the spearmint was not (P>0.05) influenced by spatial arrangement and population density. A significant yield advantage and economic benefits were observed for the maize-spearmint intercropping over sole planting. Intercropping maize with a 100% spearmint population at a double row arrangement gave the best total LER of 1.63 and MAI of 71108. This was followed by a 75% spearmint population under a double row arrangement, which produced a total LER of 1.58 and MAI of 65275, which was statistically at par with 100% population density and a similar spatial arrangement. In general conclusion, through intercropping of maize with spearmint, farmers can achieve the full production of the main crop (maize) and also, an additional yield (bonus) associated with an increased plant population and double row arrangement of the second component (spearmint). Hence, intercropping justifies that planting maize in association with spearmint was more advantageous than planting it as a sole crop as it provides extra incomes obtained by smallholder farmers in areas where labor is not a shortage, like in the Wondogenet area, Southern Ethiopia. It also reduces risks involving market fluctuation and unfavorable growth conditions resulting from the growth of a single crop, which is more prone to climate variability. The farmers need to use the appropriate population and spatial arrangement of spearmint in intercropping systems to maximize biological efficiency and economic advantage. To this end, it is advisable for farmers to adopt a 75% spearmint population with one row of maize followed by two-row of spearmint to realize the best advantages from maize-spearmint intercropping at Wondogenet and areas with similar agroecology.

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