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Determination of Appropriate Planting Space and Vertical Numbers for Hybrid Arabica Coffee at Yeki District, Southwestern Ethiopia

Behailu Mekonnen[1*], Shiferaw Temeteme[1], Essubalew Getachew[2], Habtewold Kifelew[3], Tesfaye Shimber[4]

[1]Tepi National Spices Research Center, Tepi, Ethiopia
[2]Jimma University College of Agriculture and Veterinary Medicine, Jimma, Ethiopia.
[3]Holetta Agricultural Research Center, Holetta, Ethiopia
[4]Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia
*Corresponding author: Behailu Mekonnen, Tepi National Spices Research Center, P.O.Box, 34, Tepi, Ethiopia, Tel: +251-92-091-82-78; E-mail: behailumekonnenba@gmail.com

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An experiment was conducted at Tepi National Spices Research Center for five years, to determine the optimum planting space and vertical numbers that promote growth and yield of hybrid Arabica coffee variety. The treatments consisted of three levels of planting space (2.5 m x 2.5 m, 2.5 m x 2.0 m, 2.0 m x 2.0 m) and three vertical numbers (single stem, two stem, free growth). The experiment was laid out in Randomized Complete Block Design with three replications. The recorded data on yield and yield attributes like internode length of primary branches, number of bearing and non-bearing primary branches, number of nodes of primary branch and the main stem were significantly influenced by the interaction effects of planting space and vertical numbers. Similarly, the coffee yield was also significantly influenced by the interaction of planting space and vertical numbers. The highest plant height and internode length of primary branches were recorded at the same planting space of 2.0 m x 2.0 m with two stem and free growth habit, respectively. Whereas, the maximum node number on primary branches and main stem were recorded from treatments which had the same planting space (2.5 m x 2.0 m) with single stem and two stem, respectively. The maximum number of bearing primary branches was recorded from trees which treated with 2.0 m x 2.0 m with free growth habit. Likewise, the highest coffee yield was found in a planting space of 2.0 m x 2.0 m with free growth habit. Therefore, it could be concluded that using of an optimum planting space of 2 m x 2 m with free growth habit enhanced the growth, yield and yield components of hybrid coffee. However, it is important to repeat the study using other coffee varieties in their respective adaptable locations, and cup quality parameters also need to be done.

Key Words: Hybrid coffee, Pruning, Clean coffee, Planting space

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INTRODUCTION

Coffee belongs to the genus *Coffea* sub-genus *Coffea*, family *Rubiaceae* and is mostly present in tropical and subtropical regions of the world (Davis *et al.,* 2006). The species which are economically important and cultivated world-wide are *Coffea arabica* (Arabica coffee) and *Coffea canephora* (Robusta coffee) (Kathurima *et al.,* 2012). Ethiopia is the primary center of origin and diversification for Arabica coffee (Vavilov, 1951; Workafes and Kassu, 2000; Kebede and Bellachew, 2008). In Ethiopia, Arabica coffee grows under very diverse agro-ecologies and wider ranges of altitudes, temperature, rainfall, humidity and soil types (Mesfin and Bayetta, 1987). It grows wild in some forest areas, from semi Savannah climate of the Gambella plain (500 m.a.s.l.) to the continuously wet mountain forest zones of the southwest, in gardens and back yards of southeast and northern regions up to 2600 m.a.s.l. (Bayetta and Mesfin, 1986; Mesfin and Bayetta, 1987). The soil varies from sandy loam to heavy clay while the dominant soil types are acidic (pH 4.2-6.8) red, reddish brown lateric loams or clay loams of volcanic origin and total annual rainfall varies from 750 to 2,400 mm (Tewoldebirhan, 1988).

The crop is mainly produced in the South Western, Southern and Eastern parts of the country. According to Desalegn (2017), the total area coverage of coffee in Ethiopia is estimated to be around 800,000 ha, and an estimated annual national production is about 419,980.20 tons. Coffee production is important to the Ethiopian economy, it contributes about 60% of the country's foreign currency earnings (Desalegn, 2017). More than 15 million people directly or indirectly depend on coffee value chain for their income and employment (Petit, 2007; Jean-Pierre *et al.,* 2008; Desalegn, 2017). Moreover, about 35% of the total production is consumed within the producing areas (Chauhan *et al.,* 2015) and in general, over 50% of the coffee produced is consumed within Ethiopia (Bart *et al.,* 2014). Even though Ethiopia has high genetic diversity, diverse and suitable agro-ecologies and suitable land mass, the national coffee yield per unit area is generally low (748 kg ha^{-1}) (Mawardi, 1995). Since, the majority of coffee farmers in the country practice the old traditional cropping patterns. Besides, several production constraints were faced, among which the most important could be cultivation of unimproved coffee cultivars with poor agronomic practices, including low-density coffee planting patterns and inappropriate pruning practices.

