Review of Arabica Coffee Management Research in Ethiopia

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Abstract

Coffee seeds with moisture content grater than 40% when stored in moisture vapor barrier containers, *viz.* glass jar and polythene bag had retained their viability and vigor for a longer period. However, sowing coffee seeds immediately after harvesting and processing was found to be the best option for higher germination rate and better seedling growth. Pre-germination is the primary cause of multiple and crooked tap roots and eventual tree death in the field. Forest soil or a mixture of top soils (TS), compost and sand (S) in 3 : 1: 0 and 2 : 1 : 1 ratios or blends of organic manure and TS in 1 : 4, 2 : 4 and 3 : 4 ratios resulted vigorous seedling growth. Applying 750 mg P or a combination of 2.31 g lime and 250 mg P pot^{-1} (2.5 kg sieved TS) ensured production of quality seedlings. Sowing coffee seeds at a depth of 1 cm with the grooved side placed down and embryo tip up had improved germination. Seedbeds covered with 3 - 5 cm thick mulch after seed sowing and watered at 2 days interval until hypocotyl emergence had higher germination percentage. After emergence, with the removal of mulch, nursery beds provided with 50% over head shade and irrigated twice a week until seedlings attained 2 to 4 pairs of leaves and then after at a week interval produced vigorous seedlings. Sowing clean coffee seeds after soaking in cold water for 24 hours hastened germination and seedling growth. Soft wood single node cuttings with one pair of leaves and blends of TS, S, and manure in 2 : 2 : 1 ratio was recommended for vegetative propagation of hybrid coffee. Rrejuvenation practices, *viz.* topping, agobiado and eskeletamento increase forest coffee yield by 43.2, 40.4 and 38.0% over clean stumping and 12.5, 8.4 and 4.7% over control (not rejuvenated trees), respectively. Earlier stumping immediately after harvesting tends to promote yield. Coffee trees stumped at 50 cm height had slightly higher yield than the conventional 30 cm stump. Tied ridge gave respective yield advantage of 19.0 and 23.6% over untied ridge and traditional flat land field. Maintaining 3 - 4 bearing heads per tree or stump and adjusting plant population to 4000 - 5000, 5000 - 6000 and 7000 - 8000 trees ha^{-1} had maximized productivity of forest coffee at Tepi, Jima and Metu and Agaro, respectively. On the other hand, forest coffee stands did not respond to mineral fertilizer application and weed management. Deeper and wider hole size and transplanting July/August increased field survival rate of coffee seedlings. Tractor and oxen cultivation, planting coffee seedlings 10 cm deeper than the collar level and ball root transplanting mehod had significantly improved early growth performance and survival rate of of the plants. *Millettia ferruginea, Albizia* spp. and *Acacia abyssinica, Erythrina abyssinca, Calpurnea subdecondra* and *Cordia africana* shade trees promoted coffee yield especially when strip planted with coffee trees. Based on the canopy architecture three distinct morphological classes (open, intermediate and compact) Araabica coffee types are identified. High density planting increased coffee yield especially in the open sun fields; however its efficiency has been found to vary depending on the canopy nature of coffee plant and agro-ecological condition of the area. The use of locally available and cheap organic fertilizer sources such as coffee husk and manure as complements to mineral fertilizer was found to be very important for sustainable soil fertility amendment and promotion of organic coffee production. Intercropping did not significantly affect growth and development of coffee trees when planted in proper combinations. Among coffee cultivars, the compact types were more suitable for intercropping than the intermediate and open coffee type to sustain crop yields. Moreover, higher yield advantage was obtained from intercropped plots as compared to sole stands. This was particularly noticed for annual crops at early stage and with lower coffee population and decreased with increasing years of coffee production. Similarly, the gross monetary benefits were greater due to intercropping coffee with potato, turmeric and ginge than for sole coffee plots. In general intercropping coffee with locally adapted and compatible cash and food crops is agronomically beneficial and economically feasible in south and southwest Ethiopia.

Keywords: Arabica coffee, coffee seed, forest coffee, intercropping, plantation coffee

Introduction

In Ethiopia, coffee (*Coffea arabica* L.) production systems grouped into four , *viz.* forest, semi-forest, garden and modern plantations accounting for 10, 35, 50 and 5% of the total production, respectively (Workafes and Kassu, 2000). Despite the existence of enormous genetic diversity and importance of the crop in the national economy of the country, its production potential hardly exceeds 0.7 ton ha^{-1} clean coffee (Central Statistical Authority, 2012). Such a low productivity of the crop stems from the use of weak and weepy seedlings with undesirable shoot and root growth for field transplanting, erroneous management of the plant during the initial and latter stage in the field. These emanate from poor seed preparation and handling, use of deteriorated seeds as planting material and growing media not suitable for germination and seedling growth, improper depth of seed sowing, pre-germination practice and inadequate or excessive shading and watering during the nursery period, exhaustion due to aging, unregulated tree growth and population density, drought, inadequate or excessive light or shade, low soil fertility and undulating topography and associated factors, such as soil erosion (Paulos, 1994; Wondyifraw, 1994; Institute of Agricultural Research, 1996; Yacob *et al.*, 1996; Tesfaye *et al.*, 2005).

In order to alleviate the constraints several pre- and -post seed sowing and field management practices have been tested aiming at promoting quality coffee production in the country. Therefore, outstanding research achievements generated so far pertaining to coffee seed and nursery management, and forest and coffee plantation management in Ethiopia are reviewed and briefly presented in this paper.

Research Findings

1. Pre-sowing coffee seed management

1.1. Stage of fruit maturity and seed drying

Stage of harvest of the cherries, the condition of processing and drying affect germination of coffee seeds. In line with this, results revealed that red ripe cherries are the best stage of maturity for seed purpose (Figure 1a). After pulping the cherries and removing the floaters, drying parchment intact seeds in a well aerated, cool and shaded condition till they attained the desired moisture level before sowing/planting or further storage ensured higher germination percentage (Figure 1b).

1.2. Seed storage time

Studies revealed that coffee seed germination percentage, percentage of seedling emergence (%E) and seedlings attained first true leaves (%FTL) decreased gradually since the second month and rapidly after the third month of storage (Figure 2 and Table 1). Besides, mean days to germination (MDG) and mean days to first true leaves (MDFTL) consistently delayed with prolonged storage time (Table 1). Thus, immediate sowing after harvesting and processing is always the best option for higher germination and subsequent growth (Wondyifraw, 1994; Tesfaye *et al*., 1998; Anteneh *et al*., 2008; Anteneh, 2015).

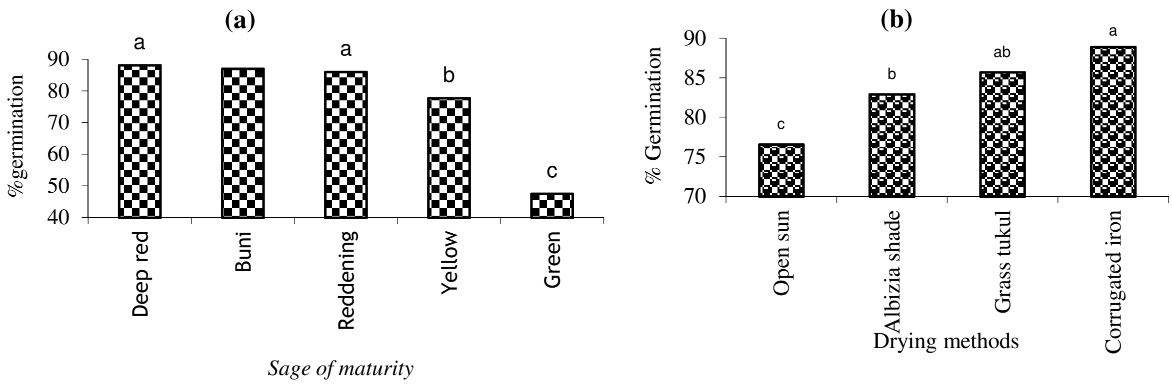


Figure 1. Germination of coffee seeds as affected by stage of fruit maturity (a) and drying condition (b). Bars capped with same letter(s) are not significantly different at 0.05 probability level. *Source: Anteneh et al. (2008) and Anteneh (2015).*

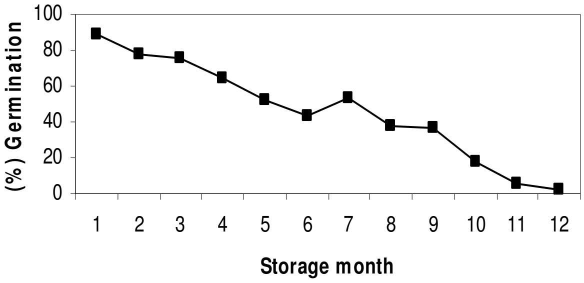


Figure 2. Effect of time of storage on germination of coffee seed. *Source: Tesfaye et al. (1998)*.

Table 1. Effect of time of storage on coffee seed germination and growth performance of seedlings

Storage time in month	%E	%FTL	MDG	MDFTL
0*	93.9^{a}	88.4^{a}	32.2^{f}	94.2^{f}
1	84.4^{b}	76.2^{b}	39.6^{e}	99.4^{e}
2	81.0^{c}	76.9^{b}	41.6^{d}	105.4^{d}
3	78.0^{d}	69.2^{c}	44.^{7c}	109.5^{c}
4	55.5^{e}	51.7^{d}	52.1^{b}	114.2^{b}
5	51.0^{f}	43.6^{e}	59.9^{a}	116.3^{a}

Figures followed by same superscript letters within a column are not significantly different at 0.01 probability level. *The time just at the date of storage. %E = Percentage of seedling emergence; %FTL = percent age seedling attain first true leaves; MDG = Mean days to germination and MDFTL = mean days to first true leaves. *Source: Wondyifraw (1994).*

1.3. Seed moisture content and types of container

A combination of high initial seed moisture level (not less than 40%) and moisture vapor barrier containers relatively better preserved coffee seed viability longer and improve growth of coffee seedlings. Accordingly, Wondyifraw (1994) reported a combination of seeds with moisture content of 55.2% and glass jar resulted 97.5, 84.5 and 89.1% values for seed germination, seedling emergence and seedlings attain first true leaf stage after five months of storage. While seeds stored at 45.2% moisture content in plastic bag (polythene tube) resulted 89.0, 82.0 and 86.3% values for the respective parameters (Figure 3 a, b and c).

