# EFFECTS OF HONEY BEE DENSITY AND HIVE DISTANCE FROM AVOCADO (*Persea americana*) POLLEN DONOR ON FRUIT SETTING OF AVOCADO TREE: THE CASE OF DARRA OTILCHO DISTRICT, SIDAMA REGION, ETHIOPIA

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APPROVAL SHEET

As member of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by Mr. **Meseret Mulugeta** entitled " Effects of honey bee density and hive distance from avocado (*persea americana*) Pollen donor on fruit setting of avocado tree". We hereby certify that, the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences. (M.Sc.) in Animal Production.

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DECLARATION

The Thesis Entitled as **“Effects of Honey Bee Density and Hive Distance from Avocado Pollen Donor on Fruit Setting of Avocado Tree: The case of Darra Otilcho, Sidama Region, Ethiopia”.** Submitted in partial fulfillment of requirements for the degree Masters of Science with specialization in Animal production. Graduate program of the school of Animal and Range Science College of Agriculture, is a record of original thesis carried out by **Meseret Mulugeta Hewiso**, ID.NO GpAProR/0009/13, under our supervision, and no part of thesis has been submitted for any other degree or diploma. Therefore, we recommended that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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DEDICATION

This study document is dedicated to my family and my lover Yelibe Tariku for treating me with care, unlimited support and for their encouragement in my academic carrier and life.

## BIOGRAPHICAL SKETCH

The author, **Meseret Mulugeta**, was born in Bensa District, Sidama Region in 1996. He attended elementary school at Bensa Kebado Junior Secondary School, Sidama Region and his preparatory education also at Hayole Education Project Furra Model Academy, Hawassa. He joined the Ambo University Guder Campus College of Agriculture and Veterinary Science in 2016. He graduated with Bachelor of Science Degree in Animal and Range Science in 2018. After his graduation, he was employed in the Extension Work at Bensa District, Department of Animal and Fisheries Office. In July 2020, he joined the School of Graduate Studies of the Hawassa University to pursue his MSc study in Animal Production.

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## LIST OF ACRONYMS AND ABBREVIATIONS

AWFPT………………………………………… Average Weight of Fruit per Tree

BPT………………………………………………Bees per Tree

CAD……………………………………………...Canadian Agricultural Development

CSA………………………………………………Central Statistical Agency

DHBPT……………………………………………Density of Honey Bees per Tree

EP…………………………………………………Efficiency of pollination

FAO……………………………………………....Food and Agriculture Organization

FAOSTAT………………………………………...Food and Agricultural Organization Statistics

GIS……………………………………………… Geographical Information System

GLM………………………………………………General Liner model

HBRC……………………………………………. Holeta Bee Research Center

HH…………………………………………………Households

NFPP……………………………………………...Number of Fruit per Plant

NRC………………………………………………National Research Council

NPGPS……………………………………………Number of Pollen Grain per Stigma

RP…………………………………………………Rate of Pollination

SAS………………………………………………Statistical Analysis System

TNFPT……………………………………………Total Number of Fruits per Tree

TWFPT……………………………………………Total Weight of Fruit per Tree

Title: Effects of Honeybee Density and Hive Distance from avocado (*Persia americana*) pollen donor on Fruit Setting of Avocado Tree: The case of Darra Otilcho District, Sidama Region, Ethiopia.

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**ABSTRACT**

*Pollination is an essential ecosystem service that enables plant reproduction. Avocado is one of at least 105 crops that receive yield benefits from animal pollination. This study determines the effects of honey bee density and hive distance from avocado pollen donor on the number fruit per tree, weight of individual fruit and total weights of fruits per tree. The research was carried out in Darra Otilcho district, Sidama region, Ethiopia. Data was collected through household interview from purposively selected household to know the perception of farmers on pollination and pollinator. For experimental work, four avocado orchards with three replications, totally twelve orchards were selected, each one with an area of 1.5hectare. The treatments were:1)three beehives/1.5ha,2)two beehives/1.5ha,3)one beehive/1.5ha, and 4)control without beehives with three levels of foraging distance ( 50m, 100m, and 150m from the hives) with12 treatments in nested design. The treatments of three and two beehive/1.5ha obtained significant difference compared to the control, with a honey bee per tree of 15.2, 8.7, 6.0 and 2.9, rate of pollination 70, 47.8, 47.8 and 41.1%, efficiency of pollination 16.6, 8.8, 7.2 and 5.4 respectively. As well as total number of fruit per tree 392.2, 309.6, 245.2 and 193.2, average weight of individual fruit 215.3, 204.0, 193.4 and 188.4gm and total weight of fruit per tree, 84.5, 63.1, 47.4 and 36.4 kg for treatments 4, 3, 2, and 1, obtained significant differenceres respectively. The results obtained show that an increase in the density of honeybees per tree, increased the rate of pollination, efficiency of pollination, and total number of fruit per tree as well as average weight of fruit per tree and total weight of fruit per tree. This study recommended three beehives/ha to be introduced in the avocado orchard for effective pollination and increase of avocado yield.*

Key words: *avocado, fruit set of avocado, hive distance, honey bee density, rate on pollination,.*

# 1. INTRODUCTION

## 1.1 Background of Study

Avocado (*Persea americana* ) is an evergreen subtropical fruit tree native to Central America and Mexico where it was domesticated and cultivated since ancient times (Galindo-Tovar *et al*., 2008; Chen *et al*., 2009). It is a member of the Lauraceae; a mostly subtropical or tropical family included within the order Laurales in the evolutionary early divergent angiosperm clade Magnoliid. Large number of cultivars (More than 200) of cultivated avocado is classified into three distinct races: West Indian, Guatemalan, and Mexican. During the last century, it has been widely distributed to more than 50 countries around the world, which mainly includes sub-tropical and tropical areas such as sub-Saharan Africa. Ethiopia is one of the top five avocado producers in sub-Saharan Africa. Avocado was first introduced to Ethiopia around 1938 by private orchardists in Hirna (Eastern highlands of Ethiopia) and Wondo-Genet (Southern Highlands of Ethiopia). Gradually, it has been distributed to different agro ecological conditions where the crop could be adapted (Edossa 1997; Woyessa and Berhanu 2010; Megersa and Alemu 2013). Despite its long history since introduction and the diverse agro-ecological conditions of Ethiopia, its distribution is still limited to few areas of the country (CSA 2014). Currently, the main avocado producing areas include Sidama and Wolayita areas in the South, Jimma and Mizan areas in southwestern and Hararghe area in eastern region of the country (Megersa and Alemu 2013; CSA 2014).

In Ethiopia, avocado trees are mainly grown as an integral component of coffee (*Coffee Arabica L*.) and enset (*Enset ventricosum*) agroforestry systems and to a lesser extent in combination with other crops like maize (Moges 2009; Shumeta 2010). As coffee requires shade trees and known for its shade-tolerance, smallholder producers consider avocado as one of the important shade trees while also benefiting a lot from the sale of the avocado fruits (Kahuranga *et al*., 1993; Moges 2009; Shumeta 2010). It is also grown as individual trees around the court yards where it is used also as shades for people and livestock. The Sidama Highland in Southern Ethiopia is known for the traditional coffee- and enset-based agroforestry system (Asfaw and Agren 2007; Abebe *et al*., 2009; Moges 2009; Asfaw and Lemenih 2010). This region is one of the areas where avocado was first introduced to Ethiopia (Zekarias 2010; Megersa and Alemu 2013). The

Sidama highlands have suitable agro-ecological conditions for rain fed avocado production. It accounts about 36 % of the national annual avocado production (CSA 2014). Therefore, the Sidama highlands are important sources of avocado fruits for major cities such as Hawassa and Addis Ababa. Despite the suitable agro-ecological conditions to grow avocado and economic importance of the crop for smallholder producers, studies focusing on characterization of the avocado production systems are generally limited in Ethiopia (Shumeta 2010; Megersa and Alemu 2013). It is hypothesized that the avocado tree holding by smallholder farmers could be influenced by various socio-economic and institutional factors. Moreover, the fruit yields from individual trees could be influenced by production systems and tree management practices.

Avocado is one of at least 105 crops that receive yield benefits from animal pollination (Rader *et al*., 2020); Pollination is an essential ecosystem service that enables plant reproduction. More than 75% of leading food crops depends on animal pollinators. Among these honeybees are substantially important in world's agricultural economy, in that 35% of the world's food production relies on pollinators, of which the honeybee accounts for 70-80% which is the largest portion (Klein *et al.,* 2007). This is attributed to the body structures, social and instinctive behavioral characteristics of the honeybee. Insects, particularly, honeybees are the most important animal pollinator and are thought to facilitate avocado pollination and thus increase production, and there is evidence of opportunities to improve yield through improved pollination service (Klein *et al.,* 2007). Furthermore, like many insect-pollinated crops, avocado yields may be adversely affected by widespread pollinator declines (Biesmeijer *et al.*, 2006; Potts *et al*., 2016). Optimizing avocado yields is increasingly important as demand for this product is rising with 32.6 million tons produced from 1999 to 2008 and 50.4 million tons from 2009 to 2018 globally (FAO, 2020). Today, avocados are not only a nutritious staple but also an important export crop for many countries (USD 6.84 billion globally for 2018) (FAO, 2020).

In avocado orchards, it is common practice to introduce colonies of bees to promote pollination (Pérez-Balam *et al.,* 2012). Goodwin (2012) recommended the introduction of hives when the crop presented between 5 and 10 % of flowering, guaranteeing its persistence in the flowers. Pollination of avocado is pre-requisites for fruit set. Avocados apparently are not wind-pollinated and require active transfer of pollen by insects, particularly honeybees (Free, 1993). Generally 2-3 beehives/ha are recommended for pollination (McGregor, 1976). However, literature on the density of bees per tree, number of trees per hive, honeybee flight patterns in orchards, the bee plant value of avocados, or the minimum standards of hives used for pollination, is scarce or non-existent in our country.

### 1.2. Statement of the problem.

Avocado is a tree that mainly relies on insect pollinators for formation of fruits and viable seeds (Ish-Am, 2004). Many countries around the world have been experiencing dwindling trends in avocado fruit production. This has been partly attributed to inadequate insect pollination (Evans *et al.*, 2010).