Several studies have indicated that coffee may be more suited for a dense planting pattern. DaMatta (2004) reported that the productivity of densely planted coffee is generally much greater than that of traditional plantings. It has been also reported that a closely planting space favors the individual coffee plant to utilize the environmental resources such as light, moisture and nutrients throughout the growing period (Taye *et al.,* 2001). In other study, closely planted coffee results almost a complete ground coverage and better uptake of available soil nutrients by denser rooting (van der Vossen, 2005). In dense plantings, coffee roots develop deeper so that they take up water and nutrients from lower soil horizons (Cassidy and Kumar, 1984). Although a densely planting systems may increase production per unit area increases along with population density up to a certain level, but the yield per tree could be decreases with high planting density (Kuguru *et al.,* 1978). The reduction of yield per individual tree with close spacing may be attributed to the effect of shading on the number of fruit-bearing nods and fruit number per node (Kuguru *et al.,* 1978; Avelino *et al.,* 2005).

Pruning is an important cultural practice in management of modern coffee farms. It helps to create well-structured, healthy trees that give good yields over a long period of time without alternate bearing or biennial production (Weldemariam *et al.,* 2016). Moreover, it also favor in balancing fruit to leaf ratio that enhance the nutrient translocation (source to sink), facilitate harvesting and other crop managements (Yilma, 1986). However, past research attempts have not focused on details of coffee planting space and pruning practices for this growing area particularly for hybrid varieties. Accordingly, information is also scarce about the use of optimum planting space and pruning practices for hybrid varieties to widely adopt by coffee growers in the study area. Therefore, this study was proposed to solve the above stated research gaps for low land area like Tepi and its surrounding with the objective of determining optimum planting space and vertical numbers that promote yield of hybrid Arabica coffee variety.

MATERIALS AND METHODS

The experiment was conducted at Tepi National Spices Research Center (TNSRC) from the year 2012 - 2016. The center is located at 7° 10' N latitude and 35° 25' E longitude and situated at an altitude of 1200 m.a.s.l representing a lowland altitude according to Ethiopian traditional agro-ecological division, elevation is the basis for this classification (Dereje and Eshetu, 2011). It is characterized by hot humid with an average annual rainfall of 1559 mm (EIAR, 2012) and mean maximum and minimum temperature of 30.23 ºC and 16.09 ºC, respectively (Girma *et al.,* 2008). The soil type of the experimental site is classified as Nitisols and Fluvisols with minor occurrence of Leptosols, which is dominated by a loam texture with a pH range of 5.60 to 6.0 (Abayneh and Ashenafi, 2005). The soil depth is very deep (>150 cm) and have a color of dark brown (7.5 YR3/2) when moist. The organic matter content is medium to very high (2.47 to 7.02%) according to Murphy (1968) classification. The total nitrogen content is low to very high (0.09 to 0.73%) according to Tekalign *et al.* (1991) classification, while the available phosphorus is

