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Coffee (*Coffea arabica* L.) Field Establishment and Management Practices in Ethiopia

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Abstract: Coffee is one of the most important beverage crops, ranked the second most traded commodity next to oil globally, and grown for its health values, economic and socio-political benefits for several countries including Ethiopia. The arabica type is a highly produced coffee in different countries and dominates 70% of the world coffee trade for its quality requirements. It was first originated and is still there naturally under the shadow of the forest canopy in Ethiopia and best adapted to the higher elevations for the best quality. Nowadays, the crop has been grown naturally in the forest, in semi-forest, in the small home garden areas and plantation systems, in the country. But both the small home garden and plantation systems need human interference to produce quality coffee for domestic consumption and global market purposes. The former production system is traditionally practiced by small holder producers while the plantation was recently introduced and it is a kind of production system in a specific area by providing the agronomic requirement and others based on the plant growth stages throughout the crop ontogeny. As a result, the first and fundamental practice in the plantation system is the coffee field establishment (coffee seedling preparation on nursey, the plantation site selection and preparation and field transplant of the seedlings) at selected production areas. Also, soon after the coffee field establishment, the field management activities like shade regulation for the newly planted coffee seedlings and coffee trees permanently (coffee is the shade-loving plant), nutrients (organic sources) and water/irrigation/ application are practiced, especially around water deficit areas depends on the crop growth stages, environmental conditions and plant densities, and the weed, major diseases and insect pest occurrences to produce quality bean. Hence, most of the practices in the field establishment and field management activities have a positive contribution on the coffee production sector to be competent in the business and to fetch the foreign currencies for the country. But the Ethiopian coffee farm management systems and the agronomic practices are still traditional (90-95%) and need improvement. Thus, this paper was aimed to review the coffee field establishment and field management activities practiced in the center of arabica coffee origin, Ethiopia.

Keywords: Coffee Seedlings, Nursery, Nutrients, Plantation, Pests, Pruning, Shading, Yield

1. Introduction

Coffee is belonging to the Rubiaceae family which contains several species including *Coffea arabica*, *Coffea canephora* and *Coffea liberica* [1]. The arabica and canephora coffee are commercially grown types, but, the *Coffea arabica* dominates 70% of the world coffee trade for its best quality requirements. The arabica coffee was first originated in the south-western highlands of Ethiopia and still there naturally under the shadow of the forest canopy at an altitude of 1600-2800 m [2]. The coffee species have been widely disseminated from their center of origin to most parts of the tropics and sub-tropics suitable for their cultivation, and are now found in over 100 countries worldwide [3]. The arabica coffee is best adapted to the higher elevations of 18-22°C temperature range with a well-distributed annual rainfall of 1400 mm - 2400 mm for a continuation of about seven to eight months for the best quality [1]. As a result, the tree productivity of arabica coffee is highly associated with climate factors (rainfall, temperature, elevation, and aspect) and any changes beyond and below the ideal requirements affect the performance of the crop [4, 6].

Coffee is an important global beverage crop ranked as the second most traded commodity next to oil and most popular

drink next to the water which is widely known to provide economic, socio-political, and health benefits for the producers, traders, and consumers found in the value chain [5, 6]. For instance, coffee is the most important export commodity crop in Ethiopia which have a share of about 20-25% of total foreign exchange earnings and source of livelihood for more than 15 million people, especially for those engaged directly or indirectly in the production and marketing systems [7]. Therefore, coffee production has an economic, environmental, and social significance to the country.

Ethiopia has a huge potential for coffee production as it is endowed with suitable elevation, temperature, soil fertility, indigenous quality planting materials, and sufficient rainfall in coffee-growing belts of the country [8]. The main coffee growing areas in Ethiopia are Oromia region and South Nation, Nationalities and Peoples Regional State (Including the Sidama Region at the time), with modest production in Amhara region and minor output in Benishangul gumuz region [9]. According to the authors further noted, coffee farming in different parts of the country takes place over a vast area, under a wide variety of production systems and various growing conditions, with many different cultivation practices. As a result, based on the management level, vegetation coverage, structural complexity, and agronomic practices, the coffee production systems in Ethiopia can be categorized into forest coffee, semi-managed forest coffee, garden coffee, and plantation coffee production [10]. Since, the first three production systems have been traditionally practiced, whereas, the last plantation production system is introduced very recently with a range of 5-10% area coverage compared to the former production systems [10]. The plantation system is a type of producing coffee in specific areas by providing all the required growth conditions starting from the field establishment to the entire life cycle of the crop.

Nowadays, arousal of strong competition in the world coffee market and effects of climate change shifted the coffee production system from traditional to plantation system. Since quality coffee production in the home garden and plantation systems is the primary concern of producers due to the highest quality allows them to charge higher prices [11]. Thus, quality coffee production has interrelated with quality seedlings preparation, farm establishments in suitable growing areas, and application of appropriate management practices throughout its developmental stages [3]. However, the Ethiopian coffee farm management system and the agronomic practices are still traditional (90-95%) and need further improvements [8, 10]. As a result, this paper was aimed to assess the coffee field establishment and field management practices mainly focusing on the homegrown and plantation coffee production systems in Ethiopia.