Moreover, the mobility of the honeybee (*Apis melifera* ) during foraging has a great influence on the effectiveness of the bees as cross-pollinators (Herbert *et al.*, 1996). Report indicated that pollinator mobility is essential mainly to plants that require, or are benefited by cross-pollination (Ish-Am & Eisikowitch, 1998). Honeybee hives are commercially introduced during bloom to most avocado orchards for pollination purpose. However, the distance between the hives from the pollen donor trees and the distance between pollen donor and pollen receiver treees influence the mobility of bees and chance of pollinating flowers. Believing this fact, studies on hive distance and effect of honeybee density and fruit set of avocado was helpful to improve production and productivity of avocado in Ethiopia especially in Sidama region, Darra Otilcho District. So that, the fruit yields from individual trees could be influenced by production systems and tree management practices.

### 1.3 Objectives

#### 1.3.1 General Objective

- ✓ To assess the effect of honeybee density and hive distance on pollination and fruit yield of the hass avocado at Darra Otilcho district, Sidama Region, Ethiopia.

#### 1.3.2 Specific Objective

- ✓ To assess the role of honeybees in the pollination of avocado trees in the study area
- ✓ To identify optimum hive distances from avocado pollen donor on fruit yield in the study area.
- ✓ To determine the impact of honeybee density on fruit yield and its weight in the study area.

## 1.4 Research Questions

- ✓ What is the importance of Honeybees (*Apis mellifera*) as an Avocado Pollinators at the study area?
- ✓ How many crops are there which need honeybee pollination at the study area?
- ✓ How close do Avocado trees need to be to pollinate at the study area?

## 1.5. Limitation of the study

The pollination experiment was done in one season to assess the contribution of bee pollination on avocado fruit yield. Long-term experimental studies may be required to assess the stability of pollination service for all crops as the pollinating insects are known to show high temporal variation. However, the experiments are helpful and act as an indicator to the importance of bee pollination not only in the research area but also in the country as a whole.

# 2. LITERATURE REVIEW

## 2.1. Theoretical Framework

### 2.1.1 Avocados' concepts and definitions

Avocado (*Persea americana*) is an evergreen subtropical fruit tree, native to Central America and Mexico. It is grown commercially in the warmer, northern parts of New Zealand. Flowering within a tree is synchronous (Ish-AM & Eisikowitch 1993). The synchronous nature of dianthesis in the avocado flowers is sensitive to environmental conditions (Davenport 1986). Pollination usually requires an insect vector (Ish-AM & Eisikowitch 1993). Bees visit avocado flowers to collect nectar and/or pollen. Only nectar foraging bees visit both pistillate and staminate flowers and contribute to pollination (Ish-AM & Eisikowitch 1993).

Avocado flowers can be cross-pollinated (from flower to flower on different trees) or close-pollinated (from flower to flower on the same tree). Close-pollination occurs during the trees' daily bisexual phase, when pistillate flowers are closing and staminate flowers are opening (Ish-AM & Eisikowitch 1992, 1993). Avocado trees typically produce more than one million flowers, of which less than 0.3% set fruit (Blumenfeld & Gazit 1974; Blanke & Lovatt 1993; Dixon & Sher 2002). A slight variation in percentage fruit set can lead the trees to produce either too many fruit in an 'on' year or very few fruit in an 'off' year (alternate bearing). The avocado fruits were consumed by the local human populations for thousands of years, and numerous cultivars were developed during its long domestication process.

## 2.2 Floral biology

Avocado flowers are hermaphroditic, coupled in sub terminal racemes which contain from 200 to 545 flowers (Cossio *et al.,* 2007; Romero, 2012). During the flowering period, a tree can produce more than a million flowers, which mostly fall without producing fruit. It has been estimated that only between 0.001 and 0.23% of the flowers reach fruit set (Gazit & Degani 2002). The flowers have a small size of one cm wide by seven mm long. They have a light yellow-green color, made up of nine perianths, nine stamens and one pistil.On the inside of the stamens filaments there are two nectars, the anther have four pollen sacs (Scora *et al*., 2002).

The avocado has two types of inflorescences: determined and indeterminate, in the former forms a flower in the meristem of the primary axis, in the latter on the axis primary a bud forms at the apex that continues to grow as a shoot (Salazar, 2000). In California, it was found that the majority of avocado cv. Hass were indeterminate and only 5 to 20% were determined (Schroeder, 1954).

Salazar & Lovatt (1998) determined that the numbers of flowers produced by buds indeterminate floras are (120.4) and that of determined are (105.2) of cv. Hass. However, it has reported that buds may be present in certain inflorescences vegetative plants in dormant form, which may sprout after fruit set or remain dormant or die, so it could be concluded that the two types of inflorescence are indeterminate, but with differences in time (Bernal *et al.*, 2014). The avocado has a particular flowering; it is self-compatible but presents the synchronized protogyneal dicogamy phenomenon. Therefore, it is in the female phase that stigma is not receptive to pollen; however anthers do produce it, a mechanism that prevents self-pollination. In the male phase, the opposite occurs, the stigma is not receptive but the anthers do produce pollen. Each of the flowers has two opening periods; a feminine and a masculine one, in the interchange of the phases presents an intermediate closure and subsequently closes completely (Romero, 2012).

Avocado has two types of flowering, A and B, depending on their frequency of daily flowering (Ish-Am, 2004). In type A, the flowers open as female in the morning and the masculine ones in the afternoon. In type B, the flowers open as feminine in the afternoon and in the morning as male (Alcaraz *et al*., 2011). For it to be done effective pollen transfer, the male and female phase of the flower should be visited by insects (Cabezas *et al.*, 2003). It is common to plant type A and B cultivars in the same orchard, this promotes the pollination and an increase in production (Gardiazabal & Rosenberg, 1991).

### 2.3 Benefit of honeybee pollination on Fruits in Ethiopia

The huge forest area and mountains of Ethiopia host a great number of honeybee *(Apis mellifera*) colonies (Admasu *et al.,* 2014). Hence, honeybee has a great potential in raising the productivity of cross-pollinated as well as other crops those need insects for their pollination. Many farmers in Ethiopia invest in fertilizers, pest control, crop rotation and other management activities (Bizuayehu, 2014). However, the role of crop pollinators in crop pollination is totally neglected by crop growers of Ethiopian (Misganaw *et al.,* 2017). Unfortunately, both managed honeybees and wild pollinators have been contributing on raising the productivity of crops without the knowledge of growers (Admasu *et al.*, 2014).

Several horticultural crops are benefiting from honeybees worldwide in general and particularly, in Ethiopia. Some of them are listed below: From horticultural crops *Malus Sylvester's* (apple), Alliumcepa (red onion), *Citrus aurantium* (orange), *Citrus aurantifolia* (lemmon), *Carioca papaya* (papaya), *Mangifera indicia* (mango), *Persea americana* (avocado), *Coffee Arabica* (coffee), *Catullus lanatus* (watermelon), *Lycopersicon esculent* (Tomato). The effect of pollination on yield and quality of Niger seed, onion, apple and faba bean seeds have been reported, showing that honeybee pollination plays a great role in the Ethiopian crop production. Therefore, managing honeybees for crop pollination have a significant role for the improvement of agricultural crop yield in terms of quality and quantity (Tura *et al*., 2018).

### 2.4. Avocado Pollination

Pollination is the transfer of pollen from the male to female parts of the flower and this is key to the reproduction of plants that present flowers, a necessary requirement for fruit set, fertilization occurs after pollination (Alcaraz *et al*., 2011). There are three ways of transferring pollen from the male part to female flower. The first is carried out by animals the second by wind and the third by water (Westwood, 1982).

The production of attractive floras and the morphology of the flower attract insects' pollinators (Cabezas & Cuevas, 2007). When the flower is visited by insects the pollen produced by the anthers sticks to their bodies, later the pollen is deposited about stigmata. If pollination is effective, pollen grains break the stigma through the formation of the pollen tube, later they manage to reach the ovules in the ovary. Then the female gametes that contain the ovules are fertilized. These will turn into seed and the ovary into fruit (Garibaldi *et al*., 2012). Inefficient pollination has been considered one of the main reasons for the low avocado yields in producing countries (Alcaraz *et al*., 2011). This presents an open pollination mechanism where it can be limited that can limit fruit production due to the absence of pollination (Vithanage, 1990). The flowering behavior of avocado is a sophisticated mechanism, which prevents the auto gamy, enables closed pollination and encourages cross pollination (Alcaraz *et al*., 2011).

## 2.5. Mechanism of Avocado Pollination

### 2.5.1. Self-pollination

Refers to the pollination that is carried out by pollen that pollinates the same flower (Richards, 1997). Whereas, in the flowers of the avocado there is the phenomenon of synchronized protogynous dichogamy, self-pollination only possible for a short period of time in the male phase, only if the stigma remains receptive and pollen tube germination is possible (Jar don *et al*., 2013). However, in orchards the subtropical areas the pollen tube stops its growth upon reaching the style, therefore it does not reach to fertilize the ovule, and therefore this type of pollination is considered inefficient for fruit formation (Gazit & Degani, 2002). Contrary to crops located in some tropical regions this pollination mechanism is efficient. For this reason, depending on the region where regardless of where the crop is located, auto gamy may or may not be effective (Gazit & Degani, 2002).

### 2.5.2. Closed pollination

Closed pollination is a type of pollination, where pollen is produced by anthers of another flower of the same tree or of other nearby trees that belong to the same cultivar. It happens when the overlap between the male and female phase occurs (Alcaraz *et al*., 2011). In the subtropics, geitonogamy occurs at the moment when floral phases overlap taking into account pollen viability (Davenport, 1991). Gazit & Degani, (2002), determine that in crops located in Mexico between 1400 to 2500 m a s l, there is an effective overlap of the floral phases, this is favored for temperatures of 10 to 27 °c.

### 2.5.3. Cross pollination

Cross pollination is defined as the transfer of pollen from the flower belonging to a cultivar, to another flower of a genetically different cultivar (Root, 1976). For this mechanism to be efficient, plants must produce attractive flowers (nectar and pollen), have striking colors and smells, so that insects visit (Rallo, 1986). Additionally, the adhesion of pollen to the insect must be ensured pollinator; in these cases the most effective is that the pollen grain is sticky (Gazit & Degani, 2002). The attractiveness of the flowers of a plant on pollinating insects is given by the color, aroma, and quantity of the nectar, types of sugar and their concentration (Neira *et al.*, 1997). In addition, the amount of flowers present in the flowering phases (Valdes, 2002).This flowering mechanism is relevant when there is no overlap of floral phases and self- pollination (Gazit & Degani, 2002). Experiments that examined the benefits of cross-pollination by different avocado cultivars on the yields in cv. Hass have shown that certain cultivars are better at increasing yield than others (Robbertse *et al.*, 1996). In particular, the cv. Ettinger has been used as a pollen donor in both South Africa and Israel to increase yield (Ish-Am & Eisikowitch, 1998).