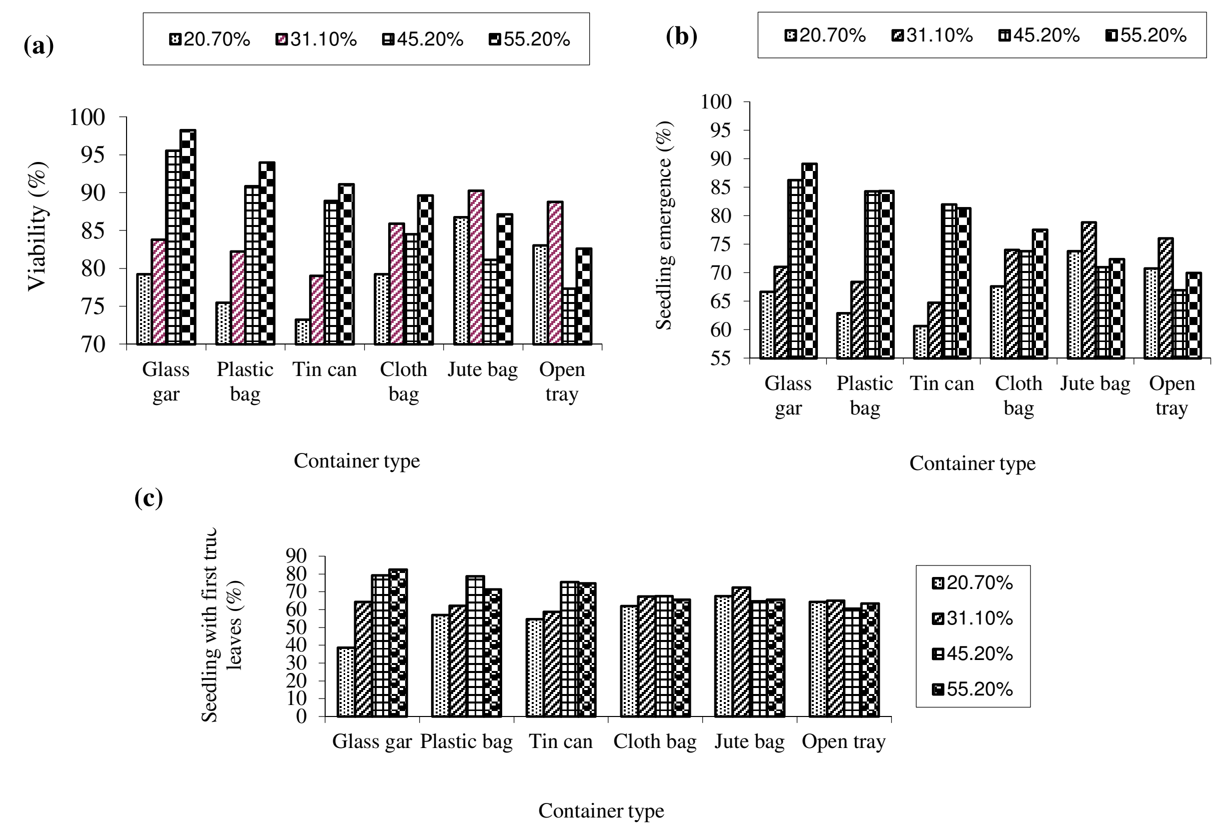


Figure 3. Effect of initial seed moisture level and type of container on coffee seed viability (a), seedling emergence (b) and seedling attain first true leaves growth stage (c). Source: *Wondyifraw (1994).*

1.4. Pre-germination practices

Available reports showed that pre-germinated and planted seeds had resulted large percentage of seedlings with deformed roots, *viz.* multiple and crooked tap roots (MTR and CTR, respectively) than sowing *in situ* in permanent bed (direct sowing) (Table 2). The practice can also delay the growth of seedlings and thus large percentage of cotyledon and first pair of true leaves was initiated much earlier from direct sowing than pre-germination practice (Figure 4a and b). Hence, coffee seeds should be seeded directly in seedbeds or polythene tube for the production of seedlings with normal root system than following the pre-germination techniques.

Table 2. Effect of planting normal (not pre-germinated) and pre-germinated coffee seeds in conventional seedbed, and fine (sieved) and course (unsived) soils filled in polythene tube on percentage of multiple tap root (MTR) and crude tap root (CTR).

Treatments	Fine soil		Coarse soil		Conventional seedbed	
	MTR	CTR	MTR	CTR	MTR	CTR
PGS	31	66	32	70	20	66
DS	1	24	6	20	0	30
LSD (0.05)	7.4	21.5	7.4	21.5	-	-
(0.01)	10.1	29.5	10.11	29.5	-	-

PGS = Pre-germinated seed and DS = direct sowing (not pre-germinated seeds). *Source: Bayetta and Mesfin (2005*).

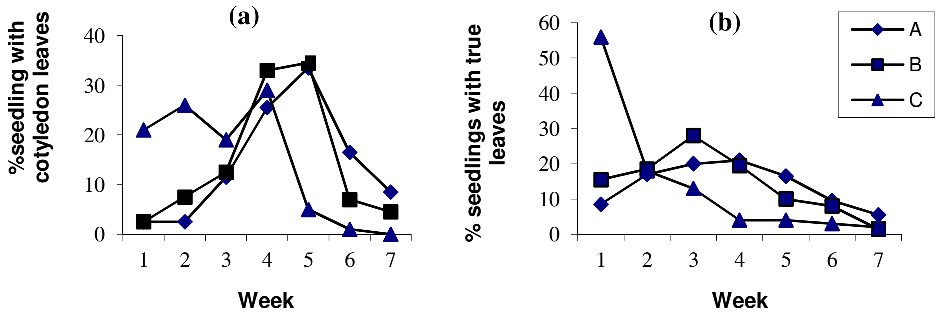


Figure 4. Weekly differences in the proportion of seedlings with cotyledon (a) and first pair of true leaves (b) for treatments A= Pre-germinated and planted in polythene tube, B = Pre-germinated and planted on conventional seedbed, and C= Direct sowing on seedbed. *Source: Bayetta and Mesfin (2005*).

1.5. Parchment removal and seed soaking

Sowing parchment removed coffee seeds had significantly promoted mean days to emergence as compared to parchment seeds (Figure 5). The practice could also enhance seedling growth (Table 3) and shortens the nursery period by about four weeks (Taye and Alemseged, 2007). Though the difference is not considerable, soaking coffee seeds in cold pure water for 24 hours immediately before sowing had improved rate of emergence, particularly during the early stage after sowing (Figure 5) and produced vigorous seedlings than unsoked seeds (Table 3).

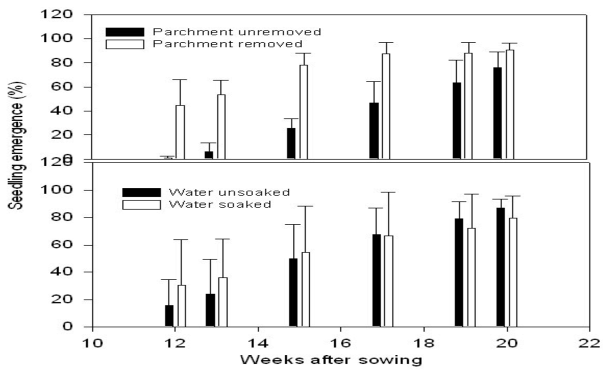


Figure 5. Effect of pre-sowing seed treatment on rate of seedling emergence of Arabica coffee seedlings. *Source:*

Table 3. Growth parameters (means ± SD) of coffee seedlings as influenced by pre-sowing seed treatments.

Growth character	Parchment removal		Water soaking	
	Unremoved	Removed	Unsoaked	Soaked
Height (cm)	28.02 ± 6.16	28.77 ± 2.89	27.33 ± 3.24	29.46 ± 5.78
Stem diameter (cm)	0.46 ± 0.08	0.49 ± 0.05	0.46 ± 0.04	0.48 ± 0.08
No. of true leaf pair	7.00 ± 0.32	7.50 ± 0.89	7.00 ± 0.71	7.50 ± 0.63
Shoot dry matter (g)	2.88 ± 1.03	3.60 ± 0.86	3.15 ± 0.63	3.32 ± 1.30
Root dry matter (g)	0.70 ± 0.22	0.77 ± 0.16	0.72 ± 0.19	0.74 ± 0.20
Total dry matter (g)	3.58 ± 1.22	4.36 ± 1.01	3.88 ± 0.78	4.06 ± 1.50
RGR* (g month^{-1})	0.58 ± 0.26	0.74 ± 0.20	0.62 ± 0.21	0.70 ± 0.31

*RGR = Relative growth rate. *Source: Taye and Alemseged (2007*).

2. Coffee nursery management

2.1. Nursery media

Coffee seedlings can be grown on raised beds (15 cm height) or in polythene tube (10 - 12 cm diameter and 22-25 cm height) filled with forest soil collected from the top 5 - 10 cm depth. However, in the absence of forest soil (FS), it was recommended to use blends of top soil (TS) and compost (C) only or TS, C and sand (S) following the order of 3TS : 1C : 0S > 2TS :1C 1S > 2TS : 1C : 0S > 6TS : 3C :2S (Figure 6). Likewise, Taye *et al*. (1999) revealed that a mixture of locally available organic manure and TS in 1 : 4, 2 : 4 and 3 : 4 ratios had promoted both shoot and root growth of coffee seedlings. However, if this media blends is suspected to be low in plant nutrients, addition of 2 g DAP/seedling after the seedling attain two pairs of true leaves would improved seedling growth (Taye *et al*., 1999).

2.2. Media amendment

It has been reported that application of 0 g lime and 750 mg P and 2.31 g lime and 250 mg P/pot (2.5 kg sieved top soil) produced seedlings with the higher dry matter yield (Figure 7). This was primarily associated to the rise in soil pH and precipitation of the exchangeable almunium that fixes P and increase in solubility and availability of soil P to the seedlings (Anteneh and Heluf, 2007).

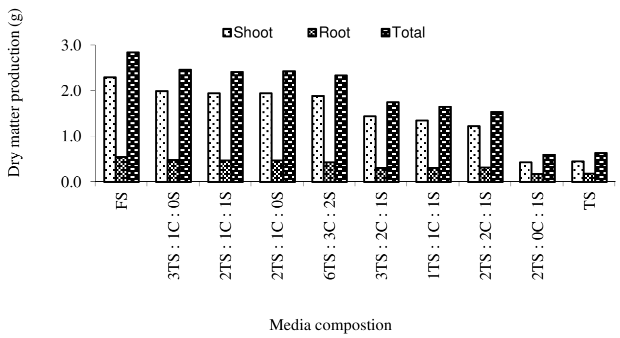


Figure 6. Effect of different media composition on dry matter production of coffee seedlings. TS = Top soil; C = Compost and S = Sand. *Source: Taye et al. (2002).*

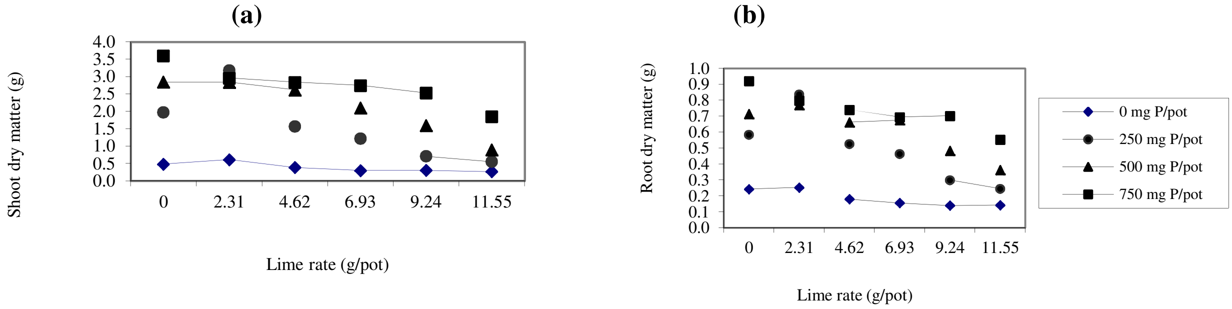


Figure 7. Effects of interaction of lime and P rates on shoot (a) and root (b) dry matter of coffee seedlings. *Source: Anteneh and Heluf (2007).*

2.3. Seed sowing

For maximum germination, coffee seeds should be sown at a depth of 1 cm with grooved side of the seed down and the embryo tip up. However, seed germination rapidly decline with sowing depth greater than 1 cm (Table 4).

Table 4. Effect of sowing depth and position of seeds on percent germination of coffee seeds.