2. Coffee Production Systems in Ethiopia

Several countries including Ethiopia have a wide range of suitable ecologies for coffee production. As a result, based on the management level, vegetation coverage, structural complexity, and agronomic practices, coffee production systems in Ethiopia can be categorized into four parts; forest coffee, semi-managed forest coffee (30-35%), garden coffee (50-57%) and plantation coffee (5%) [7, 10].

The forest coffee seems natural forests by its floristic composition, diversity and structure with little human intervention. The only management practice in the forest system is access clearing to allow movement in the forest during harvesting time [12]. The forest is managed or manipulated mainly for coffee production in the semi forest production. The activity is mainly done when the forest coffee is converted into semi forest, resulting in the reduction of plant composition, diversity and density both in vertical and horizontal structures. The garden coffee production system composes a major portion of the production system, accounting for almost half of the coffee production in the country. More of the produced coffee in the country comes from the smallholders whose average size is less than one hectare. The production can be as small as very few trees around a homestead up to about three hectares and intensive field management activities like weeding, fertilizing (farmyard manure and crop residue), shade management and cultivations are mainly practiced by growers in southern, eastern and southwestern parts of the country [10]. According to the author noted, the plantation system has contributed a small portion of the production share and is mostly held by state enterprises (Coffee Plantation Enterprise), private companies and some well-managed smallholder's coffee farms. The majority of this production system is found in Arsi, Bench-Maji, Gambella, Jimma, and Sheka zones of the country. In this system, the coffee plants are well managed and the recommended agronomic practices like improved seedlings, spacing, proper mulching, weeding, shade regulation and pruning are widely practiced.

Now a days, the coffee production in Ethiopia is changing gradually to the garden and plantation system due to heavy forest deforestation, climate change and decrement of land endowment with increasing population density. On the other hand, the demand for quality coffee in the international market and domestic consumption has forced the country's coffee production increments both in quantity and quality. Even if the arabica coffee is naturally grown under shade covers for the quality yield purpose, the management practices can also contribute a lot to produce higher and quality products to compete in the global coffee market. Therefore, the management practices in the garden and plantation coffee production system have to start early during the field establishments period and should continue throughout the growth stages.

3. Coffee Field Establishment

The quality coffee production especially the garden and plantation system require an appropriate selection of growing ecology. During the site selection, the long-term socio-economic factors involved with coffee production like labor

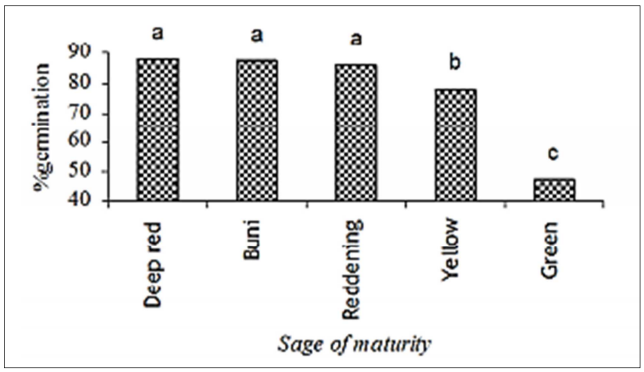
availability, processing facilities, and marketing arrangements need to be taken into account [3]. The next task to be done is the propagation of seedlings from known and healthy coffee cultivars on the carefully selected nursery site. Then, adequate field preparation activities like the hole digging based on the recommended spacings for the coffee types (compact or open types) have been done before the seedlings arrive for field transplanting. The coffee seedlings can be transplanted on the prepared hole during the wet season and immediately cover the mulch and temporary shade to allow sufficient sunlight for seedling growth. Hence, coffee is a perennial crop that needs intensive field management activities based on the crop's growth stages for long-term sustainable quality yield production.

3.1. Coffee Nursery Establishment and Seedling Preparations

The Coffea spp. can be propagated by seed or clonal plants in the form of cuttings, grafts, or tissue culture methods [13]. Arabica coffee is the most commonly grown from selected seeds unless there are special reasons for using clones. *Coffea canephora* can also be propagated by seed but due to its allogamous nature, material raised from seed is very variable and vegetative propagation is a usual practice [3].

The success of the coffee plantation system depends on the success of nursery site establishment and management practices. Before going to raise the coffee seedlings, a careful selection of appropriate nursery site is a very important task, especially for the presence of a permanent water source to irrigate the seedlings frequently, the proximity to the future plantation areas, absence of permanent shade near the nursery site, the land orientation is not exceeding more than 5%, can fairly drain excess water from the site and should not extremely cold and hot area, freedom from wild and domestic animal nuisance and the accessibility to the transportation system to bring the seedling to the permanent field. Therefore, the failure in one of these fulfillments can bring the seedling to weak performance and can result in low productivity and reduction in quality of yield at the end [14].