Pollinating insects are the main pollen vectors, relevant in the plant reproduction (Gazit & Degani, 2002). It has been determined that the Avocado pollen is heavy and sticky and that only by pollinating insects' pollen transport from anthers to flower stigmas is possible (Visscher and Sherman, 1998). Environmental factors play a fundamental role in avocado pollination (Davenport *et al.*, 1994 and Valdes, 2002). In the USA determined that self-pollination in the male phase is effective, ruling out insects pollinators, this is possible due to environmental conditions present in the region study, because stigma under these conditions prolongs their receptivity (Cabeza & Cuevas, 2007). In other regions where avocado is grown such as South Africa, Spain, Israel and Australia the self-pollination process is not efficient or is null, giving the pollinating insects the main role which perform the cross pollination and geitonogamy, giving the honey bee a role fundamental (Ish-Am &Eisikowitch, 1998b).

## 2.6 Factors That Affect Flower Formation.

### 2.6.1 Juvenility

Most grafted avocado cultivars will not begin to flower until the third year after planting. Some cultivars are more precocious; ‘Gwen’ and progeny siblings with the ‘Gwen’ line of genetics, such as Lamb Hass, will often flower in the second year after planting. Most un-grafted seedlings have a long juvenile phase and may not flower for 10 – 15 years after planting.

### 2.6.2 Phenology

Flower primordial are found in terminal or sub terminal buds on shoots that grew in the spring and summer flushes of growth. Recent research has shown that differentiation from vegetative buds to reproductive buds takes place at the end of shoot expansion of the summer growth, usually in August in California (Salazar-Garcia *et al*., 1999). Later, these reproductive buds grow to form multi-branched panicles upon which the flowers form. A tree can have hundreds of panicles and the tree as a whole can have up to a million flowers (Bergh 1986). The panicles are usually determinate (no leafy buds emerging from the panicle), but some are indeterminate (with leafy buds eventually growing from the panicle). Usually these panicles are found on the outer surface of the tree, with maximum exposure to light. This presents a problem in a pruning program; when doing hedgerow pruning or shaping later in the season, many of those shoots that are ready to form panicles and flowers are removed. Research is underway which should address the question whether late season pruning is more detrimental than early season pruning.

The length of the flowering season is variable according to race, cultivar and temperature. In general, Mexican cultivars flower earliest, West Indian cultivars next, and pure Guatemalans last. West Indian cultivars flower well in tropical climates, but often flower poorly in the subtropical climate. The length of flowering season for ‘Hass’ is reduced at higher temperatures. One report has the length of flowering season at 85, 42 and 15 days at 17/12, 25/20 and 33/28 C (day/night respectively) (Sedgley and Annelis, 1981). Flowering is usually seen to start earlier in the warmer areas of the grove, along the grove roads where there is abundant light and perhaps warmth from the asphalt roads, and on the southwest side of the trees where there is long exposure to sun in the afternoon.

### 2.6.3 Temperature

Flowering in ‘Hass’ and the other subtropical avocado cultivars are induced by a period of low temperature. ‘Hass’ did not flower when kept at temperatures of 30/25, 25/20 or 20/5 C (day/night), but did flower when exposed to 3-4 months of 15/10, 18/15, 20/15 and 23/18 C (day night). Under the two last temperature regimes the flowering was delayed and sparse (Buttrose and Alexander, 1978).

### 2.6.4 Day Length

Day length does not seem to be a factor in flower induction in avocados. In Mexico, off-bloom in Hass (known as ‘crazy bloom’) is induced in September after long (greater than 12 hr) day length. Certain cultivars in California, most notably ‘Pinkerton’, have a significant off-bloom in the summer. Buttrose and Alexander (1978) reported that ‘Fuerte’ flowered under both 15 hr. day lengths and 9 hr. day lengths.

### 2.6.5 Water Stress

Water stress did not appear to increase flowering in trees subjected to either high temperatures or low temperatures. Flowering was delayed after the water stress (compared to the non-stressed control trees) and occurred about a month after cessation of the stress (Chaikiattiyos *et al*., 1994). It has been observed by the author that water stress in California usually results in less flowering the following spring because water stress almost always leads to chloride tip burn, and eventual leaf drop. With severe tip-burn, leaf drop is excessive and an abnormal leaf flush in the spring is necessary to replace leaves that have dropped. It is believed that the resources in the tree are diverted to leaf growth rather than flower development. Controlled water stress as it affects flowering in avocado has not been studied in California.

### 2.6.6 “On Year” vs. “Off Year”

More information needs to be learned about why avocados have “on” and “off” years, but it is suspected that starch levels and perhaps certain growth regulators need to reach certain levels and in balance with each other for the tree to flower heavily. It has been noted that not all shoots develop flowers; in an “on” year 46% of shoots developed flowers but only 13% of shoots developed flowers in the “off” year (Salazar-Garcia *et al.,* 1998, Salazar-Garcia and Lovatt 2000). In the year after an extremely heavy crop, some trees do not develop flowers at all.

### 2.7. The Role of Bees in Pollination.

Bees appear to be very important for moving pollen from the male stage flowers to the female stage flowers, completing the pollination process in cross pollination and close pollination. O.I. Clark observed in the 1920's that heavy crops in avocado were associated with greater work by bees on the blossoms (Clark, 1922-23). He also observed some things that we see today: "Bees prefer other bee pasture to the avocado orchards." We often see bees flying over or around avocados to get to citrus in bloom or other sources of nectar. "When bees are abundant or other pastures scarce, they do work freely on avocados." "Bees have a strong preference to sticking to one avocado tree at a time." This inhibits cross pollination between cultivars, unless the trees are very close, or intermingling with each other. Ish Am (2000) added "Most honey bees collect nectar and pollen within a limited area of 1 to 3 trees. They often perform cross pollination only between neighboring trees that carry opposite-stage flowers and are at a distance of not more than two rows. A small percentage of the foraging honey bees (2 – 4%) move farther between rows and fields, and may carry avocado pollen for hundreds of yards away from its source."

### 2.8. Honey Bees (*A. mellifera*) as a Pollinator of Avocado

Its importance in the pollination of avocado is evident from the strong positive correlation between honeybee activity and crop yield (Gazit & Degani, 2002). However, improper pollination is still common in avocado, even when honeybee colonies are introduced into an orchard. This phenomenon has been attributed to the predilection of *A.mellifera* for other species of flowers such as weeds and citrus fruits, and the high levels of potassium and phosphorus in the nectar of the flower (Ish-Am, 1994; Gazit & Degani, 2002). In avocado orchards, it is a common practice to introduce colonies of bees (*A. mellifera*) to promote pollination (Perez-Balam *et al*., 2012). Vithanage (1990) studied the introduction of beehives in avocado; found a significant increase in production, on average, 227.2 fruits per tree in orchards without hives, and 788.2 in orchards with beehives, showing a 247% increase in production. Popenoe (1963) found that bees are necessary for good pollination. Gardiazabal (1998) indicates that when introducing beehives in an orchard, the production is higher than without them depending on the number of hives and the distribution in the vegetable garden depends on the success of pollination (Lecomte, 1961) proposes two hives / ha. In New Zealand, four to ten hives are recommended of bees per hectare (Evans *et al*., 2010). Dixon (2006) recommends eight hives / ha when the trees have a height between 6 and 10 m and ten hives / ha when the trees are over 10 m tall. In South Africa, research has shown that to achieve maximum pollination potential there should be six to ten hives / ha located 400 m apart (Robbertse *et al*., 1998). Arpaia & Hofshi (2004) recommend two to four hives / ha in dry years and ten or more hives if the number of competing flowers is high. Vasquez *et al*., (2011) found that with 3.2 hives / ha an increase in the number of avocados can be obtained per tree between 21 to 96% in Colombia.

Bees visit avocado flowers due to the wide offer of food resources that this plant offers them, consuming nectar from the female phase and nectar and pollen from the male phase (Ish-Am, 2004). Bees that collect pollen have a visiting frequency of seven to 15 flowers per minute, this frequency varies with respect to the need for feeding that requires the hive, the food resources that the flowers have and the environmental factors (Gazit & Degani, 2002), bees that collect nectar from both phases of the flower its frequency of visit is from two to 10 seconds (Castillo, 2002).

It has been reported that their mobility in the orchards is limited and that they work in a small radius, 150 to 250 m with the hive as a reference. On the other hand, they usually stay visiting the flowers of the same tree, which leads to cross pollination is affected. For this reason, it is recommended to distribute the hives in the orchard, thus achieving a greater dispersal of bees (Castillo, 2002). Ish-Am (2004) in research carried out in Israel reports that worker bees they work in a limited area. However, a limited group of bees known as Explorers can carry pollen over wider distances. Relating to the pollination efficiency if it is cross or geitonogamy the difference is little, all depends on where the pollen source of the pollen donor cultivar is located because this is reduced as the distance relative to it increases (Ish-Am & Lahav, 2011). Research carried out in Australia where the radius of action of the bees regarding the location of the hives found that it could move up to 300 m in the direction of the rows in the orchard and between rows only 200 m. The bees they prefer to forage between contiguous trees downwind (Ish-Am & Eisikowitch, 1998). As a recommendation, the researcher (Ish-Am *et al.,* 1999) proposed that before implement honey bees in avocado orchards, it is advisable to know the native pollinating insects present in the avocado's areas of origin, cites as example to Melipon bees, since they have coevolved with avocado since its origin, additionally, the size of your body is more efficient when visiting flowers and usually visit the flowers alternately in both phases, in addition, these species of bees have been reported as efficient pollinators in Mexico indifferent cultivars evaluated. And although *A. mellifera* is widely used in directed pollination in this fruit tree, it is not a natural pollinator of avocado; this entails to reduce its effectiveness (Afik *et al*., 2014).