Sowing depth (cm)	Seed position				Mean
	Grooved side		Embryo tip		
	up	down	up	down	
0	80.1	80.9	76.2	85.7	**80.7**
1	80.9	85.7	90.7	69.0	**81.6**
2	64.3	69.1	69.0	69.0	**67.9**
5	23.8	23.8	28.6	26.2	**25.7**

Source: Yacob (1986).

2.4. Watering seedbeds

It was observed that coffee seed beds covered with 3 - 5 cm thick mulch need to be watered at 2 days interval until seedling emergence during the dry season. After emergence by removing mulch and providing moderate overhead shade, watering seedbeds twice a week until seedlings produce 2 to 4 pairs of true leaves and then after at a week interval resulted vigorous seedlings (Tesfaye *et al*., 2005).

2.5. Mulching seedbeds

Seedbeds covered with 3 - 5 cm thick mulch of straw or dried grass, banana or enset leaves etc., immediately after sowing had resulted in significantly higher germination percentage than did mulch + shade and shade alone (Figure 8). Relatively higher germination response to mulch alone could be ascribed to regulation of the diurnal temperature in the nursery beds, which ensued from its insulating nature against fluctuations of soil temperature. However, the mulch should be removed and replaced by moderate (50 - 75%) overhead shade when the seedlings start to emerge.

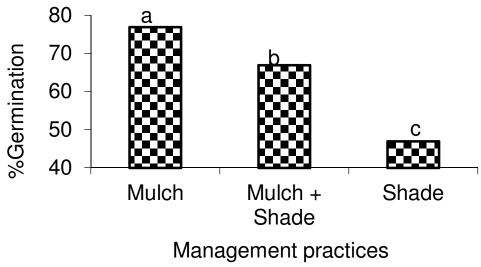


Figure 8. Germination percentage of coffee seeds as affected by mulch, shade and their combination. Bars capped with different letter(s) are significantly different at 0.01 probability level. *Source: Yacob (1986).*

2.6. Overhead shade

Provision of moderate level of over head shade (25 - 75%, but 50% is the best option) to coffee seedlings upon emergence and removal of mulch resulted vigorous seedling growth with the highest total dry matter yield and relative water content and improve moisture content of the rooting medium (Table 5). To harden the seedlings, it is recommended that the watering frequency and the overhead shade level should gradually be reduced one month ahead of transplanting to the field at a stage of six to eight pairs of true leaves (Tesfaye *et al*., 2006).

Table 5. Effect of shade level on growth and relative water content of seedlings (RWC) and medium moisture content (MMC).

Shade level (%)	Plant height (cm)	Leaf number	TDM* (g) of seedling	RWC (%)	MMC (% by volume)
0	24.7^{c}	14.4^{c}	5.3^{c}	64.9^{b}	14.6^{b}
25	28.5^{b}	15.3^{b}	6.1^{b}	68.0^{a}	21.7^{a}
50	30.0^{a}	17.0^{a}	6.6^{a}	68.5^{a}	22.8^{a}
75	30.2^{a}	15.1^{b}	6.1^{b}	68.9^{a}	23.5^{a}

Means within a column followed by same superscript are not significantly different at 0.01 probability level.

*TDM = Total dry matter. *Source: Yacob et al. (1996).*

2.7. Vegetative propagation

Research results showed that a combination of single node with soft wood cuttings with one pair of leaves taken from orthotropic shoot and rooting media composed of top soil, sand and manure in 2 : 2 : 1 ratio were recommended for propagation of hybrid coffee. It was observed that this practice resulted the highest rooting ability of stem cuttings (89.2%) and survival rate (63.3%) at hardening off stage (Behailu *et al*., 2006).

3. Forest coffee

3.1. Old coffee rejuvenation

In four, five and seven year's cycle stumping trials, stumped plots gave higher yields than unstumped coffee (Figure 9a, b and c). Similarly, it was observed that yield of old coffee stands increased by 43.2, 40.4 and 38.0, and 12.6, 8.4 and 4.7% using rejuvenation methods, namely topping, agobiado and eskeletamento, as compared to the conventional clean stumping and the control (not rejuvenated) plot, respectively (Figure 10). However, the adoption of the different rejuvenation methods may be influenced by stem nature of coffee trees (flexible or stiff), spacing between plant (population density), age of coffee trees, economic status of the farm and management system (Yacob *et a*l., 1996; Anteneh, 20015). Thus, these factors determine the economic feasible method to be adopted to renew old coffee orchards.

3.2. Time and height of stumping

It was observed that earlier stumping and increased stumping height significantly promoted forest coffee yield at different locations (Figure 11a and b). Relatively higher yield response to increasing stumping height could be attributed to the large amount of carbon compounds (photosynthates) accumulated in the stump, nourishing the newly growing suckers and the root system. This could maintain optimum shoot to root ratio and thus, promote productivity of coff

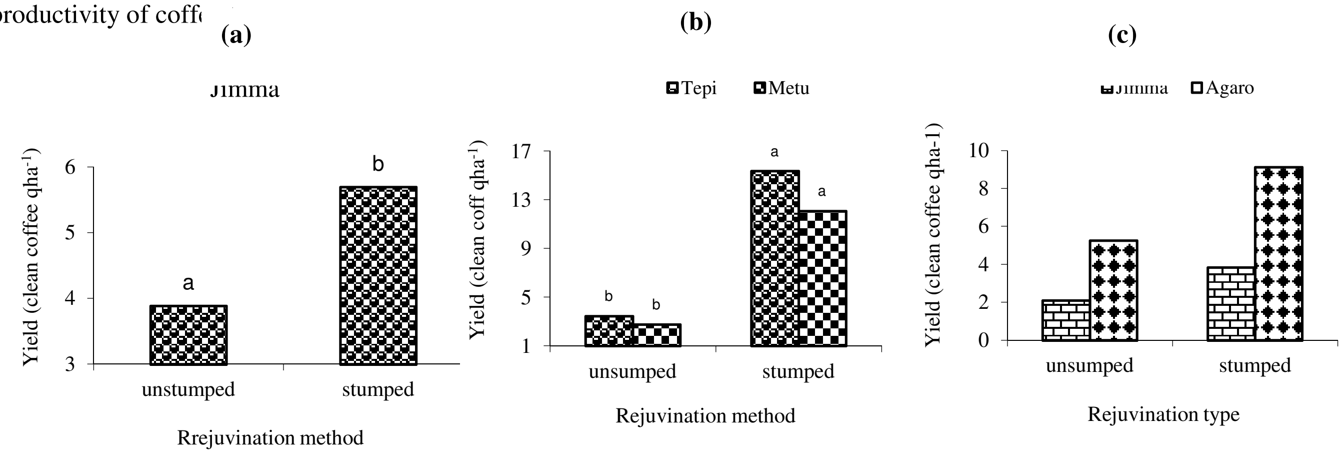


Figure 9. Four (a), five (2) and seven (3) year stumping trial. Bars capped with same letter(s) are not significantly different at P = 0.05 probability level. Yield is given in quintal (q), which is equivalent to 100 kg. *Source: Anteneh (2015).*

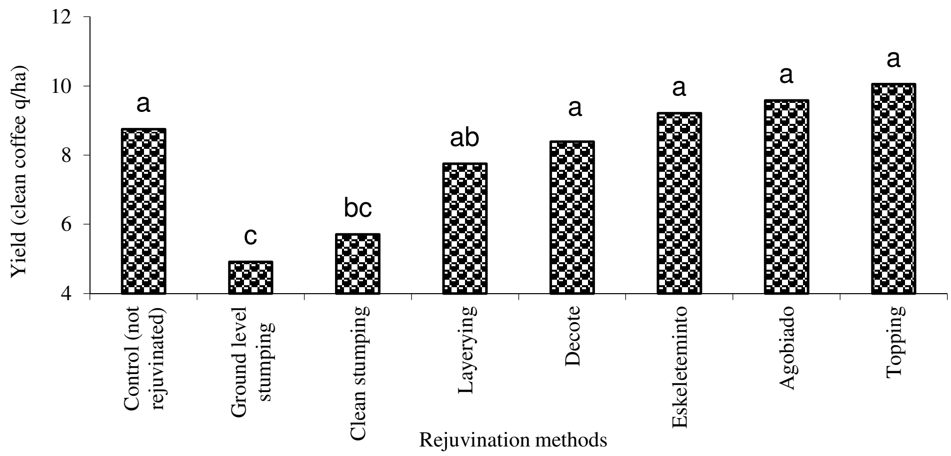


Figure 10. Effect of different rejuvenation methods on yield of forest coffee. Bars capped with same letter(s) are

not significantly different at P = 0.05 probability level. Yield is given in quintal (q), which is equivalent to 100 kg. *Source: Anteneh et al. (2008).*

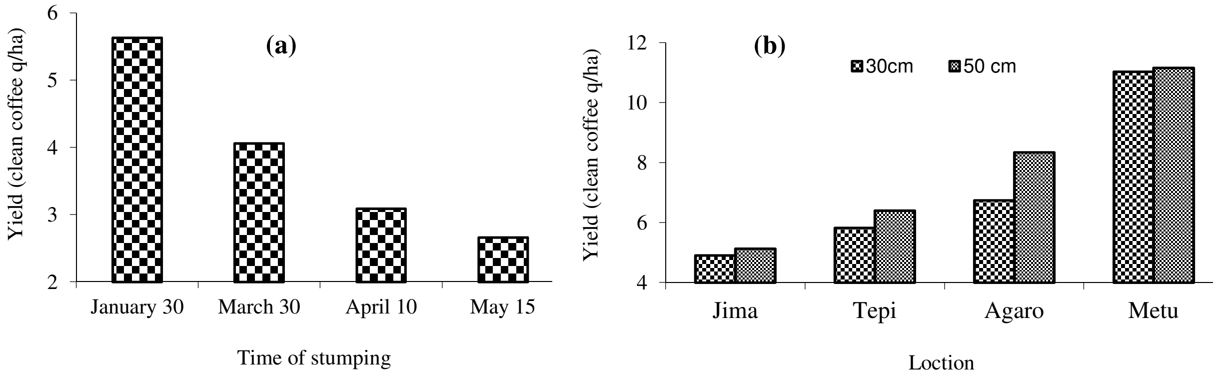


Figure 11. Effect of time (a) and height (b) of stumping on yield of forest coffee. *Source: Anteneh (2015).*

3.3. Population density and bearing heads

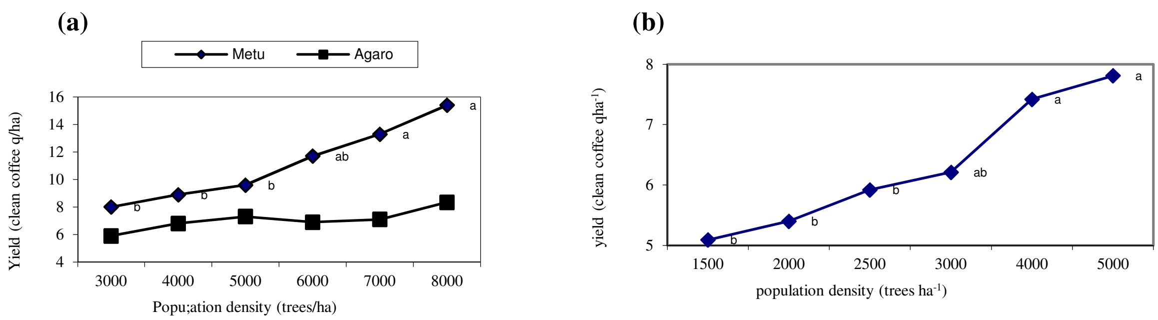
Higher population density improved forest coffee yield, culminating the highest value at 5000, 6000 and 8000 trees ha^{-1} at Tepi, Jimma, Metu and Agaro, respectively (Figure 12 a, b and c). Besides maintaining optimum population density yield of forest coffee stands linearly increased with increasing number of bearing heads per tree or per stump (Figure 13b). The increase in coffee yield with increasing population density has been attributed to efficient utilization of environmental inputs, *viz*. light, moisture and nutrients, until the biological optimum is attained (Taye *et al*., 2001).