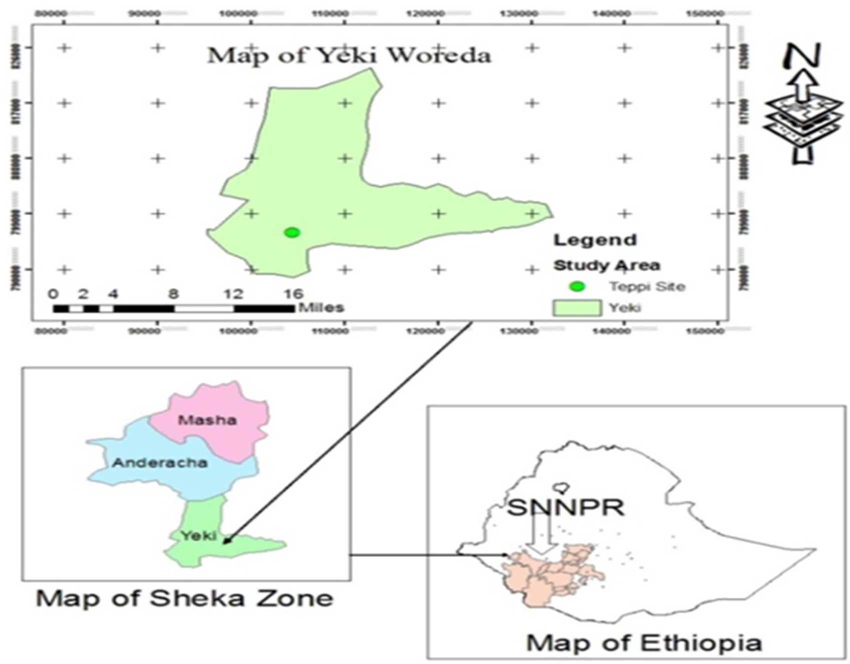

Figure 1. Administrative map of the study area (Source: Regional statistic and population office of SNNPR)

low to medium (0.97 to 7.36 ppm) based on the rating of Olsen *et al.* (1954). (Figure 1)

The treatments consisted of three levels of planting space; Sp_1 (2.5 m x 2.5 m), Sp_2 (2.5 m x 2.0 m), Sp_3 (2.0 m x 2.0 m) and three types of vertical numbers; P_1 (single stem), P_2 (two stem), P_3 (free growth). The plant population density for Sp_1, Sp_2 and Sp_3 were 1600, 2000 and 2500 tree ha^{-1}, respectively. The experiment was conducted in RCBD with factorial arrangement of 9 treatment combinations (3 planting space x 3 vertical number) in three replications. The experimental area was divided in to three blocks, nine experimental plots were enclosed by each block and each experimental plot was held a total of 30 trees. Hybrid Arabica coffee variety (74165 x Dr1) was used for this experiment. Coffee seedlings were transplanted in June 2012, based on their respective spacing. Training and pruning of coffee tree were also practiced as per the treatment arrangement, except for the free growth one. For two vertical stems, pruning was done when the seedlings reached at the height of 45 cm above ground to allow two active stem per plant. All routine field management activities were uniformly and timely applied as per the recommendations.

Yield and yield component parameters were recorded from ten representative trees for each experimental plots, the representative trees were randomly selected only from the central rows. The data collected were; number of primary branches, number of nodes of primary branch, number of nodes of the main stem, stem girth (cm) and canopy diameter (cm), internode length of primary branch (cm), number of bearing and non-bearing primary branches and coffee yield (kg ha^{-1}) data were recorded from the representative sample trees.

The method of data collection for each parameter was as follows;

Number of primary branches: This parameter was recorded by counting the number of primary branches.
Number of nodes of primary branch: This parameter was recorded by counting the number of nodes.
Number of nodes on main stem: Measured as a total number of nodes count per tree
Stem girth (cm): This was measured above 5 centimeter at the ground level using caliper
Canopy diameter (cm): Average length of tree canopy measure twice, east-west and north- south, from the widest portion of the tree canopy
Internode length on longest primary branch (cm): This parameter calculated as LLPB/NNPB, where Length of longest primary branch (cm), NNPB = number of nodes on longest primary branch.
Number of bearing and non-bearing primary branches: This was measured by counting the number of bearing and non-bearing primary branches per tree
Coffee yield (Kg ha^{-1}): Fresh cherry weight that had already been recorded per tree bases was used and converted to clean coffee in quintals per hectare.

Table 1. Number of bearing and non-bearing primary branches of hybrid coffee as influenced by the interaction of planting space and vertical numbers.

Treatments	Number of Bearing Primary Branches Plant^{-1}			Number of Non-bearing Primary Branches Plant^{-1}		
	Sp_1	Sp_2	Sp_3	Sp_1	Sp_2	Sp_3
P_1	21.80 ^{e}	39.73 ^{bc}	46.80 ^{ab}	11.80 ^{e}	16.33 $^{a-d}$	19.47 ^{a}
P_2	28.00 ^{de}	42.87 ^{bc}	42.87 ^{bc}	14.97 $^{b-e}$	16.07 $^{a-d}$	17.17 ^{abc}
P_3	26.33 ^{de}	35.03 ^{cd}	53.03 ^{a}	13.50 ^{cde}	12.57 ^{de}	18.70 ^{ab}
CV%	23.80			26.19		
$LSD_{(0.05)}$	*			*		

*Means followed by the same letter within a column are not significantly different at 5% level of significance; *= significance at 5% probability, CV= coefficient of variance; LSD= least significance difference;* Sp_1*= 2.5m*2.5m,* Sp_2*= 2.5m*2.0m,* Sp_3*= 2.0m*2.0m,* P_1*= single stems,* P_2*= two stems,* P_3*= free growth.*

Data Analyses

The collected data were subjected to statistical analysis. Analyses of variance was carried out using SAS version 9.2 English (SAS, 2008). Significant differences between and or among treatments were delineated by Least Significant Differences (LSD) at 5% probability (Gomez and Gomez, 1984).