In countries where the avocado is native, there is a lack of knowledge about insects pollinators and their influence on fruit production, if it is considered that this plant has coevolved with insects since their origins, it is likely that these species exert a significant effect on pollination (Castaneda *et al.*, 1999).

### 2.9 Avocado Mass Flowering Effects

An adult avocado tree, in a good season, may bear about one million flowers, but only several hundred fruits. Only 0.05% of the flowers (one of 2,000) give fruits. This effect, which is very common for Sub-Tropical trees, was termed: “mass flowering”.

#### 2.9.1 Cooperation among Flowers

A single small flower produces very low attractively for its potential pollinators. Its advertising power for a distant pollinator is low, and the approaching visitor may receive a very limited amount of reward. However, an inflorescence, composed of many dense small flowers, may advertise itself like a big flower, and can offer the visitor more reward. Most importantly, it also forces the pollinator to visit many flowers at a time. The blooming avocado tree acts like a giant inflorescence, where thousands of flowers cooperate in attracting the potential pollinators (Laheva & Zamet, 1999).

#### 2.9.2 Competition and Cooperation among Pollen Grains

Although the avocado-flower ovary holds only one ovule, it was demonstrated in Israel, in the cultivars ‘Hass’, ‘Ettinger’ and ‘Reed’, that a single pollen grain on the stigma has a very low probability of fertilization. Twenty pollen grains or more should reach the stigma to achieve a high fertilization probability. Namely, a cooperative effort of many pollen grains is needed to break through the style and into the ovary. An average of only 1-3 pollen grains are deposited on an avocado stigma by a single visit of a pollen-carrying honeybee. Therefore, more than one visit per flower is necessary to achieve the needed pollen amount. In addition, in many cultivars a higher likelihood of fertilization by out-crosses pollen, compared to that by self-pollen was found. Moreover, it appears that pollen of certain cultivars is more potent as a cross-fertilizing agent than pollen of others, namely, the formers result in higher fertilization rates. Therefore, simultaneously with the cooperation, a competition develops among the pollen grains for fertilizing the single ovule that is waiting inside the ovary. The competition selects for the best pollen grain out of the selves, and furthermore for the most potent out-crosses pollen, if available (Laheva & Zamet, 1999).

**2.10. Effects of Hive Distance to Number of Honeybees Visiting Avocado Trees.**

According to (Carabali & Pena, 2018), the number of bee per tree was higher in the distance range of 0 to 150 m which indicates that the distance that exists from the hives to the trees influences the number of bees visiting the flowers of the trees. At distances between 200 and 250 m, the number of bee per tree was smaller, and these bees may have been scouts that had a broader flight range whose objective was to collect information from the available food sources and were able to transport the avocado pollen up to several hundred meters away from the origin (Ish-Am, 2004). Carabali & Pena (2018), reported that it is recommended to install the hives in the orchard, each spaced at 150 m from the tree. Honey bee activity was highest in the time period between 11.00 and 14.00, when the male and female states of the flowers more likely overlapped, the period that the bees move freely between pistillate and staminate flowers and collect pollen and nectar.

**2.11. Effects of Honeybee on Pollination Rate and Efficiency of Avocado Flower**

Five avocado cultivars over seven seasons, significant positive correlations were found between pollination rate and honeybee density when analyzing the data of all five cultivars together, as well as those of each cultivar separately (Ish-Am *et al*., 2011). Working on 'Hass' and 'Fuertes' the researcher formulated a "pollinator index" as a means of measuring the efficiency of avocado pollinators. The author found that honeybees were 16 to 200 times more efficient than other visiting insects, mostly fly species. Placing two beehives per hectare in the plantation increased both bee activity and avocado yield (3.5-fold). Adding one more hive per hectare further increased productivity by 20 to 38%. Heavy fruit set began immediately after the bees visited on the trees. When bumblebees (*Bombus terrestris*) were added, the yield increased further (Ish-Am *et al*., 2000). Ish-Am (2004), reported that five to ten numbers of honeybees per tree were necessary to achieve a reasonable pollination. However, the optimal density is at least ten to twenty numbers of honeybees per tree, and six to ten grains of pollen per stigma and 60 to 80% of pollinated stigmas are obtained.

Carabalí *et al*., (2017), found that numerous families of insect pollinators of the avocado, mostly belonging to the orders Dipterans, Hymenoptera, Coleopteran and Hemiptera. With this wide diversity of pollinators in Colombia, it is possible that the number of honeybees required is lower than in Israel, as these species contribute to pollination. This information is corroborated by the high pollination rates, greater than 50%, that occurred in all three treatments.

**2.12. Impact of Temperature on Flower Production and Insect Pollinators**

Individual flowers open first as functionally female, and then close and later reopen functionally male to reveal pollen. Cultivars can be classified into two complementary flowering types. "A" flower cultivars have flowers that open as female in the morning of the first day, and then reopen as male on the afternoon of the following day. "B" cultivars have flowers that open as female in the afternoon of the first day and reopen as male the morning of the following day. The opening and closing times of the flowers tend to be synchronized within a tree as well as among trees of like cultivar within an orchard. This means that type A or B pollen is released in the orchard at the same time that type B or A flowers of the complementary cultivar are in the female stage, respectively. For this reason, it is common for growers to facilitate cross pollination by introducing honeybees and pollinizers into orchards (Griesbach, 2005).

Flower size of avocado cultivars like Fuertes, Ettinger and Hass vary with changes in temperatures. Because low temperature negatively affects pollen germination and pollen tube growth rate (Milatovic *et al*., 2016). A majority of bees have an upper critical body temperatures of 45-50°C however, tropical and desert bees face both high temperature and solar radiation thus no major difference in the upper critical temperature in different biogeographically regions (Kjøhl *et al.*, 2011). Though, it has been postulated that the density and population of honeybees is likely to be high in warmer conditions (Florence Dem, 2011). Honeybee queens lay more eggs in warm weather (Conte & Navajas, 2008) and are more likely to be fertilized by drones at high temperatures (Needham, 2010). Low temperatures induce cluster formation within hives for heat generation. Although honeybees might break from such clusters and make short flights for excretion when it is sunny, low temperatures keep honeybees in hives and induce feeding on honey amassed during warmer periods there by limiting their foraging activity (Needham, 2010).

### 2.13. Effects of Rainfall on Avocado Flower and Insect Pollinators

Rain is the main form of precipitation in lower altitudes while higher altitudes receive precipitation in the form of rain, mist or dew (Florence Dem, 2011). Occasional rain showers during avocado bloom period are not harmful to flowers (Griesbach, 2005). However, heavy rainfall can result in cool weather that delays avocado flowering. Rainfall also influences activity, reproduction, growth and development of pollinators. Avocado pollinators like bumble bees are active in rainy weather (Jiju, 2011), Continuous rains may also shorten pollinator metamorphosis and facilitate their growth and development while low temperatures and frequent rains may be inhibitive (Florence Dem, 2011). Abundant rainfall can disrupt the lifecycle of bumbles bees by destroying their nests (Chagnon, 2008). Poorly drained soils harbor microbes that often attack food and immature of ground nesting bees (Park *et al.,* 2012).

### 2.14. Effects of Wind on Avocado Flower and Insect Pollinators

Higher elevations have high wind speeds than low elevations (Ferreira *et al.,* 2012). The contribution of wind as an avocado pollen vector is low (Ish-Am *et al.,* 2011). Strong winds might lead to flower desiccation and ultimately low fruit production (Howden *et al.,* 2005).The highest wind velocity measured in the open field for the 61 days was 9.7 m sec-1. No pollen dispersal was recorded from the male 'Hass' or 'Fuertes' flowers when subjected to wind velocities of up to 10 m sec-1 in the laboratory. With a stronger wind (13-14 m sec-1), slight pollen dispersal was observed. The pollen was not dispersed as separate grains, but in clusters. At a higher wind velocity of 15 to 16 m sec-1, all pollen clusters were disconnected from the valves of the anthers. Honeybee density had a significant positive effect on the percentage of pollinated stigmas while neither maximum nor average wind velocities had any effect on this variable. The "average temperature" (positive effect) and the "Cultivar" had also a significant effect on percent pollination (Ish-Am *et al*., 2011).

### 2.15. Influence of Honeybee Density on Avocado Fruit Number and Weights

Direct pollination with *A.mellifera* in four varieties of avocado (Vasquez *et al*., 2011). They incorporated an average of 3.6 hives/ha and found that production increased between 21% and 96 % (Pena & Carabali, 2018). The average number of fruits/tree was 212 and 231 and the increase in production of 54 and 68% with the introduction of four and six hives/ha. However, the activities of honeybees increase the number of fruits. Avocado is characterized as having a low fruit set, and the values worldwide vary from 0.2 to 0.001% (Goodwin & Mcbrydie, 2010). The Hass avocado has been described to have a fruit set of 0.14% in years of high production and 0.07% in years of low production (Garner & Lovett, 2008) & (Cossio-Vargas *et al*., 2007). Finding in Chile indicated that in the Hass avocado an initial and final fruit set of 0.04% and 0.01%.

# 3. MATERIALS AND METHODS

## 3.1. Description of the Study Area

The study was conducted in Sidama Region, Darra Otilcho District and located in southern Ethiopia, about 63 km from Hawassa, the capital city of Sidama Region and 284 km from the capital Addis Ababa. The agro-ecology of the district is characterized as Woina-Dega (Mid-altitude) Zone and some areas are highlands. The area receives bimodal rainfall where the high rain is between March to April and the small rain is from September to October. The mean annual rainfall of the area is 1600- 1800 mm; with a minimum and maximum temperature of 18.5℃- 32$^{o}$C.The major cultivated flowering fruit crop in the district includes perennial crops including Coffee, Avocado and Mango (Agricultural and Natural Resource Management Office, 2020). It is found at the latitude of $6^{0}$.5’ and longitude $38^{0}$.4’. It has an *Altitude*, 2709 masl. Lat (DMS), 6° 30' 0N, Long (DMS), 38° 23' 60E.Its geographical coordinates are 6° 30' 0" North, 38° 24' 0" East and its original name (with diacritics) is Teferi Kella. The soil of the experimental site is mainly clay loam. When the district was named Darra district and based on the 2007 Census conducted by the CSA, this district has a total population of 155,265, of whom 76,475 are men and 78,790 women; 10,660 or 6.87% of its population are urban dwellers. The majority of the inhabitants were Protestants, with 85.54% of the population reporting that belief, 7.04% practiced Ethiopian Orthodox Christianity, 2.55% were Muslim, 2.36% follow traditional religions, and 1.43% were Catholic.