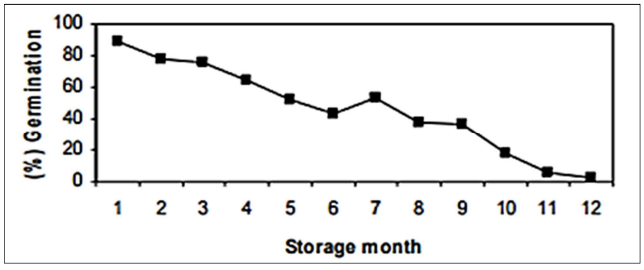
After proper nursery site selection, determination of the nursery size based on the required coffee seedlings for field transplant is very important task to reduce over production. The nursery sites can be prepared either on the nursery seedbed for bare-root seedling production or seedling transfer into the pot after seed emergence. It is also possible to prepare the coffee seedlings by direct sowing into the polyethylene tube to raise with normal root systems [15] (Anteneh, 2015). Therefore, the coffee nursery plot preparation can be a raised piece of land which ideally should be 1.2 m wide and 20 cm deep consisting of fertile topsoil (50%) mixed with sand (50%) [16]. Then, a coffee seed has been sown at a depth of 1 cm flat side down with the distance between seeds and rows of 2 to 3 cm and 3 cm on the well-prepared nursery bed or polyethylene tube, respectively. Soon after, covering the bed with an appropriate thickness of mulch depending on the environment of the area. Before coffee seed sowing, the cherries have been selected from vigorous and healthy coffee trees that can give the average yield for three or four years [17]. Hence, cherries that are fully ripe during the peak of the harvest time from the middle part of the tree are usually preferred and best for propagation purposes (Figure 1). The collected seed must be sown immediately after pre-sowing seed management for a successful germination rate because the age of coffee seed has a direct influence on germination rate and coffee seedling emergence.



Source: Anteneh, [15]

Figure 1. *Germination of coffee seeds as affected by stage of fruit maturity.*

The germination rate of coffee seed in the field is slow by nature especially when it gets dries more and stayed for a long period [18]. However, for the best seedling establishment, operating the pre-sowing seed management activities like proper seed collection, preparation, handling, and pre-germination of the seed are very important practices [15]. The author also noted, keeping the coffee seeds for more than three months can reduce the percentages of seed germination, seedling emergence, and seedlings' attainment to their first true leaves (Figure 2). Since, the coffee seed loses viability within three months and should not be used after that period unless the proper storage at low temperature and high humidity conditions are available [13]. Similarly, the study of Gebreselassie *et al*. [19] also reported the effects of coffee seed pre-treatment activities and found that soaking the coffee seed for 74 hours before planting were hastened the emergence and subsequent growth of coffee seedlings. However, the study of Anteneh [15] was reported the converse result that the pre-germination coffee seed treatment before seed sowing caused multiple and crooked tap roots and eventual tree death in the field.



Source: Tesfaye *et al*. [20] as cited by Anteneh, [15].

Figure 2. *Effect of time of storage on germination of coffee seed.*

After seed sowings of arabica coffee, it starts emerging from the soil after 50 to 60 days of sowing in the warmer periods of the year and it might take up to 90 days when the temperature is lower because the difference in range of temperature regulates differently the physiological activities of the seed for germination [18]. So, the first 20 days of the seed sown nursery should be kept dark and shaded to control the effects of light intensity, temperature, and humidity regulation [16]. Based on the environmental conditions, the nursery shade might vary from 70 cm height at high altitudes and one-meter height at low altitudinal areas for each bed [17]. Thus, following the seed sowing on the nursery site, the coffee seeds will germinate within six to twelve weeks depending on altitude and season of production and the applied suitable nursery management practices. According to the study of kuit *et al.* [16] noted that after coffee seed germination, the parchment has shed the first two leaves and is oval-shaped called the bracteoles, and together with the bracteoles, the terminal bud appears. After the emergence of the bracteoles, the coffee seedlings will be transferred to the plastic bags at about two to three months after sowing until it gets transplanted to the permanent field [13].

The main purposes of growing coffee seedlings on the plastic pot are to make ease the normal growth rate on the ideal media which facilitates the seedling root development, retain media moisture and supply sufficient nutrients to the developing seedlings (Figure 3). The potting media can be prepared by mixing the soil which contains 4:2:1 part of forest soil, compost and sand, respectively [17]. Also, adding organic nutrient sources to potting media is essentially important for coffee nurseries and the production of vigor seedlings [21]. The organic media source is used mainly to conserve the moisture in the soil and buffer the soil CEC for normal growth and development of the seedlings. Different sizes of plastic polyethylene bags are used as a seedling pot for the proper growth and development of seedlings in coffee nursey. However, the study of Ibrahim *et al*. [22] reported as the smaller pot sizes were preferred by growers recently due to its conveniences for handling and transportation to the long distance from the nursery site to the farming area, even though the largest pot size allows the seedlings root to grow vigorously and absorbs enough water and nutrients freely from the media. Immediately after the seedlings transferred to polytene bag, regular watering, shading preparation, weed control, and other management activities have been applied as per requirements until it gets ready for field transplant.