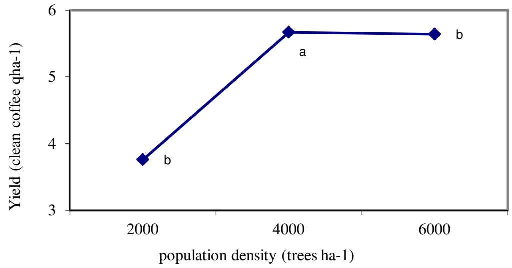
3.4. Soil and moisture conservation

Soil and moisture conservation structures, such as ridging tree rows were found to be effective in improving yield of forest coffee stand especially on sloppy lands. With regard to this, tied ridge exhibited 19.0 and 23.6% yield advantage over untied ridge and flat land, respectively (Figure 13a). Similarly yield advantage observed with closed end ridges for annual crops (Heluf, 2003) and for tree crops like coffee (Yacob *et al.,* 1996).

3.5. Mineral fertilizer and weed control

It was observed that forest coffee yield was not significantly affected by application of mineral fertilizer and weed management (Figure 14a and b). This could be associated to high organic matter content of the soil, resulted from mineralization of dense litter fall from the shade trees, and heavy over head shades that mask, depressed or nullified the effect of fertilizer and weed management, respectively, on the performance of coffee tees underneath.





(c)

Figure 12. Forest coffee yield (clean coffee q ha^{-1}) as affected by population density at Metu and Agaro (a), Tepi (b) and Jimma (c) (five years mean). Figures followed by the same superscript(s) are not significantly different at P = 0.0. *Source: Anteneh et al. (2008) and Anteneh (2015).*

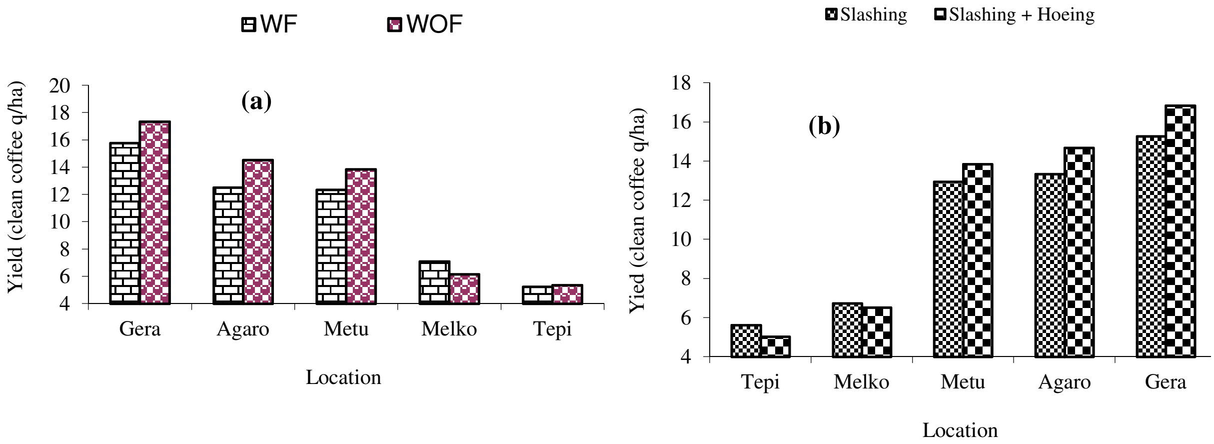


Figure 14. Forest coffee yield as affected by mineral fertilizer application (a) and weed management (b) (four years mean). WF = With recommended rate of fertilizer ($N_{172}P_{77}$ and $N_{150}P_{63}$ kg ha^{-1}), WOF = Without fertilizer. *Source: Anteneh et al. (2008) and Anteneh (2015).*

4. Plantation coffee

4.1. Hole size and time of transplanting

Results showed that survival rate of coffee seedlings increased with increasing hole size; though, the response varies among ecological conditions (Figure 15a). Moreover, appropriate time of transplanting is also important to ensure better survival of coffee seedlings. Although proper planting time has to be best predicted and modeled using several years' weather data, May/June and July/August transplanting resulted in better field survival rate of coffee seedlings in most of the study sites (Figure 15b).

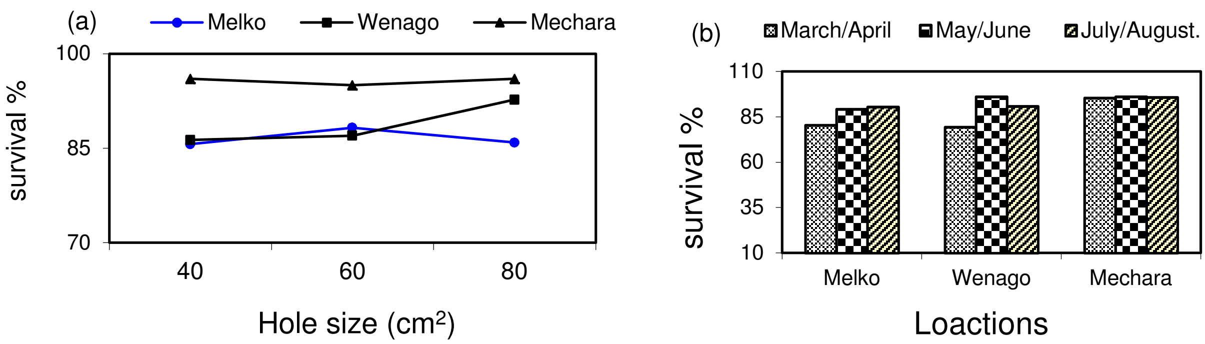


Figure 15. Influence of hole size (a) and time of transplanting (b) on survival rate of Arabica coffee seedlings. *Source: IAR (1996) and Endale et al. (2008).*

4.2. Tillage methods

At Jima significant difference in seedling survival rate has been observed due to tillage treatments, where 85.3, 82.5, 76.7 and 70.3% were recorded for tractor cultivation, oxen plow, manual digging and conventional holing on untilled plots, respectively (Table 6). Though the difference is not significant, various tillage treatments had also improved survival rate and early growth parameters of coffee seedlings at Tepi (Table 6 and 7). In contrast, at high land area of Gera, high seedling survival rate was recorded under zero tillage as compared to oxen cultivation (Table 6) indicating the location specific effect of tillage operations. On the other hand, the aftereffect of early tillage treatments on yield of coffee was not significant at both Gera and Tepi conditions (Table 6). Furthermore, substantial variations were also evidenced among coffee cultivars for survival rate at Jimma and most growth parameters evaluated at Tepi (Taye *et al*., 2001). The findings of Yacob *et al*. (1996) and Taye *et al*. (2001) have also indicated the existence of such genetic variation among Arabica coffee materials with regard to their adaptation along topographic gradients.

Table 6. Per cent seedling survival rate and mean clean coffee yields of Arabica coffee as influenced by tillage methods across different agro ecologies.

Tillage method	Survival rate (%)			Yield (kg ha^{-1})	
	Jimma	Tepi	Gera	Tepi	Gera
	*	NS	**NS**	NS	NS
Tractor cultivation	85.28[a]	-	-	-	-
Oxen cultivation	82.50[a]	94.45	92.13	141.76	274.81
Manual digging	76.67[ab]	95.06	99.54	137.31	307.70
Conventional holing	70.28[b]	93.21	96.30	134.46	322.02
SE (±)	2.92	0.52	1.89	6.62	18.57
CV (%)	15.73	28.86	5.79	9.61	12.32

NS, *, Non-significant and significant at 0.05 probability level, respectively. Means within each column followed by the same superscript letter(s) are not significantly different from each other at P = 0.05 probability level. *Source: Taye et al. (2001) and Endale et al. (2008).*

Table 7. Early destructive growth parameters of CBD resistant coffee cultivars as affected by different tillage methods at Tepi.

Tillage Method	Tap root length (cm)	Leaf dry matter (g)	Shoot dry matter (g)	Root dry matter (g)	Total dry matter (g)
	NS	NS	NS	NS	NS
Oxen cultivation	24.02	18.87	41.61	8.61	50.59
Manual digging	23.23	18.33	40.59	8.31	48.87
Conventional holing	23.16	17.56	38.99	7.10	47.43
SE (±)	0.77	0.57	1.05	0.40	1.31
CV (%)	17.15	16.32	13.47	25.08	13.88

NS = Non signifiant. *Source: Taye et al. (2001).*

4.3. Depth of planting

The depth at which coffee seedlings are planted affects the success of survival and growth performance in the field. With this regard, results obtained at Tepi revealed that deeper planting of coffee seedlings had improved early field growth performance of coffee seedlings as compared to collar planting (Table 8). However, difference between treatments was not significant in early growth parameters of coffee seedlings observed at Gera (Taye *et al*., 2001). The result indicates that the choice of planting depth depends on agro-ecological conditions of the area.

Table 8. Early growth performance of three Arabica coffee cultivars as affected by depth of planting at Tepi.

Transplanting depth	Leaf dry matter (g)	Stem + branch dry matter (g)	Shoot dry matter (g)	Tap root length (cm)	Root dry matter (g)	Total dry matter (g)
	**	**	**	**	**	**
Collar level	16.57[c]	19.80[b]	36.37[c]	21.71[b]	7.11[b]	44.59[c]
5 cm deeper than collar	18.31[b]	22.59[a]	40.91[b]	23.33[b]	8.02[b]	48.93[b]
10 cm deeper than collar	19.87[a]	23.98[a]	43.85[a]	25.37[a]	9.50[a]	53.37[a]
SE (±)	0.48	0.60	0.78	0.65	0.37	1.02
CV (%)	13.79	14.43	10.10	14.49	23.21	10.79

** Significant at 0.01 probability level, mean within each column followed by the same superscript letter are not significantly different at 0.05 probability level. *Source: Taye et al. (2001) and and Endale et al. (2008).*

4.4. Transplanting methods

Methods of transplanting had substantial influences on percent survival rate of coffee seedlings. Polythene pote raised (ball root transplanted) coffee seedlings showed 92.92% field survival as compared to the those raised on seed bed (bare root transplanted) seedlings with mean value of 62.44% (Figure 16a). There was a significant difference between coffee cultivars when bare root transplanted, where the open type (752257) exhibited lower survival rate than did the intermediate (7440) and compact (74112) types Figure 15b). However, all the cultivars showed maximum mean survival under ball root transplanting methods. Yacob *et al*. (1996) had also observed similar adaptations patterns of the three coffee types along with the different soil moisture regimes. On the other hand, the impact of transplanting methods on coffee yield response was non-significant at Gera and Tepi (Taye *et al*., 2001).