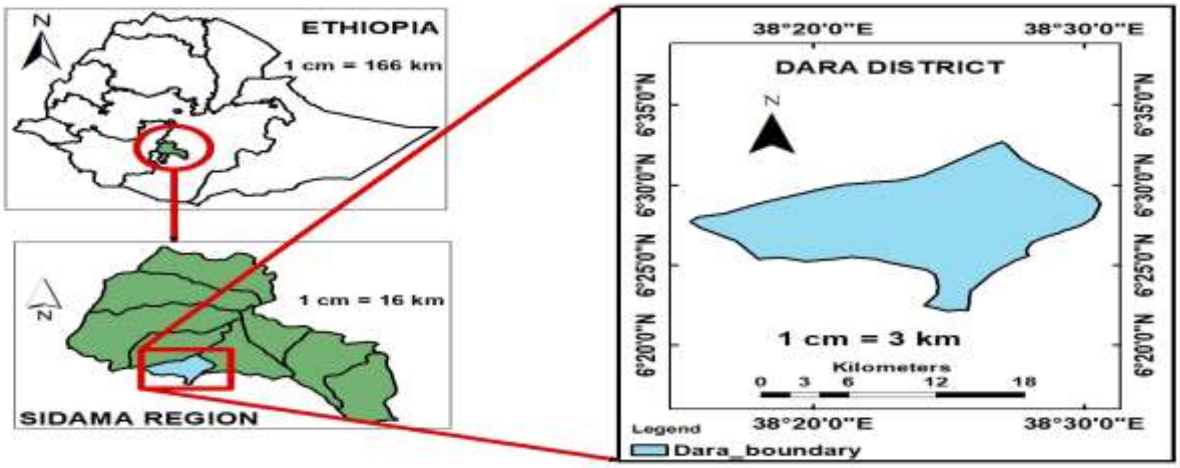



Figure 1: Map of Sidama Region and Study District.

**3.2 Household Survey**

The check-list questionnaire was designed to obtain data on household characteristics, the cropping, and land management practices and their proximity to each other, honey yield, the perception of farmers on pollination, the role of honey bees on avocado fruit production and the type of hive they have were recorded. The target population of the study was avocado fruit farmers and beekeepers around Darra Otilcho District. Totally, four Kebeles (4) were purposively selected based on their potential of avocado production and bee keeping practice. A total of 60 farmers, fifteen (15) farmers from each PAs were selected purposively. A checklist was pre-tested before the actual data collection, and appropriate modifications and corrections were made. The checklist was filled by the trained enumerators under the close supervision of the researcher.

Table 1: Number of Sampled Household from Each Kebele (N=60)

| Name of Kebeles | Male | Female | Total respondents |
|---|---|---|---|
| Shilcho | 12 | 3 | 15 |
| Lella honcho | 11 | 4 | 15 |
| Womerero | 13 | 2 | 15 |
| Babe komolcha | 10 | 5 | 15 |
| Total | 46 | 14 | 60 |

### 3.3 Data Sources and Collection

A single- visit multipurpose survey was conducted to catch the general information on avocado cultivation and the farmer perception on pollination as well as beekeeping practices in the study areas.

Both primary and secondary data were gathered for this study. The primary data consists of open and close-ended Checklist questionnaires and field observation were used. Furthermore, for secondary source of data, various District bureaus like pastoral development offices, and other related study documentations were used. Various documents (published and unpublished) were reviewed to collect secondary data. In addition, different websites were browsed to obtain secondary data and ideas related to the issues under study.

Field observation was used to understand the potential of avocado producer site, farmer, and bee keeping practice data through physical observation was gathered.

### 3.4. Experimental Design and Treatment

#### 3.4.1. Treatments

Twelve avocado orchards with a minimum area of 1.5ha for each site and the differences between each site, 1km were selected and a nested design was applied.

The treatments were: 1) one hive per 1.5ha, 2) two hives per 1.5 ha, 3) three hives per 1.5ha and control without hives was evaluated on orchard.

The honey bees (*A.m.scutellata*) were used with Transitional (Kenya top bar) hives. Distances from the apiary to the trees were selected as the sampling unit (50,100 and 150m) constituted the sub-plots, for each sowing distance, one tree randomly selected with a total three (3) per orchard was evaluated for the variables density of bees per tree, rate of pollination, pollination efficiency, fruit number per plant, the average weight of fruits and total fruit weight per tree.

### 3.4.2. Experimental Design

Figure 2: Nested Design

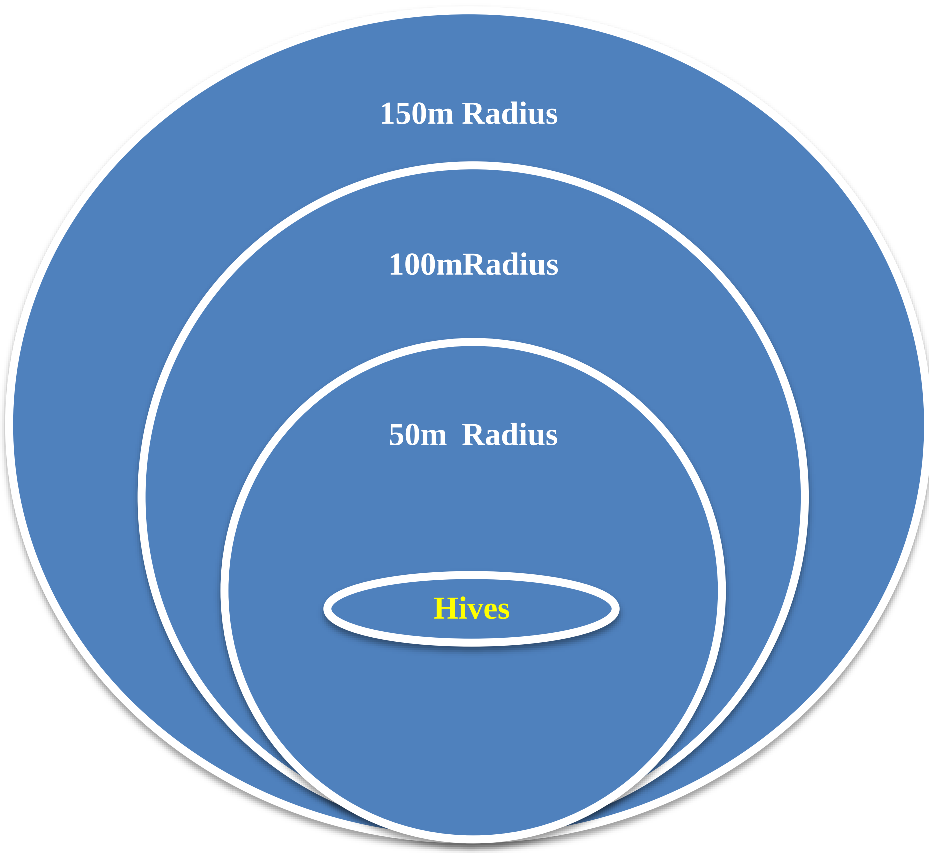



Figure 2: Nested Design

### 3.5. Plant Material

Twelve orchards of avocado (*P. Americana*) were located at considerable distances (minimum 1 km) between treatments and to which homogeneous agronomic management was carried out. The sampled trees were selected from 12 farms owned by households that were part of the survey. The main criteria for the selection of these12 farms were the similarities in the inherent soil and topographic characteristics of the fields, the similarities of their historical cropping and land management practices and their proximity to each other.

### 3.6. Hive Characteristics and Species of Bee Used

Transitional (Kenya top bar) hives type was used and *Apis mellifera scutellata* honeybees were used for this study as they are the geographical races of honeybees existing in the area.

Figure 3: Transitional (Kenya Top Bar) Hives and *Apis mellifera scutellata* Honeybees.

### 3.7. Data Collection.

#### 3.7.1. Observation of Honeybees per Avocado Tree.

Observation of honeybees per avocado tree was recorded during the flowering period; between September 20 to October 20/2021.The number of honeybees foraging per avocado tree was quantified by a person walking around a tree and counting with a manual counter per 2(two) minutes following the methodology of (Ish-Am & Lahav, 2011). The number of honeybee per tree was documented on every observation day in each treatment; and recorded every hour from 7.00am to 17.00pm. Four (4) recordings (two times per week) were performed per treatment during the flowering phase in one tree for each distance.

### 3.8. Pollination Rate and Efficiency

A sample of stigmas per tree was collected in the female flowering stage, three hours after the opening of the flower in the female phase. The stigmas were collected with a clamp and placed on a microscope slide covered with 2% (w/v) gel of carboxymethyl cellulose [in a ratio of 1:2:7 (v/v/v) ethanol: glycerol mixture: water, with the addition of aniline blue, to create a light blue solution] and the number of pollen grains per stigma were recorded under a microscope optical (Ish-Am & Amp; Eisikowitch, 1991a; Ish-Am & Amp; Eisikowitch, 1991b; Ish-Am &Amp; Lahav, 2011). A total of 180 stigmas samples were collected, 15 per treatment, 5 stigmas per tree, three (3) recordings per treatment (three times per week) during the female flowering phase. The rate of pollination (percentage of stigmas pollinated) and efficiency of pollination (average number of pollen grains in the stigma) was quantified for each treatment. Laboratory analyses were done at Holeta Bee Research Center.

### 3.9. The Number and Weights of Fruit per Plant.

All fruits from selected tree from each distance were counted from each site. Fruit counting was under taken by climbing person in each selected tree. The avocado fruit were harvested in December, 2022. Twelve avocado fruits randomly selected from all parts of the tree, from each distance and average weights of individual avocado fruit measurements were undertaken. Twelve representative sample avocado fruits from all parts of the tree, from each distance and 36 fruit per treatment, from three trees per treatment was harvested and weighed by digital caliper scale.

The total weights of fruit per tree was calculated by using the following formula

$$\text{Yield (Kg)} = \frac{\text{Total number of fruit / tree} \times \text{Average fruit weight (gm.)}}{1000}$$

As described by (Abdel-Karim *et al*., 2015).