The coffee seedlings can also be raised directly on the prepared nursery polyethylene tube media. This method of coffee seedling preparation is the easiest way because of no need for nursery seedbed preparation and seedling transfer to the polythene media. According to the study conducted at Bonga to study the survival percentage of coffee seedlings after field transplant was reported, raising the coffee seedlings on the polyethylene tube helped seedlings to survive more after field transplant than the bare-root seedlings [22]. Finally, after the coffee seed has sown either on the nursery bed or polythene tube media and the proper nursery care has been given, the coffee seedlings are getting ready for field transplant at the age of eight to nine months or when it attained a minimum of six to eight leaf pairs [17].

Figure 3. *Coffee seedling establishment and management practices on polyethylene bag in nursery site.*

3.2. Coffee Field Transplanting

Coffee field establishment is the most important activity in the home garden and plantation production system. The time spent in planning and preparing well of plantation layout before field transplanting of coffee seedlings will produce dividends in later years by achieving optimum yields in quantity and quality per given area [23]. In the coffee plantation system, every activity has a contribution to quality yield production. First of all, selection of an appropriate site is very important task for coffee production. The flat or gently sloping terrain is preferred to facilitate the operational activities of the farm and drains unnecessary water logging in the growing areas. Also, clearing unwanted plant debris like big trees and perennial weeds from the selected site during the dry season and making ease can facilitate the field transplant of coffee seedlings.

After appropriate site selection and clearance, the hole has been dug by keeping the recommended inter and intra spacings based on different factors. Hence, the planting distance of coffee seedlings are depending on a combination of cultivar type and altitude of the area [24, 25]. According to the study of Weidmann and Kilcher [26] noted, the distance of coffee planting should be based on the later tree canopy-bearing habits and covering areas. He added that the optimum intra and interspacing of the arabica coffee tree of 2.4 m x 2.4 m is appropriate and for robusta coffee, a spacing of 3 m x 3 m was found to be best. Thus, the robusta coffee tree requires a wide range of spacing for its large canopy spread than arabica trees. However, the studies reported recently indicated as the narrower spacing of arabica coffee plantation was found to be preferred because the density planting is much more yielder than the conventional system [27, 28]. Hence, the narrower spacing can cover the ground to conserve moisture in the soil, increase the fertilizer application to higher, keep the plant leaf shading, reduce the soil temperatures, and atmospheric evaporation of the leaf to produce more yield than the low-density planting [29].

Based on the recommended spacing for a particular

cultivar, ecological areas and plant canopy sizes, the planting hole has dug at 60 cm by 60 cm (hole diameter and depth) placing an upper portion of soil at one side and the lower part at another side two to three months before field transplanting [16]. This may allow loosening of the soil for better water movements, root penetration and to kill harmful root affecting organisms. Then after a month of dug, refilling the hole with the topsoil and well-decomposed manure and phosphorus sources of fertilizer per planting hole is very crucial activity for the later formation of vigor root development of the seedlings [16]. Consequently, planting the coffee seedlings at the age of six to eight months on the previously prepared hole at the beginning of the rainy season will give sufficient time for young plants to establish roots before the dry season sets in. After all successful coffee seedlings transplanting, the recommended coffee field management practices are followed based on the growing climate condition and the crop age.

4. Coffee Field Management Practices

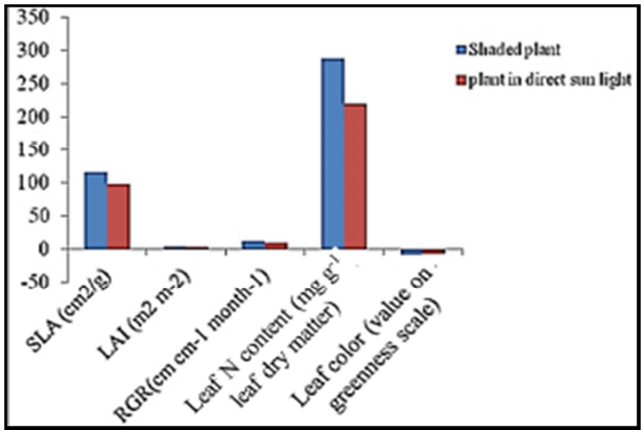
The coffee field management practices are very important activities to the growing plants depending on the crop ontogeny. These management practices are including the temporary and permanent shade regulation for the transplanted seedlings and growing trees, the soil fertility management practice, the pruning and stumping practices to remove unproductive structure and facilitate the sunlight caption, the weed management practices to reduce competitions for growth resources and the disease and insect pest management practices to reduce their effects to produce the quality coffee yield.