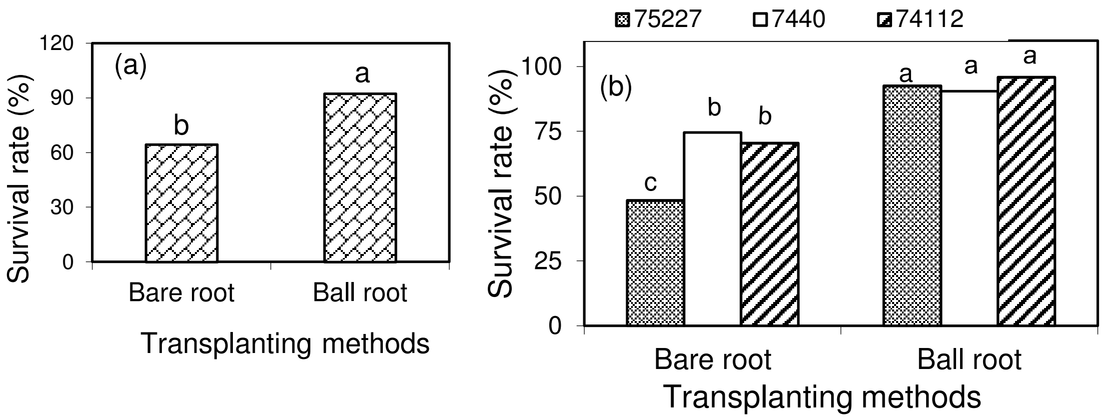


Figure 16. The effects of transplanting method (a) and interaction of cultivars and transplanting methods (b) on percent coffee seedling survival rate. Bars capped with same letter are not significantly different at P = 0.05 probability levels. *Source: Taye et al. (2001) and and Endale et al. (2008).*

4.5. Soil and Moisture Conservation

Coffee husk, grasses as mulch material and cover crops such as desmodium are found to be important in minimizing soil and moisture loss, suppression of weed seed germination and smothering of its growth in plantation coffee. In unreplicated observational plot at Jimma, noug(*Gzotia scabra*), haricot bean (*Phaseolus vulgaris* L.) and soybean (*Glycine max* L.) used as cover crops in coffee plantation reduced weed growth by 60, 40 and 30%, respectively (Paulos, 1987). In another study conducted at Jimma revealed that Desmodium planted as cover crop in coffee plantation increased coffee yield by about 30% as compared to sole coffee plots (personal communication).

Soil and moisture conservation techniques such as ridging (tied and untied ridges) enhanced yields of CBD resistant coffee cultivars in coffee plantation over the control plot, and flat land (Figure 17).

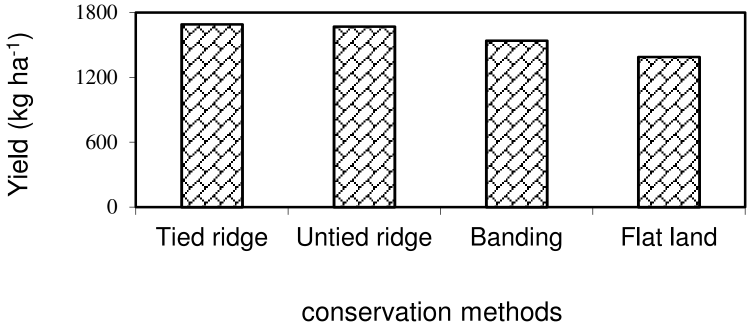


Figure 17. The influence of soil and moisture conservation techniques on yield of modern Arabica coffee cultivars. *Source: Tesfaye et al. (1998) and and Endale et al. (2008).*

4.6. Coffee shade tree management

In the center of origin, Ethiopia, Arabica coffee has been found growing naturally under the canopy strata of various shade tree species and, thus, it flourishes best when grown under shade than open sun condition (Yacob *et al*., 1996). In addition to their apparent roles in soil fertility enhancement, moisture conservation, weed suppression and modulation of light (Yacob *et al*., 1996), leguminous shade trees have tremendous use in promoting organic coffee production in the countery (Yacob *et al*., 1996; Taye and Tesfaye, 2001). Accordingly, *Millettia ferruginea, Acacia abyssinica, Albizia* sp., *Erythrinia abyssinica, Calpurinea subdecondra and Cordia african* were found to be suitable shade tree species for coffee production (Table 9) as most of them have wider canopies and feathery leaves to provide coffee plant beneath with moderate light regime and replenish organic matter through decomposition litter fall.

Strip planting of coffee trees between two established shade tree species had enhanced coffee yield as compared to intercropping under each canopy (Table 9). In line with this, unlike intercropping, the merits of strip cropping to minimize direct competition between shade tree and coffee plant for the available resources, *viz*. nutrient, moisture and light have been well documented (Yacob *et al*., 1996). In general, increament in yield of coffee grown under shade trees could be attributed to the high rate of photosynthesis of coffee plant under moderate light regimes (26 - 60%) as beloved to be a shade loving C_3 plant. However, for improved productivity of coffee tree the shade trees should be established under their recommended spacing (Table 9).

Table 9. The influenced by planting patterns on coffee yield and some desirable traits of the prominent shade tree species.

Strip planting		Intercropping		Characteristics of shade trees		
Shade tree species	Yield (kg ha^{-1})	*Shade tree species*	Yield (kg ha^{-1})	% light interception	Litter fall (kg ha^{-1} yr^{-1})	Canopy diameter (m x m)
Millettia + Albizia	2158[a]	*Millettia ferruginea*	1809[a]	40	4271.34	8 x 8
Leucaena + Acacia	1896[b]	*Albizia sp*	1521[bc]	26	1240.00	18 x 18
Millettia + Gravillea	1343[d]	*Accacia abyssinica*	1534[bc]	30	2167.00	20 x 20
Calpurnea + Acacia	1693[c]	*Erythrina abyssinica*	1485[c]	19	1022.33	16 x 16
Albiziz + Acacia	1255[de]	*Calpurnea subdecondra*	1467[c]	-	452.33	6 x 6
Tephrosia + Erythrina	1136[def]	*Cordia africana*	1204[d]	36	4511.67	16 x 16

Means with in a column followed by the same superscript letter(s) is not significant at 0.05 probability levels. *Source: Yacob et al. (1996), Tesfaye et al. (1998) and Endale et al. (2008).*

4.7. Determination of optimum spacing

Canopy volume, which is dictated by number of bearing heads, branch angle and plant height determines spatial arrangement and optimum spacing in coffee (Yacob *et al*., 1996). It is a strong genetic trait which can be used to group coffee into three broad canopy classes identified as open, intermediate and compact types, each of which requires its own spacing (Yacob *et al*., 1996). On the other hand, coffee yield and canopy diameter significantly increased and optimum population density decrease with increasing number of bearing heads (Tesfaye *et al*., 1998; Tesfaye *et al*., 2001). Taking into account the morphological nature of coffee trees and pruning systems to be used, optimum spacing, and the corresponding population density has been recommended for each canopy classs (Tesfaye *et al*., 1998).

Field trial results showed that coffee yield linearly increased with increasing population density or close spacing (Table 10) under open sun condition probably because of mutual shading. However, the efficiency of close spacing varied among agro-ecologies (Figure 18b). For instance, in low altitude area like Tepi, the efficiency of close spacing declined after four crop harvests (Figure 18a). Increase in the proportion of dead primary branches and decline in crop bearing surface, which is directly associated with the increased level of mutual shading or reduction in light interception by individual tree, could be accounted for the early exhaustion and decline in coffee yield at Tepi. On the other hand, significantly high yield gain (Figure 18b) and long lasting efficiency of close spacing were evidenced at Gera and Wenago (both high altitude areas) (Figure 18a).

Furthermore, results obtained at Metu (mid altitude area) had revealed the increased efficiency of close spacing in enhancing yield performance of compact Arabica coffee (Endale *et al*., 2006). In the same study it was also evidenced that encouraging more than two orthotropic stems per tree did not significantly improve coffee yield at close spacing or high population density. Besides, an observation trial conducted at Jimma, cova system of planting (planting more than one seedlings per hole) promoted early growth of Arabica coffee seedlings. Accordingly, planning one seedling per hole for open (75227) and three seedlings per hole for compact (74165) coffee cultivars favored earlier growth parameters, which are beloved to be indicter of the performance of coffee trees at later stage (Yacob *et al*., 1993).

Table 10. Effect of number of bearing heads on clean coffee yield (kg ha^{-1}) and canopy diameter (m) among the three canopy classes of CBD resistant Arabica coffee cultivars at Gera high land.

Bearing heads	Canopy classes								
	Open			Intermediate			Compact		
	Yield (kg ha^{-1})	Canopy diameter	Pop. ha^{-1}	Yield (kg ha^{-1})	Canopy diameter	Pop. ha^{-1}	Yield Kg ha^{-1})	Canopy diameter	Pop. ha^{-1}
1-2	82.33^{d}	1.90	2770	97.43^{d}	1.71	3425	104.10^{d}	1.62	3831
3-4	86.08^{c}	1.98	2551	100.32^{d}	1.74	3300	112.35^{c}	1.66	3623
5-6	94.88^{b}	2.08	2310	104.90^{c}	1.84	2941	117.32^{b}	1.78	3125
7-8	107.13^{a}	2.09	2288	121.94^{a}	1.83	2985	117.43^{b}	1.83	2985
9-10	107.28^{a}	2.22	2028	111.32^{a}	1.88	2857	130.07^{a}	1.91	2740

Pop. = Population; Means in a column followed by same superscript letter(s) are not significantly different at P = 0.05 probability levels. *Source: Yacob et al. (1993)and Endale et al. (2008).*

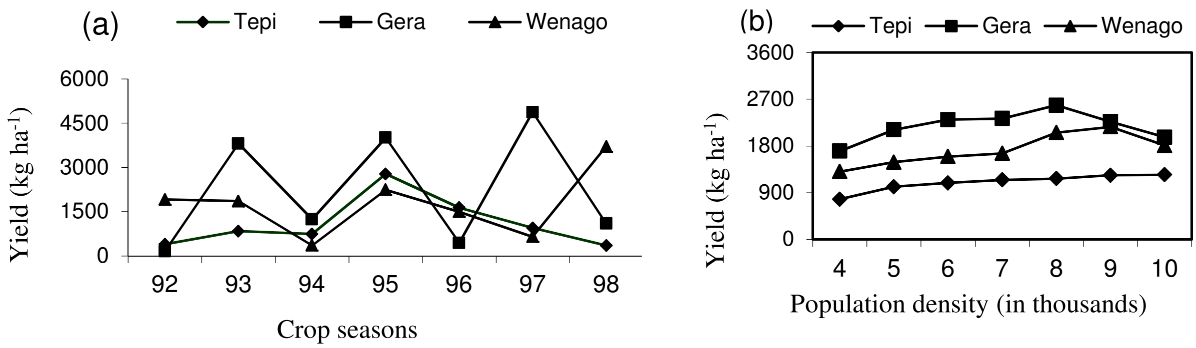


Figure 18. The influence of crop season (a) and population density (b) on mean clean coffee yield at Tepi, Gera and

Wenago. *Source: Taye et al. (2001) and Endale et al. (2008).*

Table 11. Effects of close spacing on percent light interception (LI), branch death rate, clean coffee yield and estimated crop bearing surface in the 8th crop years at Tepi

Spacing (m * m)	Canopy volume (m^3)	Mean % LI	Branch death		Clean coffee yield		Height up to 1st primary lower branch (m)	Estimated crop bearing surface (m)
			upper	Lower	Kg $tree^{-1}$	Kg ha^{-1}		
1.58	1.78	59.92 [a]	33.72	20.55	0.23	1135	0.65	79.45
1.41	1.69	29.83 [b]	33.60	20.78	0.20	1229	0.67	79.22
1.29	1.62	22.73 [bc]	32.75	20.52	0.18	1288	0.64	79.48
1.19	1.74	20.74 [bc]	29.73	25.27	0.16	1311	0.90	74.73
1.12	1.39	17.37 [bc]	27.01	30.29	0.15	1362	1.13	69.64
1.05	1.32	16.09 [bc]	28.54	34.35	0.13	1349	1.26	65.65
1.00	1.28	13. 09 [c]	25.35	33.67	0.33	1322	1.21	66.33

Pop. = Population; Means in a column followed by same superscript letter(s) are not significantly different at P = 0.05 probability levels. *Source: Tesfaye et al. (2001) and Endale et al. (2008).*

4.8. Rejuvenation of old and exhausted coffee trees

After being exhausted due to various environmental factors or aging, a coffee tree needs to be rejuvenated. Although, the conventional practice in Ethiopia is stumping, old and exhausted coffee trees can also be renovated during cycle conversion and become productive by different rejuvenation practices, *viz.* agobiado, topping, decote and eskeltamento (Yilma, 1986). However, information in the potential benefits of these methods in coffee plantations is not available in the country. On the other hand, it has been reported that stumping coffee trees in a slant position (45° angel) at 30 - 45 cm height above the ground renovate old coffee orchards and make it productive (Paulos, 1997). Rejuvenation of exhausted coffee trees may be dictated by the nature of their stem, as open varieties with stiff stem can be renovated by stumping, while the compact varieties with flexible stems are suitable for both agobiado system and stumping (Yacob *et al*., 1996).