### 3.10. Partial Budget Analysis

Partial budget analysis was also applied in order to evaluate the profitability of avocado fruit yield by placing of different density of hives per orchard/ha at Darra Otilcho avocado farm for one year. Partial budget analysis was employed using proper procedure (Upton, 1979). Current prices of the hives cost were considered in the analysis. Transportation for fruits and Labor requirement for fruit harvesting was also considered. The cost of hives was recorded from household interview.

The number of hives multiplied by the average cost of hives. The analysis was done by considering the current prices of avocado fruits and honey (i.e. 6.22 birr per kg of avocado fruit and 182.83 birr honey per kg) for calculation of total return.

NR = TR-TVC………………………………………………………………………Equation 1

Where: NR = Net return, TR = Total return, TVC = Total variable cost

The change in net return was computed as:

ΔNR= ΔTR-ΔTVC……………………………………….……………………………….Equation 2

Where: ΔNR = Change in net return, ΔTR = Change in total return, ΔTVC = Change in total Variable cost.

The marginal rate of revenue quantifies the increase in net return associated with each additional Unit of expenditure. This is expressed by percentage as:

MRR (%) = ΔNR/ΔTVC X100……………………………………………………Equation 3

ΔTVC Where: MRR (%) = Marginal rate of revenue in percentage, ΔNR= Change in net return, ΔTVC = Change in total variable cost.

### 3.11. Statistical Analysis

A generalized linear model was applied.

$$Yijk = M + Di + Hj + D*Hij + Eijk$$

Where, Y= Response (Bee density, distances from hives and others), M= Total mean, Di = Hive distances (i=3, 50m, 100m, and 150m), Hj = Effects of hive density (j=4, 0, 1, 2, and 3hives), D*Hij = Indirect effect of Hive distance and Hive density, Eijk = Error term.

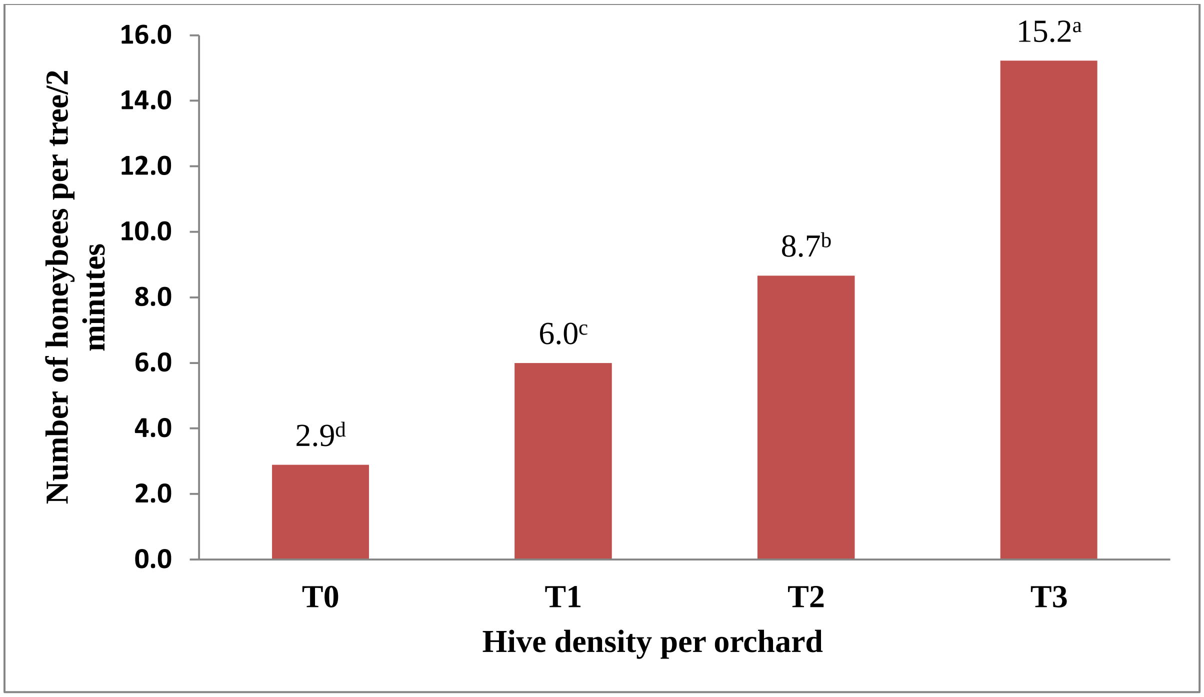
The Duncan test was used for the comparison of means for each factor. Subsequently, a factorial analysis was performed on the evaluated variables. All statistical analyzes were carried out using the SAS® statistical package (Statistical Analysis System Version 9.0). Descriptive statistics are provided (e.g., frequencies, means, and percent). Means were separated by standard deviation (SD) and significance tested at 95% level.

# 4. RESULTS AND DISCUSSION

## 4.1. Effects of Hive Density on the Number of Honeybees per Tree

The number of honeybees per tree (NHBPT) significantly increased between the treatments, in comparison to the control treatment at */P<0.05/.* By Placing one, two, and three hives/orchards with mean of *15.2*, 8.7 and 6.0 compared to control treatment 2.9 NHBPT. Density of bees per tree was significantly increased at the treatments of two and three hive/orchard. These were increased by 5.8 and 12.3%, respectively, compared to an orchard without hives (Fig 4). This was the fact that when the density of hives/orchards increased the density of bees per tree had also increased. In agreement with Pena & Carabalí, (2018) who reported that bees per tree had significantly increased as the number of honeybee hives increased/orchard. Avocado fruits are the product of pollination and fertilization, because no parthenogenesis effect has been reported, the requirement of pollinators is one of the main limiting factors in their production (Ish-Am, 2004). It is native to the neo-tropics, where it is found naturally and is pollinated by a wide variety of insects, mainly *A.mellifera,* melipon bees and wasps (Can-Alonso *et al*., 2005). Between five and ten honeybees per tree are necessary to achieve reasonable pollination. However, the optimal demand is at least 10 to 20 honeybees per tree (Ish-Am, 2004). In this study with the introduction of three and two beehives/orchard, 15.2 and 8.7 HBPT were recorded on average.

According to (Tura *et al*., 2018), various insects belonging to different orders were observed visiting the flowers of the apple during its flowering time, mostly belonging to the orders Lepidoptera, Dipterans, Hymenoptera, Hemiptera, Orthoptera and Coleopteran. With this wide diversity of pollinators in Ethiopia, it is possible that the number of bees required is lower than in Israel; since these species are contribute to pollination. This information is corroborated by the high pollination rates in five treatments, greater than 45%.




T = implies the number of hive.

Figure 4: Effects of Hive Density on the Number of Honeybees per Tree

### 4.2. Effects of Hive Distance on the Number of Honeybee per Tree

The number of honeybees per tree (NHBPT) is significantly increased at distances of 50m and 100m compared to distances of 150m at */P< 0.05/.* At distances of 50m, 100m and 150m, with mean of 9.8, 8.3 and 6.6 NHBPT was recorded respectively (Fig 5). The NHBPT was significantly higher at 50 and 100m compared to 150m distance. These were increased by 3.2 and 1.7%. Which might be due to the fact that avocado tree in the study site was very large in height and wider in canopy cover. This makes the bees get their food from the nearest avocado tree flower and also by nature honeybees prefer the nearest flower to the far distance tree. The number of HBPT was greater in the range of distance from 0 to 100m; this result indicates that the distance that exists from the hives to the trees effects to the number of bees that visit the flowers of the avocado trees. This in agreement with (Ish-Am, 2004), who determined that the mobility of bees during foraging is limited; most of the worker bees act within an area of one to three trees and can cross-pollinate only between trees of opposite flowering cultivars, at a distance of up to two rows of trees.

The movement of the honeybees was very active on the avocado flowers during the morning in the period between 10 and 13 h. These results agreed with (Castaneda *et al.*, 1999) who determined that the maximum activity of bees was among the 11 to15h. (Valdes, 2002) in Chile reported that the highest activity of bees is between 10am and1am.

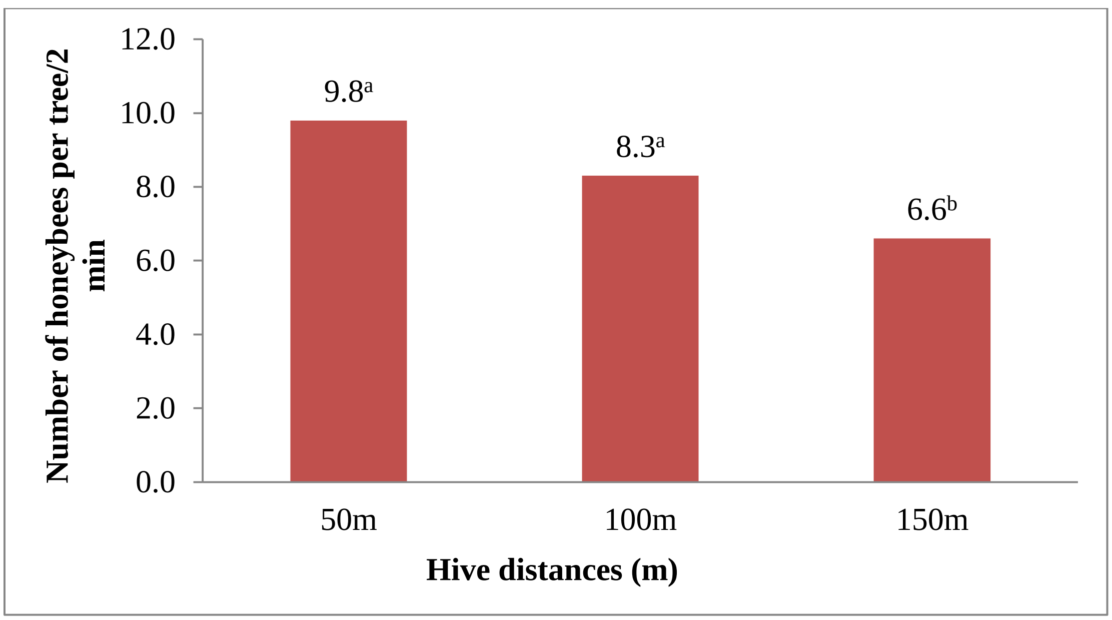



Figure 5: Effects of Hive Distance on the Density of Bees per Tree.