4.1. Coffee Shade Management Practices

In a coffee production system, as it is a shade-loving plant, shade regulation is a very important activity for quality bean production. The provision of shading trees in the coffee production system is used to regulate a microclimate which creates a suitable environment for normal plant growth and development [30]. Hence, shading helps the crop to reduce the amount of heat reaching the plant during the daytime and protects from the evening and night low temperatures, and the destruction of hailstorms and winds being as a physical barrier [31]. He further noted that plant biomass (leaf litter and small twigs) obtained from shelter trees improve the organic matter content of the soil in a coffee farm by creating a conducive environment for N-fixing microorganisms and conserving the soil moisture of the farm. In addition, coffee production under shading was reported to reduce the biennial bearing of a coffee tree. The study of DaMatta, [2] noted that the shaded coffee tree tends to flower and produce a good crop each year as compared to the open sun trees. Further, the possibility of disease and insect pest management by shade regulation as a biological controlling method of coffee pest management was reported. Accordingly, the study of Alemu [31] indicated that provisions of shade trees to coffee plants were controlled the white stem borer and leaf rust in arabica coffee trees.

Temporal shade provision for young transplanted coffee seedlings is used to reduce high sunlight intensity and frost damage. Intercropping the crop with fast-growing trees can increase ground cover and maximizes the efficiency of nutrient and water utilization rate during the juvenile phase [32]. Therefore, the best shade tree for a coffee plantation should be tall with spreading growth habits, small leaves, and resistance to wind damage. Alemu, [31] was indicated the lists of plants used for shading purpose in coffee production in Ethiopia which mainly belongs to the family leguminous like *Albizia sp., Ficus sp., Acacia abide, Cordial africana, Lucena leucocephale, Citrus sinensis, Sesbania sesban, Grevilia robusta, Pleurocarpous marsupium, Cedrella toona, Artocarpus integrifolia, Artocarpus hirsute, Bischofia javanica, Erythrina lithosperma, Terminalia bellarica* are helping to fixes nitrogen in the soil that is beneficial for plant growth and developments.

Different findings have been reported on the effects of providing shade trees for coffee productivity compared with the open sun growing plants. The coffee grown in the shading area improves the photosynthetic rate, increases leaf area index and showed better performance which gives larger and heavier fruits with better bean quality than those grown in direct sunlight [33]. In contrast to this, the study of DaMatta [2] noted that the productivity of coffee beans was decreased in shaded areas. This might be due to the carbon assimilation of the whole plant being reduced as the result of greater stimulus of vegetative growth rather than flower buds, and the presence of a fewer number of flower nodes per branch in shaded areas. Similarly, the study of Vaast *et al*. [34] reported as shelter provision for coffee trees were decreased the coffee productivity by 18% but reduced alternate bearing. The authors further indicated that the provision of shading trees to the growing coffee tree was delayed the berry ripening by one month to complete the higher sucrose, chlorogenic acid, and trigonelline contents used to give higher bitterness and astringency of the coffee beverage that positively affected the bean size, composition, and beverage qualities.



Source: Bote and Struik [33].

Figure 4. *The effects of shading and non-shading of coffee on photosynthesis variables.*

4.2. Coffee Nutrient Management Practices

In the coffee production system, soil fertility management is a very important activity for plant growth, and berry development and maturation. The coffee trees require a rich, moist, loose, well-drained soil which best composed of organic matter and important nutrients based on the plant age and growing conditions [35]. However, coffee production around a heavy rainfall can result in nutrient leaching and fixation that are to be offset by the regular application of adequate quantities of fertilizers. Arabica coffee production requires fertile soil with high levels of nitrogen, phosphorus, and potassium contents for normal tree growth and development, and adequate supplying of these nutrients is essential to obtain higher and quality bean yields [35]. As the author noted, nitrogen is essentially required for vegetative growth and phosphorous is used for root developments, especially at its early stage, whereas potassium is required for the growth of reproductive organs of coffee. Thus, the coffee essential nutrient requirements are mainly depending on the inherent soil fertility status, soil pH, level of production, and applied cultural practices like mulching, manuring, and irrigation status of the area [16]. The authors further indicated that the application of fertilizer (manure/compost and inorganic fertilizer) during planting time especially phosphate-containing nutrients is required for the development of the root system. The nutrient application to the growing coffee tree might be varying with the expected yield, fertility levels of the area, and crop age. Therefore, the application of nutrients after coffee harvesting is a very important practice based on expected nutrient removal during yield and anticipated losses to maintain healthy leaves, branches, and roots of the plant [16].

Different authors were reported on the importance of fertilizing coffee at different growth stages. Accordingly, Chemura [35] was studied the effects of organic, inorganic fertilizers and integrated soil fertility management with levels of irrigation water on the growing coffee plants. He found that the application of inorganic fertilizers sources to coffee trees showed an effective method with higher irrigation levels while organic manure performs better than inorganic fertilizers under low irrigation levels. This might be due to the organic sources of fertilizer could conserve moisture in the soil to supply water during shortages. The study of Clemente *et al.* [36] also indicated that the highest ratio of N: K applied to the coffee plant was promoted coffee vegetative growth. Hence, nitrogen enhances the vegetative growth while potassium enhances the development of coffee berries. As a result, the coffee nutrient management practices based on requirements according to its developmental stages and the growing condition is a very important activity for the producers.