RESULTS AND DISCUSSIONS

Effect of Different Planting Space and Vertical Number on Growth Parameters of Hybrid Arabica Coffee

Number of bearing and non-bearing primary branches

From the result, number of bearing primary branch was significantly ($P<0.05$) affected by the main effects of planting space and by the interaction effects of planting space and vertical numbers. However, number of bearing primary branch was not significantly affected by the main effects of vertical numbers (Table 1). Number of bearing primary branch was linearly increased along with plant population number. Thus, the maximum number of bearing primary branches were recorded from coffee tree which was planted in 2.0 m x 2.0 m with free growth followed by the treatment which received a two stem with the same planting space. Whereas, the minimum number of bearing primary branches were recorded from coffee tree which was planted in 2.5 m x 2.5 m with two stem (Table 1).

Similarly, number of non-bearing primary branch was significantly ($P<0.05$) affected by the main effects of planting space and by the interaction effects of planting space and vertical numbers. However, a main effect of vertical numbers does not influence the non-bearing primary branch number per plant. Thus, the maximum number of non-bearing primary branches was recorded from coffee tree which was planted in 2.0 m x 2.0 m with two stems. However, it was statistically non-significance difference with the treatments; two stem with 2.0 m x 2.0 m and free growth with 2.0 m x 2.0 m. While, minimum number of non-bearing primary branches were recorded from coffee tree which was planted in a narrow space (2.0 m x 2.0 m) with two stems (Table 1).

The increase in bearing primary branches per tree with increasing tree population number has been attributed to efficient utilization of environmental inputs, viz. light, moisture and nutrients, until the biological optimum is attained (Taye *et al.,* 2001). In the same way, the non-bearing primary branch number was linearly increased along with plant population number (Table 1). This result could be associated with high coffee tree population density with enhanced branching leading to insufficient utilization of nutrients for each individual tree. Moreover, it might be due to less light absorption by individual tree due to high mutual shading effects of closely planted coffee trees (Endale *et al.,* 2006).

Stem girth and canopy diameter

The recorded data on stem girth of coffee tree was not significantly influenced by the interaction and main effects of planting space and vertical number. Which indicates that there is no variation in coffee stem girth due to the effect of different population density and vertical numbers. Thus, the maximum stem girth was recorded at a planting space of 2.5 m x 2.0 m, and from free grown coffee tree (Figure 2). Similarly, the canopy diameter was not significantly ($P<0.05$) affected by the main effects of vertical number and interaction of factors being studied. A wide canopy was observed from both free grown tree and closely planted tree (Figure 3).