4.9. Soil fertility management

In Ethiopia, Arabica coffee is predominantly grown on a highly weathered and leached *Nitosols* which is deficient in nitrogen and phosphorus. Coffee is a heavy nutrient feeder. It has been documented that more nutrients are removed annually by the harvested products in comparison to other tree crops like Cocoa and Tea (Coste, 1992). However, nutrient requirement by th crop may vary among the coffee varieties, age of the tree, crop load, type of production (forest, garden, plantation, and open and low shade), sol fertility status, soil reaction and pant population. According to Taye (1998) application of nitrogen and phosphorus mineral fertilizer at Jimma at a rate of 150 and 66 kg ha^{-1}, respectively, and undecomposed coffee husk plus farm yard manure at a rate of 10 ton ha^{-1} resulted in high vegetative growth of coffee plant and improved coffee yields (Figure 19). In another trial, the application of decomposed coffee husk was better than *Sesbania sesban* applied plot in terms of improving the yield performance of coffee plant.

The use of decomposed coffee husk compost at rate of 10 ton ha^{-1} (4 kg $tree^{-1}$ on dry weight basis) with 50% soil incorporation and the remaining half surface application was found to be superior in terms of yield performance of coffee trees. Hence, it can be concluded that depending on the availability of organic inputs and plant ecological factors, the use of organic inputs at the rate of 5 to 10 t ha^{-1} (2 to 4 kg $tree^{-1}$) is advisable for Arabica coffee production (Taye, 1998; Taye and Tesfaye, 2001).

In other studies carried out at Jimma and its sub-center that represent the major coffee growing agro-ecologies of the country Paulos (1994) come out with a set recommendation (Table 12) that are of immense value to the grower. Accordingly, forest coffee, low yielding and young trees (less than three years) and rich soil (fertile soil) should be give low amount than the recommended full dose. On the other hand, open and low shaded coffee plantations, high yielding varieties and mature trees on poor soils should be given the full dose of the recommended fertilizers (IAR, 1996).

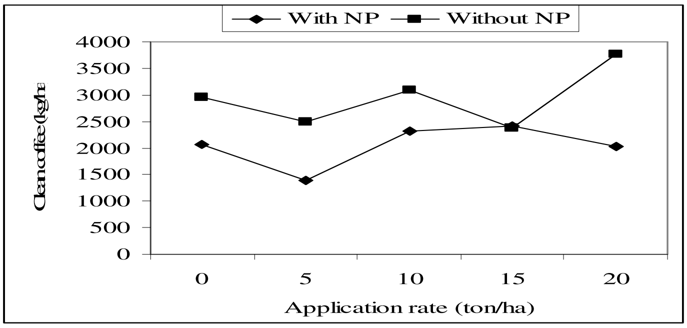


Figure 19. Mean clean coffee yield of Arabica coffee cultivar-F59 as influenced by the application rate of the two organic fertilizer. *Sources. Taye (1998).*

Table 12. Location specific NPK fertilizer recommendation for coffee

Location	Recommendation domain	Recommendation rate (kg ha^{-1})		
		N	P	K
Melko	Jimma, Maa, Seka, Gomma and Kossa	150 - 172	63	0
Gera	Gera	No fertilizer	No fertilizer	No fertilizer
Metu	Metu, Hurumu, Yayou ad Chora	172	77	0
Tepi	Tepi	172	77	0
Bebeka	Bebeka	172	77	0
Wonago	Wonago, Dale, Aleta Wodo and Fiseha Genet	170 - 200	33 - 77	0
Bedessa	Habro, Kui and Darelebu	150 - 235	33 - 77	62

Source: IAR (1996).

5. Intercropping of coffee and horticultural crops

5.1. Coffee and turmeric (*Curcuma longa*) *and ginger* (*Zingiber officinale* **Rose**)

Three CBD resistant coffee cultivars intermediate (7440) and compact (7410 and 74112) planted at population density of 1600, 2500, 3265, 4444 and 6398 trees ha^{-1} were intercropped with turmeric and ginger at Tepi Research Center. Coffee cultivar 7410 was intercropped with turmeric, while 74112 and 7440 were intercropped with ginger variety Gin.37/79 and Gin.40/79, respectively. A sole plot of each crop was also included. Results of this trial show that there were no significant differences between sole and intercropped coffee plots throughout the study period, though the latter exhibited inferior yield performance as compared to the former. Similarly, mean yield difference between the coffee cultivars was not significant. However, the intermediate (7440) coffee cultivar gave higher yield than the compact coffees (74112 and 74110) in both sole and intercropped plots (Table 13). This confirms the high suitability of the low land Tepi area for intermediate coffee cultivar.

The influence of population density was significant ($p \leq 0.01$) on coffee yield and the average clean coffee yields significantly decrease with decreased tree population across the crop years and this was presented for the last crop year (Figure 20a). The yield reduction was highest for the intermediate coffee cultivar as compared with the compact types, indicating the more suitability of the latter coffee cultivars for intercropping. This is in line with the work done by Taye *et al.* (2001).

On the other hand, mean yield of turmeric and ginger over the study period were significantly ($p \leq 0.01$) higher for sole stands than intercropped plots. However, turmeric yield was higher for intercropped plots than sole plots on the early year, and mean yield of turmeric and ginger intercropped with coffee significantly decreased with increasing population density (Figure 20b) and age of coffee trees. This is probably because of the gradual increasing shade level by the upper strata of coffee canopies and reduced light interception by turmeric and ginger underneath during the latter year of production. The biennial bearing nature of coffee trees was reflected by inconsistent yield over production season. But, unlike turmeric and ginger (Figure 20b), yields of the three coffee cultivars increased with increasing population density coffee trees (Figure 20a).

The LER depicted the yield advantage of growing coffee and turmeric and ginger together, suggesting their complementary to utilize efficiently the available resources and their beneficial effects on each other. However, LER less than one were obtained for ginger and coffee cultivar 74112 at the early crop year and for ginger and cultivar 7440 during the latter year of production (Figure 21). The average values of LER were higher for coffee than spices throughout the study period. The total LER was greater during the first two cropping years and tends to decline then after (Figure 21), indicating that intercropping coffee and spices is more advantageous at the early stages. Apart from this, higher gross field benefit or income was obtained from sole plot than intercropped plots of all crop types (Table 14). Moreover, high relative yield was achieved when ginger and turmeric were intercropped with compact coffee type than with the intermediate cultivar, indicating the more suitability of the former coffee cultivar for intercropping (Taye *et al.*, 2001; Taye *et al.*, 2008).

Table 13. Mean clean coffee yield (Qt ha^{-1}) and fresh rhizome yields of turmeric and ginger (Qt ha^{-1}) as influenced by the intercropping practices at Tepi over six crop years

Coffee cultivar	Sole	Intercropped	**Mean**	Spices	Sole	Intercropped	**Mean**
74112	10.55	9.77	**10.16**	Gin. 37/79	88.35	22.17	**55.26**
74110	10.40	8.28	**9.34**	Gin.40/79	113.70	23.68	**68.69**
7440	16.48	15.00	**15.74**	Turmeric	220.00	161.27	**190.63**
Mean	**12.47**	**11.02**			**140.68[a]**	**69.04[b]**	

Qt = Quintals, where 1 Qt = 100 kg; Figures followed by the same letter(s) within a row/column are not significantly different at 0.05 probability level. *Source: Taye et al. (2008).*

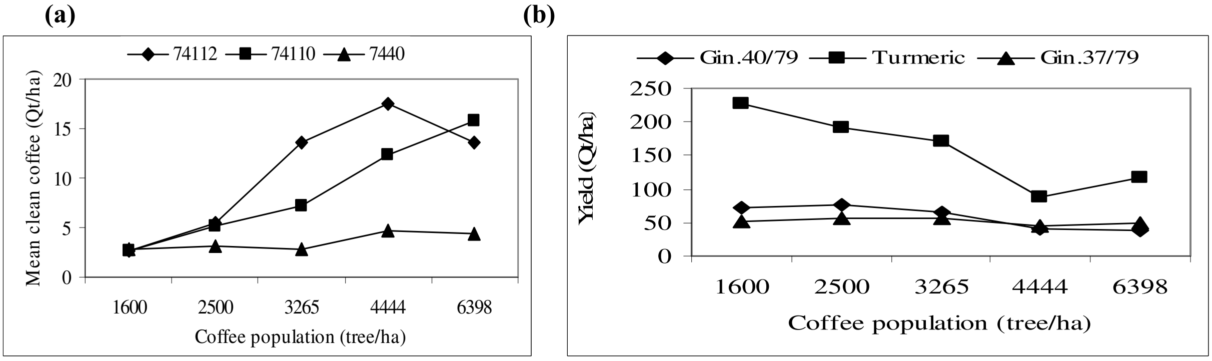


Figure 20. Mean clean coffee yield (a) and fresh rhizome yields of turmeric and ginger (b) as influenced by coffee population density at Tepi during the last crop year . *Source: Anteneh and Taye (2015).*

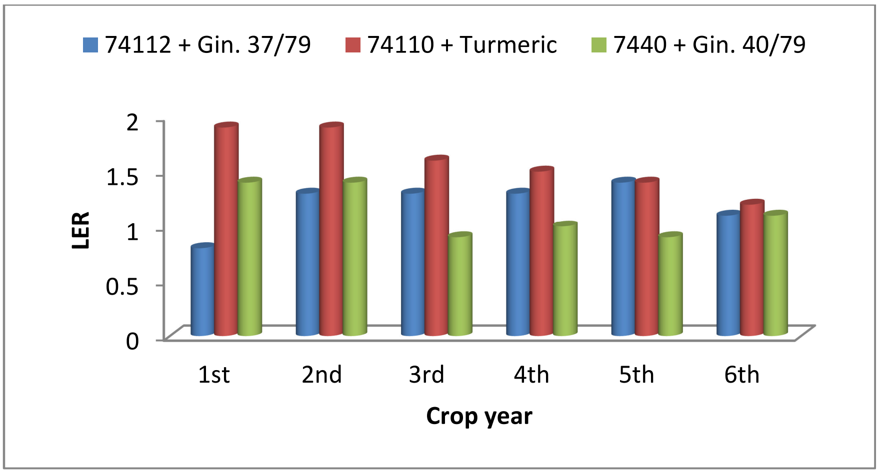


Figure 21. Land equivalent ratio (LER) of coffee cultivars intercropped with turmeric and ginger (Gin. 37/79 and Gin. 40/79) over six crop years at Tepi. *Source: Anteneh and Taye (2015).*