4.3. Coffee Pruning Management Practices

Pruning is an essential part of coffee production, and basically, it involves thinning of branches and removal of old or dead stems [5]. Coffee training is a type of management practice to create well-structured and healthy trees to provide a good cherry yield over a long period in long-term production systems [16]. As a result, coffee tree pruning is mainly practiced to determine the tree height to make easier harvesting and spray activities, to encourage the growth of new, vigorous stems and branches of coffee for next seasons by cutting the less productive parts, to reduce biennial production, to prevent the cherries overbearing and to prevent some pest and disease problems by opening the canopy for light penetration and air circulation inside the tree [5]. The coffee tree pruning is also used to avoid unnecessary nutrient competitions with unproductive parts and to remove an accumulation of high humidity under the tree canopy to reduce the fungal development through better air circulation. For these reasons, the coffee tree can be pruned into the desired structure either single or multiple stems [26]. The authors noted that the single stem system is primarily used for arabica coffee but the multiple stem systems are more used in robusta coffee production. However, using the multiple stem system in arabica coffee, in the first three to four years can give a better yield than the single stem systems, even if it will start declining more rapidly after the initial peak harvest [16]. Consequently, the precise pruning system depends on the cultivar and growing conditions are very important [37].

The rejuvenation of the older coffee tree is an important practice to get younger and more productive branches to keep the maximum production without yield decline as the previous of age. Further, removing unnecessary suckers that develop on the tree is also an important practice [3]. According to the study of Taye *et al*. [38] were reported on the effects of pruning on the growth and yields of the coffee tree, the pruned coffee trees were given higher bean yields than the non-pruned tree at Mettu, Ethiopia.

4.4. Coffee Water / Irrigation / Management Practices

Coffee is an evergreen plant that requires an ample amount of water to transpire throughout the year with some distinctive dry periods to initiate anthesis [3]. Water availability plays a dominant role in many aspects of growth, development, and yield of coffee than other factors [39]. The arabica coffee requires an annual rainfall of between 1100 to 2000 mm, with a three to four months dry season if the weather conditions are conducive to low evapotranspiration or with supplementary irrigation application [3]. However, the water requirements for coffee mainly depend on the soil type of growing area, the environmental condition, and the age of the crop. As a result, the application of below and above the crop requirement can have a detrimental effect on the growth and developmental process and crop productivities. Hence, excessive water availability reduces the root activities which causes soluble nutrient lixiviation (mainly nitrogen and potassium), flower fall, fruit ripening, retardation, a higher incidence of soil diseases, physiological disturbances, and yield reduction [40].

The amount and frequency of water requirements are determined based on the age and ecological conditions of the production areas. Therefore, the coffee seedlings in the nursery site require regular irrigation due to the availability of a high

concentration of roots in a small volume of substrates [41]. The study of Shimber and Lemaga [42] was reported the maximum growth of the stem, branch, leaf, and root extension, and total dry matter of coffee seedlings was obtained from the higher irrigation water than lower levels in Ethiopia. The authors have also observed the decrement of the root to shoot ratio of the seedlings as the irrigation water level has increased. Hence, the drought-stressed coffee plants tend to have greater biomass allocation to the root than to the shoot, lower leaf area, and heavier leaves than well-watered plants [43, 44]. The study of Kobayashi [45] also observed as regular application of sufficient water to the growing coffee is important for the seedling vigor, growth, and development (Table 1). Since the vigor seedlings are required for coffee field transplanting purpose to get robust and productive plants for higher and quality yields.

Table 1. *The effect of water frequency on the growth of potted coffee plants after four weeks. A total of 700 ml of water was applied per plant per week.*

Watering Frequency (Per week)	Plant height. (cm)	Stem Diam. (cm)	Leaf area (cm^2)	Leaf dry wt. (g)	Dry wt. (g)
1	1.78	5.74	731^b	5.69^b	9.90
2	2.44	5.75	1365^a	10.32^a	10.84
4	1.12	5.80	1296^a	10.16^a	12.36
7	1.22	5.75	1373^a	10.28^a	12.11
	NS	NS	663	4.60	NS

Mean separation in columns by Waller-Duncan K-ratio t-test, K ratio=100, NS is non-significant. The same letter indicates no significant difference among the treatments.
Source: Kobayashi [45].

Water management after the coffee field transplant is a very important activity in the coffee production system because water can limit crop growth and development by affecting the biochemical reactions inside the plants. The soil water deficiency has a direct relation to the stomatal movements and CO_2 uptake by the plants which can affect the photosynthetic rate to partition and the photo assimilate into growth and fruit-load [46]. As a result, water must be freely available to increase the turgor pressure of the plant for flower buds burst during flowering seasons and for rapid fruit expansion to ensure large and high-quality coffee seed yields [39]. According to Serra *et al.* [47] reported, the application of water to the growing coffee allows the tree to boost productivity in Brazil. This might be due to appropriate plant densities being regulated efficiently the available water under coffee trees. Similarly, the study of Assis *et al*. [48] reported the influence of different irrigation management regimes and coffee planting densities on growth and bean yield of *Coffea arabica* L. in Brasil (Figure 5). The authors observed that applying irrigation water to the coffee farms varied as a function of plant densities on the increment of yield per given unit area, even though the growth performance was recorded from the irrigated coffee farm regardless of the density.