Internode length of primary branches

Internodes length of primary branch was significantly

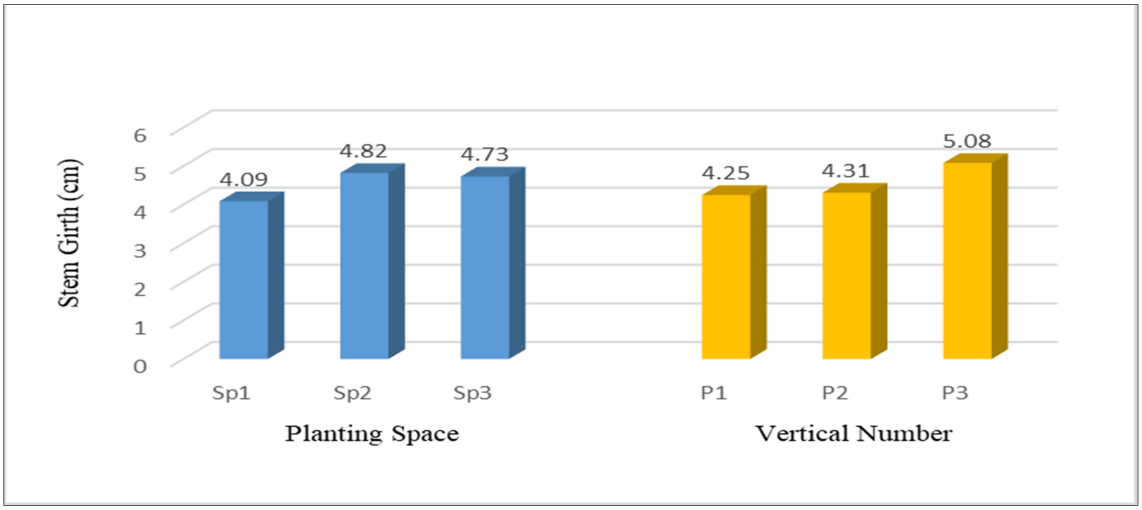

Figure 2. Effect of (a) planting space and (b) vertical number on stem girth of coffee tree

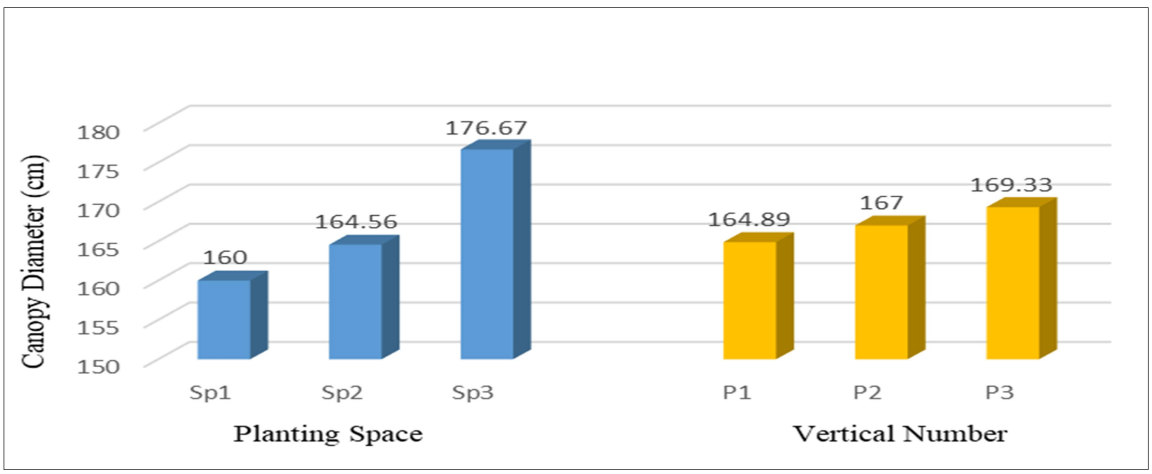

Figure 3. Effect of (a) planting space and (b) vertical number on canopy diameter of coffee tree

Table 2. Internode length of primary branches of hybrid coffee as influenced by the interaction of planting space and vertical numbers.

Treatment	Internode Length of Primary Branches (cm)		
	Sp_1	Sp_2	Sp_3
P_1	4.70 ^{bc}	4.22 ^{de}	4.48 ^{cd}
P_2	4.78 ^{b}	4.59 ^{bc}	4.59 ^{bc}
P_3	5.20 ^{a}	4.11 ^{e}	4.53 ^{bc}
CV%		5.90	
$LSD_{(0.05)}$		*	

*Means followed by the same letter within a column are not significantly different at 5% level of significance; *= significance at 5% probability, CV= coefficient of variance; LSD= least significance difference; Sp_1= 2.5m*2.5m, Sp_2= 2.5m*2.0m, Sp_3= 2.0m*2.0m, P_1= single stems, P_2= two stems, P_3= free growth.*

($P<0.05$) affected by the main effect of planting space and vertical numbers, as well as by the interaction effect of the two factors. Thus, the highest internodes length was recorded from coffee tree which was planted in 2.5 m x 2.5 m with free growth followed by the treatment which consists of similar planting space with two stems. Whereas, the lowest internode length was recorded from coffee tree which was planted in 2.5 m x 2.0 m with free growth habit (Table 2). This result could be association with the wide planting space of coffee tree, thereby the

Table 3. Number of nodes of primary branch and main stem as influenced by the interaction of planting space and vertical numbers