### 4.3. Effects of Hive Density on the Rate of Pollination

The rate of pollination (RP) was increased significantly at the treatments of three and two hives per 1.5ha orchard compared to the control at */P<0.05/*. By placing one, two, and three hives/orchards with the mean of pollination rate 47.8%, 47.8%, and 70% compared to an orchard without hives 41.1 % (Table 3). This was increased by 29 and 6.7% respectively. This might be due to the fact that in high density of hives the number of honeybees per tree is high therefore the rate of pollination was increased. In agreements with (Ish-Am *et al*., 2011) who reported that rate of pollination rates in each of the five cultivars were positively correlated with honeybee density, but none had a significant correlation with wind velocity. Pollination rates on days of low honeybee activity (*i.e.* number of bees per tree ≤ 2) were 6.3%, 14.6%, and 12.5% for the early-blooming cultivars Hass, Ettinger, and Fuertes, respectively. Honeybee activity on the late-blooming 'Reed' and 'Nabal' was always high (≥ 10 bees per tree), and pollination rates were always high as well (≥ 40, and ≥ 50 in 'Reed' and 'Nabal', respectively).

### 4.4. Effects of Hive Density on the Efficiency of Pollination

The efficiency of pollination (EP) was increased significantly at the treatments of three and two hives per 1.5 ha, compared to the control treatment */P<0.05/*. By placing one, two, and three hives/orchards with mean of 7.2, 8.8 and 16.6 NPGPS, respectively, compared to an orchard without hives (5.4). EP was highly significant at treatments of two hives and three hives/orchard compared to control treatment (Table 3). These was increased by 3.4 and 11.2 pollen grain per stigma (NPGPS) respectively compared to an orchard without hive. This might be due to the fact that when the number of hive per orchard increased, the efficiency of pollination per orchard also significantly increased. This result is in agreement with (Ish-Am, 2011), who reported that efficiency of pollination was increased with increasing number of hives per orchard. (Pena & Carabalí, 2018) report also indicated that by introducing four and six hives/orchard, NPGPS was significantly increased.

Table 2: Effects of Hive Density on the Rate and Efficiency of Pollination

| Hive Density | Rate of Pollination | Efficiency of Pollination |
|---|---|---|
| 3 | 70.0[a] | 16.6[a] |
| 2 | 47.8[b] | 8.8[b] |
| 1 | 47.8[b] | 7.2[bc] |
| 0 | 41.1[c] | 5.4[c] |
| P value | *< 0.05* | *< 0.05* |
| CV | 6.42 | 17.82 |

*Mean with the same letter in the column is not significantly different

**4.5. Effects of Hive Distance on the Efficiency of Pollination**

The efficiency of pollination (EP) was significantly different */$P<0.05$/* at evaluated distances of 50,100 and 150m, with mean of 11.9, 8.9 and 8.4 EP/average number of pollen grain per stigma (Table 4). The number of pollen grain per stigma (NPGPS) was highly significant at 50m distances compared to 100m and 150m distances .These were increased by 2.5 and 4.6% NPGPS in agreement with (Ish-Am, 2011), who reported the efficiency of pollination was increased with decreasing hive distance from avocado pollen donor. Although the avocado flower ovary has only one ovule, it was demonstrated in cv. Hass, that when a single pollen grain reaches the stigma the probability of fertilization is very low. In fact, 20 or more pollen grains are required for high probability of pollination. Therefore, the greater number of pollen grains, the greater the probability of fertilization, because there is a cooperative effect between the pollen grains to reach the ovary (Ish-Am, 2005; Arpaia & Hofshi, 2004).

**4.6. Effects of Hive Distance on the Rate of Pollination.**

The Percentage of pollination/Rate of pollination (RP) was not significantly different */$P>0.05$/* at evaluated distances of 50m, 100m and 150m,with mean of 53.3%, 51.7%, and 50.8% rates of pollination as shown in (Table 4).

Table 3: Effects of hive distance on rate and efficiency of pollination

| Hive Distance | Rate of pollination | efficiency of pollination |
|---|---|---|
| 50m | 53.3[a] | 11.9[a] |
| 100m | 51.7[a] | 8.9[b] |
| 150m | 50.8[a] | 8.4[b] |
| P Value | *>0.05* | *< 0.05* |
| CV | 6.42 | 17.82 |

*Mean with the same letter in the column is not significantly different

**4.7. Effects of Hive Density on the Total Number of Fruits per Tree**

The total number of fruit per tree (TNFPT) is significantly different at */P<0.05/* in four treatments of one, two, and three hives/orchards with mean of 245.2, 309.6, and 392.2 number of fruit per tree compared to the control treatment with mean of 193.2 (Table 5). Placing one, two, and three hives per orchard, TNFPT was increased by 52, 116.4, and 199 total numbers of fruit per tree (TNFPT), respectively; compared to an orchard without a hive. This might be due to the fact that more hive density per orchard had positive impacts on the (TNFPT). In agreements with (Vithanage, 1990), who introduced bee hives into avocado orchards and found a significant increase in production, on average 227.2 fruits/tree in orchards without hives and 788.2 in orchards with hives, an increase of 247%. (Vasquez *et al.,* 2011) reported that he used direct pollination with honey bees in four varieties of avocado. They incorporated an average of 3.6 hives/ha and found that production increased between 21% and 96 %.( Ish-Am & Eisikowitch, 1993). A study in Israel has shown that high correlation between honey bee activity and fruit set of avocado.

**4.8. Effects of Hive Density on the Average Weights of Fruits per Tree**

The average weight of individual fruit per tree (AWFPT) was significantly different at */P<0.05/* in all four treatments of one, two, and three hives/orchards with mean of 193.4gm, 204gm, and 215.3gm compared to the control 188.4gm (Table 5). This was an increment by 5gm, 15.6gm and 26.9 of AWFPT, respectively compared to an orchard without hives. This shows that there is percentage increment per treatment over the control.These results is in agreement with Buaban *et* *al*. (2018) who reported that density of honey bees per orchard had a major effect on the individual fruit weight. The quality of avocados measured as weight was significantly higher in the honeybee treatments than in the domestic pollinators, with average weights 138.74, 141.74 and 90.52 g / fruit in the Asiatic honeybee, European honeybee, and domestic pollinators. This study is in agreement with (Pena & Carabali.2018), who reported that the introduction of four and six hives per orchard had increased individual fruit weight by 50 and 100gm.

### 4.9. Effects of Hive Density on the Total Weight of Fruits per Tree.

The total weight of fruit per tree (TWFPT) was significantly different */$P<0.05$/* in four treatments of one, two, and three hives per 1.5 ha with mean of 47.4Kg, 63.1Kg, and 84.5Kg compared to the control treatment 36.4Kg (Table 5). By placing one, two and three hives per orchard, the TWFPT was increased by 11kg, 26.7kg, and 48.1kg respectively compared to an orchard without a hive. These results indicate that the number of hives per orchard had a major effect on total yield in agreement with (Vithanage, 1990). A density of two hives per ha was sufficient to improve the yield but three hives per ha significantly increased the mean weight of experimental tree. As reported by (Eisikowitch, 1998; Gazit & Degani, 2002; Pena & Carabali, 2018), the main pollinator is the honeybee, whose importance is evident in the strong positive correlation that exists between the activity of the bees and the yield of the crop.

Table 4: Effects of hive density on total number of fruit, average weight of individual fruit (gm.) and total weight of fruits (Kg) per tree.

| HIVE DENSITY | TNFPT | AWFPT | TWFPT |
|---|---|---|---|
| 0 | $193.2^{c}$ | $188.4^{c}$ | $36.4^{c}$ |
| 1 | $245.2^{bc}$ | $193.4^{c}$ | $47.4^{c}$ |
| 2 | $309.6^{b}$ | $204^{b}$ | $63.1^{b}$ |
| 3 | $392.2^{a}$ | $215.3^{a}$ | $84.5^{a}$ |
| P value | *<0.05* | *< 0.05* | *< 0.05* |
| CV | 18.44 | 2.15 | 18.82 |

*Mean with the same letter in the column is not significantly different

### 4.10. Effects of Hive Distance on Weight and Number of Fruits per Tree.

The average weight of fruit per tree (AWFPT), was not significantly different */P>0.05/* at evaluated distances of 50m, 100m and 150m,with mean of 200.4gm, 200.3gm and 200.1gm AWFPT respectively as shown in (Table 6). The total number of fruit per tree (TNFPT) was not significantly different (P> 0.05) at evaluated distances of 50,100 and 150m with mean of 289.8, 282.8 and 282.7 TNFPT respectively as shown in (Table 6).

The total weight of fruit per tree (TWFPT) was not significantly different */P> 0.05/* at evaluated distances of 50, 100 and 150m, with mean of 58.8kg, 57.4kg and 57.4kg TWFPT as shown in (Table 6).

Table 5: Effects of hive distance on total number of fruit, average weight of individual fruit and total weight of fruits per tree.

| Hive Distance | TNFPT | AWFPT (gm.) | TWFPT (kg) |
|---|---|---|---|
| 50m | $289.8^{a}$ | $200.4^{a}$ | $58.8^{a}$ |
| 100m | $282.8^{a}$ | $200.3^{a}$ | $57.4^{a}$ |
| 150m | $282.7^{a}$ | $200.1^{a}$ | $57.4^{a}$ |
| P value | *>0.05* | *>0.05* | *>0.05* |
| CV | 18.44 | 2.15 | 18.82 |

*Mean with the same letter in the column is not significantly different

### 4.11. General Information of the Respondents in Darra Otilcho District

Most of the respondents of the Darra Otilcho interviewed had basic formal education (Table 2), with over 57.1% of both gender having had more than five years of schooling. The mean number of years spent in school by female respondents was lower than that of male respondents, as expected. The average age of the respondents was 31.86 years. However, the mean age of males was higher than that of the female respondents. Age difference is a common phenomenon in a household as most husbands are older than their spouses. Also most of the respondents (76.6%) were male, who happen to be the main participants in farming. About (33.3%) respondents said they had been visited by a government extension office at least once in a year.