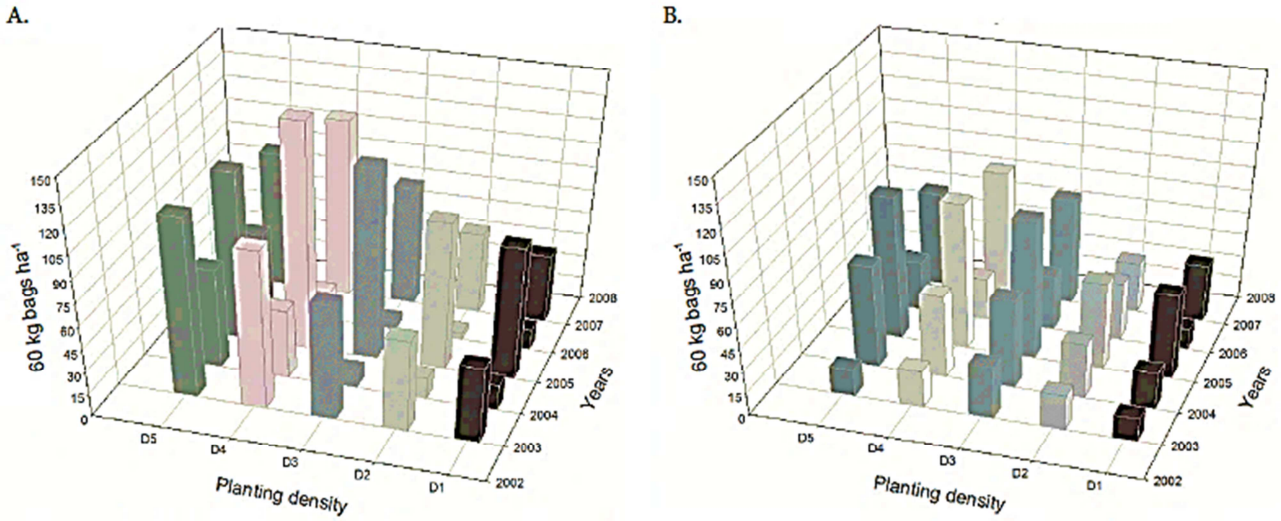


Figure 5. *Yield of five harvests (2003-2007) in bags ha^{-1} of processed coffee irrigated (A) and non-irrigated (B) in the function of the planting densities.*

D1, D2, D3, D4 and D5 refer to 2,500, 3,333, 5,000, 10,000 and 20,000 plants ha^{-1}, respectively
Source: Assis *et al*. [48].

Water management in coffee production is a very crucial practice, at almost all growth stages. Therefore, the production and productivities of coffee are positively affected by the availability and even distribution of water, especially at flowering, fruit settings, and berry development stages that are directly linked with the final berry yield. Production of coffee by irrigation is mainly practiced in Amhara and Benishangul-Gumuz Regions, and the northeast part of

Oromia region (Harar coffee zone) [9]. Hence, the coffee water management practices can be done by supplying irrigation water based on the crop requirements and environmental conditions, especially where the rainfall distribution is erratic.

4.5. Coffee Weed Management Practices

Weed is a plant growing where it is not wanted and in competition with cultivated plants [49]. The broadleaved species predominated the coffee plantations, and Asteraceae and Poaceae were the dominant families of weeds [50]. They negatively affect growth and yield by competing with crops for nutrients, sunlight, space and water [51, 52]. Thus, the crop and weed nutrient concentration and competition degrees greatly varied depending on both weed species and densities. For instance, in Ethiopia, loss in coffee yield due to weed infestation was recorded to be as high as 65%, depending on the type and frequency of weeding operations [50]. At the young stage, coffee plants are sensitive to weed infestation which causes a reduction in nutrient content on the growing seedlings [53]. The authors noted that the critical periods of weed infestation to coffee are at the seedling stage after the field transplant which causes a severe reduction in growth and developments of the crop mainly with increasing weed densities. The competition of weed is more intense in the dry season than the moist period due to a scarcity of water and available mineral nutrient in the soil [53]. They further indicated that higher competition of weed was affected the leaf area, leaf number and leaf dry biomass and dry stem biomass of coffee resulting in a reduction in growth and yield.