Table 14. Estimated gross field benefit [Ethiopian Birr (ETB)* ha^{-1}] from coffee and turmeric and ginger over three consecutive crop years

	4th year			5th year			6th year		
Crop type	Sole	Intercrop	Mean	Sole	Intercrop	Mean	Sole	Intercrop	**Mean**
Coffee	9747	8665	**9206**	8398	6892	**7645**	9982	8298	**9140**
Turmeric	6659	3509	**5084**	3185	1438	**2312**	9675	3647	**6661**
Ginger	12394	1933	**7164**	6442	1474	**3958**	4392	1145	**2768**
Total	**28800**	**14107**	**21454**	**18025**	**9804**	**13914**	**24049**	**13090**	**18569**

*20 ETB = 1 US Dollar; Field prices of dry coffee for the respective crop years were 225, 475 and 591 ETB Qt^{-1}. The respective field prices of processed turmeric and fresh ginger yields were 150, 100 and 200 and 100, 75 and 50 ETB Qt during the 4th, 5th and 6th crop years, respectively. *Source: Anteneh and Taye (2015).*

5.2. Coffee and orange (*Citrus sinensis*)

Again, coffee berry disease resistant selection was row interplanted with local sweet orange (*Citrus sinensis*) at ratios 1 : 1, 3 : 1, 1 : 3, 3 : 2, and 2 : 3 at Jimma. Sole plots of both crops were also included in the trial for comparison. Accordingly, the highest mean coffee yields were obtained at the fifth (29.5 Qt ha^{-1}) and the eight (32.5 Qt ha^{-1}) crop years, while the lowest at first (7.0 Qt ha^{-1}) and sixth (5.3 Qt ha^{-1}) crop seasons (Table 21). These results may largely be attributed to the biennial bearing nature of coffee plant. In most crop years, sole planted coffee gave the lowest yield as compared to the intercropped stands, suggesting the benefits of intercropping to use efficiently the available open spaces. It may also explained in terms of mutual shadings and efficient utilization of the available light due to intercropping of the two perennial fruit trees. This is particularly the case for maximum coffee yield recorded at 1:3 coffee to orange (25% coffee to 75% orange) for most the cropping years. This is in agreement with the previous findings of Taye *et al*. (2001) and Tesfaye *et al*. (2002).

Because of disease attack, orange fruits from all the plots were not healthy and normal and considered unmarketable biological yield and, hence it was not possible to compute the economic benefits. In general, intercropping coffee with orange resulted in higher yield advantage over the sole plots (Table 22). The LER were greater than a unity for all intercropped plots (Table 22), indicating the yield advantages of intercropping of the two crops as compare with sole plots of each crop. The findings of this study were reported by Taye *et al*. (2004).

5.3. Coffee with avocado (*Persea americana*)

Coffee berry disease resistant coffee cultivar 7440 was intercropped between rows of already established avocado (*Persea americana*) trees at Jimma at the ratio of 0 :28, 67 : 24, 63 : 28, 71 : 20, 75 : 16, 79 : 12 and 91: 0 with a total plant density of 91 trees per plot. In addition, a sole stands of both crops were also included for comparison purpose. The results depict that the pure stands of coffee plots out yielded the intercropped plots (Table 23), indicating the dense shading effects of avocado trees on the coffee plants underneath. Average yields and yield benefits of both crops showed increasing trends for over years with increasing populations of coffee and decreasing avocado trees. Moreover, relatively maximum yield advantages of coffee and avocado were found intercropping ratios of 75 : 16 (Table 23 and 24).

Similarly, the calculated LER also depicted the yield benefits of the same combination and its values were lower at the higher population densities of avocado trees. In addition, higher LER values were obtained during the early crop year (Figure 22). These show the adverse effects of dense shading from the closely spaced avocado trees, particularly with ageing. Hence, the ideal combination of the intercropping coffee to avocado seems to be 75 : 16 in areas with similar to Jimma condition. Besides, it is advisable to remove either parts of the branches of avocado plants or thin out coffee trees beneath the canopies for maximum light interception and increased crop productivity.

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Table 21. Mean clean coffee yield (Qt ha^{-1}) as affected by different coffee to orange tree intercropping ratios (1991/92-2000/01 crop seasons) at Jimma.

Coffee: orange ratio	1991/92	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/2000	2000/01	**Mean**
	NS	NS	NS	*	*	**	NS	*	NS	**
1:1	8.5	20.7	12.3	34.5a	38.6ab	7.3a	14.4	34.1b	8.4	**19.3[ab]**
3:1	5.3	21.5	14.6	17.1b	24.3b	5.6bc	17.9	31.7bc	15.1	**17.0[bc]**
3:2	6.7	16.9	13.7	18.6b	26.5b	4.4bc	15.4	32.8bc	10.1	**16.1[bc]**
1:3	9.8	18.9	21.6	17.6b	46.8a	3.9c	23.8	43.7a	15.7	**22.4[a]**
2:3	6.1	19.7	13.2	14.3b	27.7b	6.0ab	19.5	29.3bc	10.5	**16.3B[c]**
Sole coffee	5.8	15.4	7.8	20.1b	18.3b	4.6bc	22.9	23.6c	8.9	**14.2[c]**
Mean	**7.0[de]**	**18.9[b]**	**13.9[c]**	**20.4[b]**	**29.5[a]**	**5.3[E]**	**19.0[b]**	**32.5[a]**	**11.5[cd]**	**-**
CV (%)	**35.7**	**34.7**	**38.5**	**31.5**	**30.4**	**16.5**	**66.7**	**15.6**	**39.3**	**38.3**

NS = Not significant, * and ** significant at 0.05 and 0.01% probability levels, respectively. Figures followed by same superscript letter(s) within a column and a row are not significantly different at 0.05% probability level. *Source: Taye et al. (2008).*

Table 22. Mean clean coffee and fresh orange fruit yields, their relative yields and LER as affected by the intercropping ratios of coffee and sweet orange at Jimma.

Coffee : orange ratio	Plant population (tree ha^{-1})		1994/95					2000/01				
			Crop yield (Qt ha^{-1})		Yield advantage		LER	Crop yield (Qt ha^{-1})		Yield advantage		LER
	Coffee	Orange	Coffee	Orange	Coffee	Orange		Coffee	Orange	Coffee	Orange	
1: 1	1250	1250	12.3	9.1	1.6	1.8	3.4	34.1[b]	42.3	1.5	4.3	5.7
1: 3	625	1875	21.6	10.2	2.8	2.0	4.8	43.7[a]	9.8	1.9	0.9	2.8
3: 1	1875	625	14.6	29.5	1.9	5.9	7.8	31.7[bc]	16.6	1.4	1.7	3.0
3: 2	1500	1000	13.7	13.6	1.8	2.7	4.5	32.8[bc]	20.5	1.4	2.1	3.5
2: 3	1000	1500	13.2	47.9	1.7	9.6	11.3	29.3[cb]	13.5	1.2	1.4	2.6
Sole plots	2500	2500	7.8	5.0	-	-	-	23.6[c]	9.9	-	-	-

Figures followed by same superscript letter(s) within a column are not significantly different from each other at 0.05% probability level. *Source: Taye et al. (2008).*

Table 23. Mean coffee yield (kg ha^{-1}) and its yield advantages at the different intercropping ratios of coffee and avocado at Jimma (1993/94-1995/96).

Coffee to avocado ratio	Coffee yield			**Mean yield**	Coffee yield advantage			**Coffee yield advantage**
	1993/94	1994/95	1995/96		1993/94	1994/95	1995/96	
0:28	-	-	-	**-**	-	-	-	**-**
67:24	121.5	656.6	636.3	**471.5**	0.29	0.47	0.47	**0.41**
63:28	107.1	788.1	553.6	**482.9**	0.23	0.57	0.41	**0.40**
71:20	103.7	745.8	1226.5	**692.0**	0.25	0.54	0.91	**0.57**
75:16	232.5	1077.3	1301.7	**870.5**	0.56	0.78	0.97	**0.77**
79:12	301.3	994.8	983.8	**760.0**	0.72	0.72	0.73	**0.72**
91:0	416.7	1390.0	1343.3	**1050.0**	-	-	-	**-**

Table 24. Mean avocado yield (kg ha^{-1}) and its yield advantages of the different intercropping ratios at Jimma (1993/94-1995/96).

Coffee to avocado ratio	Avocado yield			**Mean yield**	Avocado yield advantage			**Mean yield advantage**
	1993/94	1994/95	1995/96		1993/94	1994/95	1995/96	
0:28	58.7	127.4	252.1	**164.1**	-	-	-	**-**
67:24	61.2	196.9	303.1	**187.1**	1.04	0.60	1.20	**0.95**
63:28	47.5	240.6	310.8	**199.6**	0.81	0.73	1.23	**0.92**
71:20	210.1	143.3	350.5	**234.6**	3.58	0.44	1.39	**1.80**
75:16	229.7	348.6	353.0	**310.6**	3.91	1.06	1.40	**2.12**
79:12	164.7	125.8	381.9	**224.1**	2.50	0.38	1.51	**1.46**
91:0	-	-	-	**-**	-	-	-	

Source: Taye et al. (2008).

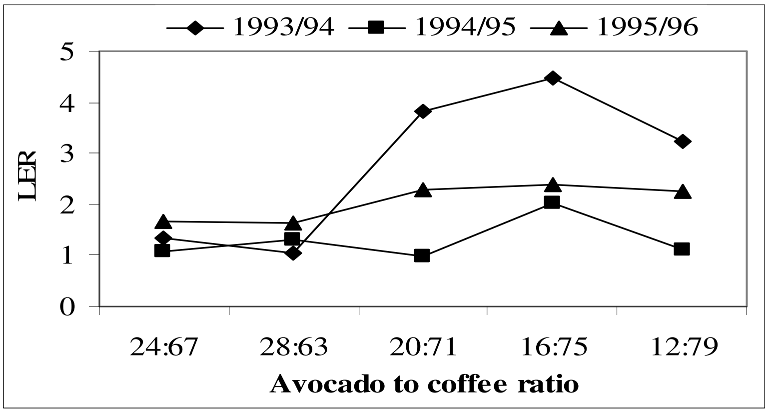

Figure 22. Land equivalent ratio (LER) of intercropping avocado with coffee at various ratios and crop years at Jimma.

5.4. Coffee and potato (*Solanum tuberosum*)

Three CBD resistant coffee lines with compact (74110 and 74148) and open (741) canopy natures were row intercropped with Irish potato (*Solanum tuberosum*) at Jimma. For comparison sole coffee plants and sole plot of potato was included. The results of the experiment depicted that coffee line 74148 grown sole gave the highest average coffee yield, followed by the intercropped plot of coffee cultivar 74110. Among the intercropped plots, the lowest coffee yield was obtained from cultivar 74148, while yield of 74110 planted sole was more or less equivalent to the cultivar 741 intercropped with potato (Table 25). Accordingly, the highest and least coffee yield advantages and LER were calculated for cultivars 71110 and 741148, respectively (Table 25). Similarly, higher average potato tuber yields were obtained from the pure stands than those intercropped with coffee. On the other hand, potato plants intercropped with cultivar 74148 gave the highest potato tuber yield as compared to other combinations. As a result, greatest potato tuber yield advantage was recorded when interplanted with the compact coffee cultivar 74148 (Table 25).