Treatment	Number of Nodes of Primary Branches			Number of Nodes of the Main Stem		
	Sp_1	Sp_2	Sp_3	Sp_1	Sp_2	Sp_3
P_1	19.53 bc	21.04 a	18.66 cd	34.43 c	48.07 ab	47.27 ab
P_2	17.93 de	19.98 ab	19.41 bc	45.30 ab	50.33 a	39.63 bc
P_3	17.31 e	20.57 ab	19.49 bc	46.17 ab	39.87 bc	39.57 bc
CV%	6.30			21.03		
$LSD_{(0.05)}$	*			*		

*Means followed by the same letter within a column are not significantly different at 5% level of significance; *= significance at 5% probability, CV= coefficient of variance; LSD= least significance difference; Sp_1= 2.5m*2.5m, Sp_2= 2.5m*2.0m, Sp_3= 2.0m*2.0m, P_1= single stems, P_2= two stems, P_3= free growth.*

Table 4. Clean coffee yield as influenced by the interaction of planting space and vertical numbers.

Treatment	Clean Coffee Yield (kg ha^{-1})		
	Sp_1	Sp_2	Sp_3
P_1	727.50 bcd	509.33 d	650.17 cd
P_2	581.00 d	846.33 abc	680.33 cd
P_3	863.87 abc	953.47 ab	1028.93 a
CV%	33.59		
$LSD_{(0.05)}$	*		

*Means followed by the same letter within a column are not significantly different at 5% level of significance; *= significance at 5% probability, CV= coefficient of variance; LSD= least significance difference; Sp_1= 2.5m*2.5m, Sp_2= 2.5m*2.0m, Sp_3= 2.0m*2.0m, P_1= single stems, P_2= two stems, P_3= free growth.*

primary and secondary branches might be grown faster and elongated.

Number of nodes of primary branch and main stem

Number of nodes of primary was significantly (P<0.05) affected by the interaction of planting space and vertical numbers, as well as by the main effects of both factors. Thus, the highest node number in primary branch was recorded from treatment in which coffee planted in 2.5 m x 2.0 m with two stems, but statistically it is similar with two stems and free growth with a planting space of (2.5 m x 2.0 m). Whereas, the lowest node number on primary branch was recorded from coffee tree which was planted in 2.5 m x 2.5 m with free growth habit (Table 3). On the other hand, number of nodes of the main stem was significantly (P<0.05) affected by the interaction effects of planting space and vertical numbers, as well as by the main effects of planting space. The highest node number on the main stem was recorded from coffee tree which was planted in 2.5 m x 2.0 m with two stems. While, the lowest node number on the main stem was recorded from coffee tree which was planted in 2.5 m x 2.5 m with two stems (Table 3).

As a result, two stems with optimum population density increase primary branches and node number, which is associated with enhanced branching and increasing of light interception by individual coffee tree (Yacob *et al.,* 1993). On the other hand, the response of node number on the main stem could be associated with the enhanced growth of two verticals height.

Effects of different planting space and vertical numbers on clean coffee yield

Clean coffee yield was significantly (P<0.05) influenced by the interaction effects of planting space and vertical numbers, as well as by the main effects of vertical numbers. The yield showed an increment as the population density of coffee tree increased. Thus, the highest clean coffee yield was obtained from closely planted coffee (2.0 m x 2.0 m) with free growth habit followed by the treatment which is a planting space of 2.5 m x 2.0 m with free growth habit. Whereas, the lowest clean coffee yield was obtained from treatment which is a planting space of 2.5 m x 2.0 m with two stems (Table 4).

The coffee yield increases with population density of coffee tree, it could be attributed to efficient utilization of environmental inputs, viz. light, moisture, nutrients, until the biological optimum is attained (Taye *et al.,* 2001).

Moreover, the free growth habit of coffee gave higher yield as compared to multiple stem uncapped and multiple stem capped growth habit.

CONCLUSION

Based on the outcome of the study, planting space and vertical numbers had a significant effect on yield and yield attributes, viz., number of bearing and non-bearing primary branches, length of internode, node number on primary branch and main stem, yield of coffee. The clean coffee yield was increased as the number of coffee tree increased or population density increased. The highest coffee yield was found from closely planted coffee tree (2.0 m x 2.0 m) with a free growth habit. Therefore, it could be concluded that using of optimum planting space of 2 m x 2 m with free growth habit enhanced the growth, yield and yield components of hybrid coffee in the study area and its surrounding as well. However, it is important to repeat the study using other coffee varieties in their respective adaptable locations, and cup quality.

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