The main purpose of weed control in coffee production through sustainable systems is to minimize the competition of weed with the main crops. The ways of weed management in coffee production have an influence on the environmental quality and crop yields if it isn't properly practiced [54]. On the other hand, the weed controlling system in coffee plantations must be efficient and rational without causing negative interference in the growth, development and yield of coffee. In the coffee plantations system, the fields start from the transplanting time to about two years and in the stumped coffee field, the wide space founds in inter-rows, are commonly intercropped to reduce the weed growth [55]. Therefore, cultivating annual or perennial legumes in a coffee plantation, in addition to serving as green manure, may have the purpose of reducing weed infestations [56]. Also, the combination of partial slashing and application of herbicides in patches was found more effective in reducing the unwanted weed biomass and enhancing the spread of the ground cover legumes [57]. Furthermore, shade regulation in coffee production also reduces the intensity of weed infestation by inhibiting their growth and development by restricting the light penetration for photosynthesis and altering the microclimate of the area [49]. As the last option of weed control in the coffee plantation, different herbicide brands are used in large-scale coffee production areas and they are found to be effective in controlling different families of weeds in coffee farms [53].

4.6. Coffee Disease and Insect Pest Management Practices

Despite its overall importance, coffee is a crop which widely susceptible to diverse diseases and insect pests that are increasingly evident with climatic changes and cause damage and yield loss [3]. Hence, arabica coffee is more susceptible to a wide range of insect pests and diseases.

The incidence and severity of insect pests and disease vary with ecological areas which greatly affect the crop at different temperatures [3]. According to the authors indicated, the coffee leaf rusts, leaf miner, and stem borers are more severe at lower altitudes (on robusta coffee), whereas coffee berry disease is worse under cooler and wetter conditions at higher altitudes (on arabica coffee). Since over 900 insect species have been known to infest coffee, however, only a tiny fraction of these is economically damaging. The insect pests like coffee berry borer (*Hypothenemus hampei*), coffee stem borers, coffee bug (*Antestia species*), Scales and Mealybugs, and leaf miners are an important pest that economically causes yield loss. Similarly, different types of coffee disease like the coffee leaf rust (*Hemileia vastatrix*), bacterial blight (*Pseudomonas syringae*), cercospora leaf and berry spot (*Cercospora coffeicola*) (can be important in coffee nurseries), coffee berry disease (*Colletotrichum kahawae*), and coffee wilt disease (*Gibberella xylarioides*) also cause important damage and yield losses in coffee-growing areas including Ethiopia [3, 9]. Further, coffee root diseases and nematodes are important factors affecting coffee production.

Different pest management strategies were widely adopted to reduce the incidence of coffee disease and insect problems in different areas. The first and most strategy is to exclude pest (disease, insect, and root nematodes) introduction to the coffee farm by using the clean (pest-free) seed at planting time to control the seed-borne diseases, such as coffee wilt diseases Waller *et al.* [12]. Some coffee insects' pests and diseases like coffee bugs (*Antestia SPP)* and coffee berry disease can be managed by removing unproductive vegetation and less vigor plant parts. Also, opening up the leaf canopy of the coffee plant to allow more light penetration and to create air movement for humidity and temperature reduction commonly practiced around the coffee production areas [30]. The Coffee and Tea Authority of Ethiopia, [17] recommended removing mulching materials after coffee seedling emergence to reduce the damping-off disease at the nursery sites. Further, Waller *et al*. [12] pointed out that regulation of shade to the coffee tree reduces the incidence of coffee leaf rust and Asian white stem borer as well as the diseases caused by the hot and cold effects at higher altitudes areas. The authors also indicated as soil nutrient management is greatly important to crop health, especially areas where the coffee is grown on poor soils with low nutrient levels to resist the crop susceptibility to diverse insects' pests, and diseases problems.

Thus, selection of appropriate sites for the coffee farm

establishment which is free from the diseases and insect pest history before starting the field transplants or keeping the soil hygiene and disinfecting the soil to remove diseases and insect pests in the field found very important activities to reduce the plant damage and crop loss at the end [58]. The authors further indicated as regulation of tree microclimates and soil water management can enhance the natural biocontrol to manage the coffee disease.

5. Summary

Coffee is one of the global agricultural commodities which mainly grown for its economic, health, and socio-political benefits around the world. The type of arabica coffee is highly produced in different countries and dominates 70% of the world coffee trade for its quality requirements. The arabica coffee was first originated and is still there naturally under the shadow of the forest canopy in Ethiopia and best adapted to the higher elevations for the best quality. The coffee can be grown naturally in the forest, in semi-forest, in the small home garden areas and plantation systems in Ethiopia. In the semi-garden and plantation production, the coffee field establishments and field management practices like the seedling production, the site selection and land preparation, seedling transplant to the permanent field are found the most important activities practiced for coffee field establishment in both systems. Also, the coffee field management practices like shade regulation for newly transplanted seedlings and permanent coffee trees, the soil fertility (organic nutrients), and irrigation water management especially around the water deficit areas and the major weed, insect pests, and diseases (especially the type of diseases occur due to the climate change) management practices are found crucial activities that applied in coffee production sector to produce a competitive product for the world market in terms of quantity and quality yield. Hence, all the steps that followed in the coffee field establishment and field management practices have a positive contribution on the coffee production in a sustainable manner to be competent in the coffee business and to fetch the foreign currency for country development. Thus, the lack of these and other practices in field establishment and field management of the coffee production sector are leading to failarity in quality and quantity of the products that bring to kick out from the world market and puts down the country's economy.

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