On the other hand, relatively higher gross monetary return was estimated for the combination of coffee and potato in the order cultivars 74148 > 741 > 74110 (Table 26). Although sole stands had higher mean yields than did the intercropped plots of both crops, but by far less than that of sole potato stand. This is due to the higher local market price of potato than coffee. As a result, increment in gross field benefit of the intercropping over that of the sole coffee plots ranged from 9 to 11% (Table 26) indicating the economic advantage the practice. The LER were also more than a unity for all coffee cultivars and followed the order of 74110 > 741 > 74148, probably indicating their order of suitability for potato intercropping under Jimma conditions (Table 26).

Table 25. Effect of intercropping of coffee and potato on fresh cherry yield of coffee (kg ha^{-1}) and potato tuber (kg ha^{-1}) yields at Jimma.

Coffee cultivar	Coffee yield		Potato yield		Yield advantage		LER
	Sole	Intercrop	Sole	Intercrop	Coffee	Potato	
74110	636	810	11133	4714	1.27	0.42	1.69
74148	997	543	8612	8069	0.54	0.94	1.48
741	683	629	9215	6224	0.92	0.68	1.60

Source: Taye et al. (2008).

Table 26. Estimated gross field benefit (ETB kg^{-1} ha^{-1}) of intercropping coffee and potato at Jimma.

Coffee cultivar	Coffee		Potato		Coffee and potato intercropped
	Sole	Intercrop	Sole	Intercrop	
74110	572	729	11133	4714	5443 (11)†
74148	897	489	8612	8069	8558 (10)
741	615	566	9215	6224	6790 (9)

The money field prices of fresh coffee cherry and potato were 0.90 cents and 1ETB kg^{-1}, respectively. †Figures in the parenthesis represent the percent increments of the gross field benefit from intercropped coffee and potato over sole coffee. *Source:Taye et. al. (2008).*

5.5. Coffee and enset (*Ensete ventricosum*)

Coffee has been intercropped with *enset* (*Enset vetricosum*) at Jimma and Wenago, which is located in southwest and south Ethiopia using established 8-year old coffee and young coffee plantations, respectively. The coffee trees were intercropped with *enset* seedlings at a ratio of 1 : 1 and 2 : 1 at Jimma and 1 : 1, 2 : 1, 3 : 1 and 4 : 1 at Wenago. A pure stand of both test crops was included in the study for comparison. The result show that the growth of coffee trees was not affected by enset intercropping at Jimma (Table 27) due to the reduced shade casting from *enset* on the well established old coffee stands. Similarly, the differences between treatments were not significant for yield and growth performances of coffee trees at Wenago. Nevertheless, higher average values were recorded for 4 : 1 and 3 : 1 coffee to enset ratios, which were nearly equivalent to the value for the control (sole coffee) plot. In contrast, significantly the lowest value was recorded at an equal proportion (1:1) of the two crops (Tables 28 and 29).

At both sites, the yield advantages of coffee differed across crop years and the lowest results were obtained from an equal crop combination (Tables 27 and 29). The findings in general, have established the critical coffee to enset ratios of 2:1 and 3:1 for Jimma and Wenago areas, respectively.

Table 24. Yield and yield components of coffee trees intercropped with *enset* at Wenago.

Treatment	Plant height (cm)	Number of primaries	Length of 1st primary branch (cm)	Plant vigor (visual score (1-4)†	Cherry yield (g tree^{-1})
Coffee : enset	NS	NS	*	NS	*
1:0	218	75	103	3.8	5221
1:1	218	54	86	2.1	1479
2:1	248	67	105	3.3	3982
3:1	237	74	113	4.0	4681
4:1	218	73	108	3.8	4826

NS = Not significant and * = significant at 0.05 probability level. † 1 and 4 stand for poor and very good plant vigor, respectively.

Table 25. Mean fresh coffee yield and relative coffee yield of the first 3 years for coffee intercropped with *enset* at Wenago.

Coffee : enset intercropping ratio	Coffee yield (g tree^{-1})				Coffee yield advantage			
	1985/86	1986/87	1987/88	**Mean**	1985/86	1986/87	1987/88	**Mean**
	*	NS	NS	**NS**				
1:0	10999	2179	7760	**6979**	-	-	-	**-**
1:1	1364	2105	2582	**2000**	0.12	0.97	0.33	**0.29**
4:1	7766	3146	6110	**5674**	0.71	1.44	0.79	**0.81**
2:1	6798	3451	4686	**4578**	0.62	1.58	0.60	**0.71**
3:1	8513	4409	5381	**6101**	0.77	2.02	0.69	**0.87**

Ns = Not significant and * = significant at 0.05 probability level. *Source: Taye et al. (2008).*

Table 26. Mean clean coffee yield and relative coffee yield of coffee intercropped with *enset* at Jimma

Treatment	Coffee yield (kg ha^{-1})				Coffee yield advantage			
Coffee:*enset*	1986/87	1987/88	1988/89	**Mean**	1986/87	1987/88	**1988/89**	**Mean**
1:0	1955	1689	1633	**1759**	-	-	-	**-**
1:1	994	1892	1328	**1405**	0.51	1.12	0.81	**0.80**
2:1	2075	1217	1509	**1600**	1.06	0.70	0.92	**0.91**

Source: Taye et al. (2008).

Conclusion and Recommendations

Coffee seeds to be used as a seed material should be prepared from cherries picked at red ripe stage. Then, after pulping the cherries and removing the floaters, seeds with their parchment intact should be dried under shade and ventilated conditions as these reduces the drying temperature, which otherwise can injure its germinability. Farmers who want to store coffee seed for sowing should store seeds having initial moisture content of > 40% in well sealed moisture proof containers, depending on their availability, cost incurred, durability and easiness for handling, under cool and dry condition. However, if condition forces to use pores or moisture-vapor permeable container, viz. cloth bags, fiber sacks, open tray, etc., the moisture content of the seed can be reduced to < 32%.

Planting pre-germinated seeds should not be practiced by farmers as it results in large percentage of seedlings with malformed root system and eventual early (forth to fifth bearing) tree death in the field. Hence, coffee seeds should be seeded directly in seedbeds or polythene tube. However, if seed viability is doubtful, two seeds per hole should be seeded and then thinned to one plant. Furthermore, coffee seeds should be sown after removing the hard seed cover (parchment) and soaking the seeds in cold water for 24 hours as the practices enhance germination and seedling growth. These can also be shorten the nursery period and reduce the associated costs.

After sowing, seedbeds should be covered with 3 to 5 cm thick mulch (straw or other dried plant materials) and watered at two days interval until the seedling emergence. The mulch should be removed when the seedlings start to emerge. After emergence, the nursery beds should be provided with moderate (50%) overhead shade and watering frequency reduced to 4 and 8 days interval within a week until the seedlings attain 2 to 4 pairs of true leaves, respectively. Both watering frequency and shade level, however, should gradually be reduced one month before transplanting the seedlings to the field at the stage of six to eight pairs of true leaves.

For maximum germination and seedling growth, coffee seeds should be sown in forest soil to a depth of 1 cm with the grooved side of the seed placed down. However, in the absence of forest soil, divers type of alternative potting media with ideal physical and chemical conditions like forest soil can be prepared by blending decomposed compost (C) and top soil (TS) or C + TS + sand in various proportions. Phosphorus at a rate of 750 mg P/pot (2.5 kg sieved top soil) and a combination of 2.31 g lime and 250 mg P/pot is also recommended for growing Arabica coffee seedlings at Jimma. In the absence of micro propagation using tissue culture, the practice of planting soft wood single node cuttings with one pair of leaves taken from orthotropic shoot in pot filed with a mixture of top soil , sand and manure in 2 : 2 : 1 ratio should be exploited for multiplication of hybrid coffee varieties using mist propagation.

Forest coffee can be successfully rejuvenated and become productive by applying different rejuvenation practices, *viz.* topping, agobiado and eskeletamento, which out yield the conventional stumping at least by two fold. Furthermore, yield of forest coffee stand slightly improved by stumping orthotropic shoots at 50 cm height above the ground as compared the conventional 30 cm stumping height. On the other hand, tied ridge was found to be important components of land management, especially on sloppy land, to sustain and promote forest coffee yield. Maintaining coffee trees on a flat land had inferior compared to other land preparation and soil moisture conservation practices (tied and untied ridge). Application of mineral fertilizer is not recommended for forest coffee production as it promote organic coffee production by subsistence and small-scale forest coffee producers in the country. Yield of old coffee stands increase linearly with increasing number of bearing head per tree or stump by thinning out weak and closely spaced coffee trees and/or by planting new coffee seedlings in open space ranging between 4000 and 8000 trees per ha at different sites.

The choice of hole size for planting Arabica coffee in the field depends on agro-ecological conditions. Wider and deeper hole dug early in the dry season are preferable to ensure higher rate of survival and better field establishment particularly in areas with moisture deficit. Time of transplanting is also important for successful field establishment. In most of the cases, May/June and July/August transplanting seems to be proper time of transplanting, though this has to be supported by a long term rain-fall data of each location for better forecast of the planting time.

Various tillage methods and transplanting techniques improved stand establishment and subsequent growth and yield of coffee especially in the early year of production. On the other hand, a conventional holing on untilled plot and collar level of planting were found to be inferior at the different agro-ecologies. Thus, initial tillage and deeper planting should be practiced to ensure maximum field establishment of coffee plantations. Similarly, soil and moisture conservation techniques, *viz.* tied-ridge, untied-ridge and banding were found to be effective in improving productivity and yield of plantation coffee. Hence, among soil and moisture conservation techniques, tied ridges and untied ridge are recommended particularly for areas with undulated topography and frequent moisture stress.

Milletia ferruginea, Acacia abyssinica Albizia sp*., Erythrina abyssinica, Calpurnea subdecondra* and *Cordia africana* are favorable shade tree species for coffee production in areas where they can adapt with coffee. These prominent shade tree species provide moderate light intensity to coffee plant underneath; replenish soil fertility through liter fall and thus, promote organic coffee production in the country. The productivity of coffee trees could be improved by strip planting or intercropping with the shade trees. However, using strip planting pattern had more yield advantage then intercropping. Thus, shade trees, fruit trees or other complimentary crops can be stripped with coffee without affecting coffee yield as the practice minimize direct competition between shade trees and coffee plant for available natural resources, *viz.* light, moisture and nutrient.

Based on their canopy architecture and leaf, branch and stem nature Arabica coffee lines morphologically categorized under three canopy classes, *viz.* open, intermediate and compact. Such canopy spread, which is dictated by number of bearing heads, branches, angle orientation and plant height, determines special arrangement and optimum spacing between coffee plants. Under open sun condition, close spacing or high density planting of up to 10 000 trees ha^{-1} increased coffee yield, though the efficiency depend on agro-ecological factors and age of the plantation. However, to make use of the yield advantage of high density planting, more sustainable and appropriate management practices like pruning and optimum inputs should be applied and compact varieties have to be planted. For low land areas like Tepi, early cycle conversion or thinning out of trees to population not exceeding 5000 tree ha^{-1} is imperative.

Coffee can be grown with fruit and annual crops without significant yield reductions in a properly designed cropping practice. This is particularly important for intercropping coffee with enset, orange, avocado, turmeric and ginger. Among coffee cultivars, the compact varieties were found to be more suitable for intercropping. The yield performance of coffee was not much affected by intercropping and the benefits of the practice were higher at the early year of stand establishment. In general, intercropping coffee with different food and cash crops was found to be stabilizing yield advantage and gross economic returns, particularly at the early year of stand establishment. Hence, the small holding farmers can more or less be buffered against crop failure and low market price of one crop. Cognizant of the limited farm size owned by farmers and long time required for the coffee trees come into bearing intercropping is the only remedy to increase crop productivity per unit area of landed/or per year.

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