Table 6: General characteristics of the respondents interviewed in Darra District (N=60)

| Variables | Male | Female | total Respondents |
|---|---|---|---|
| GENDER(percent) | 79.3 | 20.7 | |
| Mean age(year) | 44.06 | 31.31 | 31.86 |
| Mean number of year in the school | 5.68 | 3.68 | 5.15 |
| Percent of Household visited by extension officer in a year | | | 37.1% |

N; Male-46; Female-14

### 4.12. Respondents Perception on Pollination

In the study area, almost all of the farm households grow avocado fruit and keep honeybees (Table 7). About 36.67 % of the respondents have knowledge on that flowering crops benefit from insect visits and 78.3% have knowledge on other insects visiting flower during blooming and also about 63.33% of the responders agreed on honeybees' benefits from flowering fruits crops. About 70% of the respondents agreed on the importance of flower for avocado fruit productivity.

Table 7: Respondents perception on pollination (N=60)

| Variables | Percent |
|---|---|
| Do you grow fruit crop | 99 |
| Do you keep honeybees | 99 |
| Do you think avocado produce fruits without flower visitors? | 30 |
| Do you know honey bees benefit from fruit crop flower | 63.33 |
| Do you know fruits Crop flower benefits from bees | 36.67 |
| Do you know other insects visiting flower during bloom | 78.33 |

Source Survey Result, 2021/2022

### 4.13. Percentage of Respondents Who Grow Different Pollinator Dependent Fruit Crops

Most of the respondents interviewed in Darra district had grown avocado and coffee. About 99% of the respondents grow avocado and about 95% of the respondents grow coffee and also 51.3% of the respondents grow Banana, 42.7%, and other crops (Fig 6).

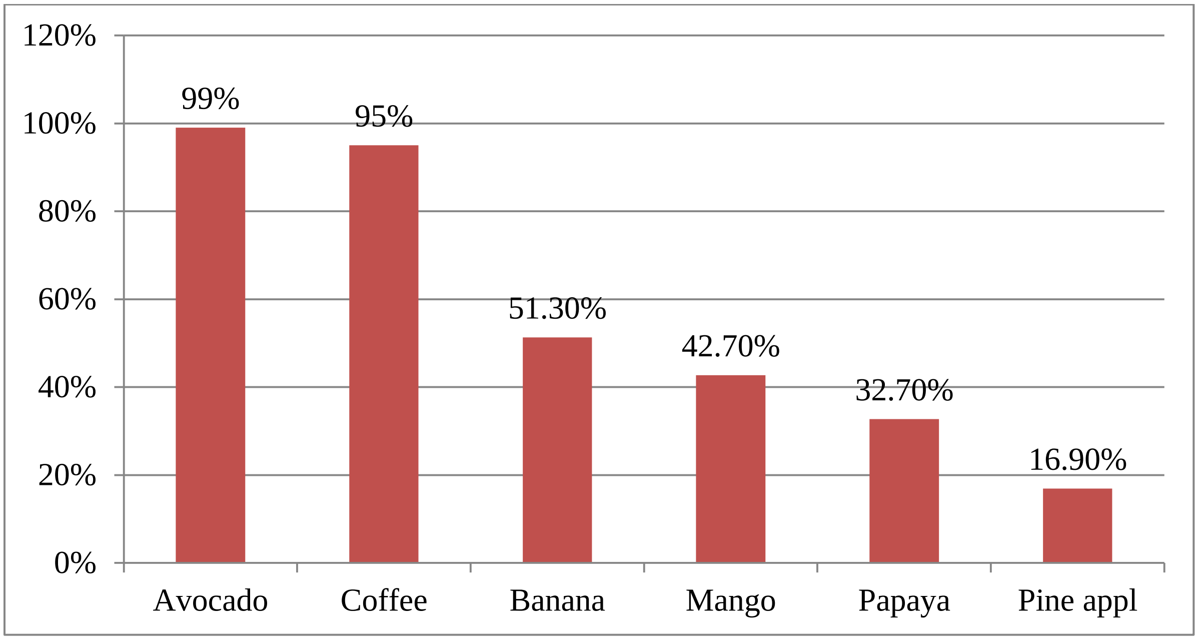



Figure 6: Percentage of respondents who grow different pollinator dependent fruit crops

(Source 2021/2022survey).

### 4.14. Honey Productivity in Different Hive Type

Table 8, shows that the overall average honey productivity per beehive in traditional, transitional and modern beehives. The average honey yield per beehives was 8.03, 12.3 and 20.14 kg for traditional, transitional and modern beehives, respectively. The result was in agreement with previous findings of (Kalayu *et al*., 2017) reported as the average honey yield per year/beehives was 7.20 ± 0.23, 14.70 ± 0.62 and 23.38 ± 0.73 kg for traditional, transitional and modern beehives, respectively (Table 8).

Table 8: Average productivity of different hive by respondents (N=60)

| Type of Hives | Honey Yield kg /hive | | Mean | SD |
|---|---|---|---|---|
| | Mini | Max | | |
| Traditional hive kg | 4 | 14 | 8.03 | 2.3 |
| Transitional hive kg | 8 | 18 | 12.3 | 2.5 |
| Modern hive kg | 15 | 27 | 20.1 | 3.5 |

### 4.15. Knowledge of Pollinators Insects

Almost all (99%) of the respondents knew honeybees (Table 9), which they mentioned without being shown pictures. Both gender had equal understanding of honeybees. However, male respondents had better knowledge of stingless bees than the female respondents.

Table 9: Percentage of Respondents familiar with different pollinator Insect

| Common Name | Scientific Name | Percent |
|---|---|---|
| Bees | *Apis mellifera* | 99 |
| Wasps | *Vespula Germanic* | 83 |
| Fly | *Chrysamya chloropyga* | 80.7 |
| Stingless bees | *Melipon beccari* | 19.7 |

## 4.16. Partial Budget Analysis

4.16.1 Partial Budget Analysis for One Year

The partial budget analysis of the hives in T1, T2, and T3 was calculated as 900, 1800, and 2700 costs of the purchase in Ethiopian birr respectively from beekeeper responding while NR of T1, T2, T3 was calculated as 3750.68, 9,296.13, and 14,859.29, respectively (Table 10). The result of the study indicated that net return increased as the density of hive per orchard/1.5ha increased because when the density of hive /orchard increased, also increased the number of honeybees/avocado orchard then improved avocado yield. These indicated that the production of avocado fruit yield affected by the number of honeybees per tree.

Table 10: Partial budget analysis of Darra Otilcho avocado farm placing different density of honey bee hives per orchard/1.5ha.

| **Variables** | Treatments | | | |
|---|---|---|---|---|
| Treatments | T 1 | T2 | T3 | T 4 |
| Total hives cost/treatments (ETB) | 900.00 | 1,800.00 | 2,700.00 | |
| Labor cost for fruit harvesting | 1,497.2 | 1,534.63 | 1684.35 | |
| Transport cost | 650.00 | 965.00 | 1,150.00 | |
| TVC (ETB) | 3,047.2 | 4,299.63 | 5,534.35 | |
| Total number of avocado tree /orchard | 24.66 | 25.30 | 24.66 | 24.66 |
| Total fruit yield per tree in Kg | 47.4 | 63.1 | 84.5 | 36.4 |
| Total fruit yield per orchard/ha kg | 1,168.884 | 1,596.43 | 2,083.77 | 897.624 |
| TVC (ETB) | 7270.458 | 9929.7946 | 12,961.05 | 5583.22 |
| Honey yield per hive Kg | 3 | 6 | 9 | |
| Total Honey yield per orchard/ha Kg | 36 | 72 | 108 | |
| Total return (TR)(ETB) | 6,797.88 | 13, 595.76 | 20,393.64 | |
| Net return ( NR) (ETB) | 3750.68 | 9,296.13 | 14,859.29 | |
| ΔTR (ETB) | 6797.88 | 13,595.76 | 13595.76 | |
| ΔTVC (ETB) | 3,047.2 | 4,299.63 | 5,534.35 | |
| ΔNR (ETB) | 3750.68 | 9296.13 | 8061.41 | |
| MRR (%) | 123.86 | 216.2 | 145.66 | |

## 5. CONCLUSIONS AND RECOMMENDATIONS

The density of bees per tree was higher within 0-50 m radius distances */P<0.05/* which indicate that distance that exists from the hive to the trees influence the number of bees visiting the flower of avocado tree and fruit set of avocado. Pollination and fertilization of avocado flower is higher in 2 and 3 hives */P<0.05/* indicating that the densities of hive per orchard determine the pollination and fertilization of avocado flower. The average honey yield per modern beehive is higher than that of traditional and transitional beehives. The conclusion was in agreement with previous findings of (Kalayu *et al*., 2017) reported as the average honey yield per year/beehives was 7.20 ± 0.23, 14.70 ± 0.62 and 23.38 ± 0.73 kg for traditional, transitional and modern beehives, respectively.

Efficiency of pollination are higher when introducing 2-3 hives with distances of 0-50m radius at */P<0.05/* implying that hive density and distance have great effects on effective of honeybee pollination services. As the number of honeybee hives/orchard increases, the total number of fruit per tree as well as average weight of fruit per tree and total weight of fruit per tree also increases within 0-50m radius distances at /P>0.05/ which indicate that distance that exists from the hive to the trees influence the number of bees visiting the lower of avocado tree and fruit set of avocado, but the result did not show that much of significant differences between them.

Recommendations

1. This study showed increased honeybees density per tree higher within 0-50m radius distance when compared to 100m and 150m.

2. Pollination efficiency of avocado flower found to be higher in 2 and 3 hives per 1.5 ha in terms of total number of fruits per tree, average weight of individual fruit and total weight of fruit per tree. So that this study recommended introducing 3 hives per avocado/1.5 ha orchard to improve avocado fertilization.

3. Efficiency of pollination was higher with distance of 0-50m radius. Accordingly, this study recommended that within distances of 50m radius show significant differences when compared with 100m and 150m radius to improve avocado pollination and better fruit production.

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**Appendix**

Appendix 1

Appendix 3 1: Factorial ANOVA table for Honey Bees Density/tree

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| DS | 2 | 60.222 | 30.111 | 12.46 | 0.0002 |
| HD | 3 | 743.194 | 247.731 | 102.51 | 0.0000 |
| DS*HD | 6 | 26.222 | 4.370 | 1.81 | 0.1399 |
| Error | 24 | 58.000 | 2.417 | - | - |
| Total | 35 | 887.639 | - | - | - |
| Grand Mean | | 8.1944 | | | |
| CV | | 18.97 | | | |

Appendix 2

Appendix 3 2: Factorial ANOVA table for Pollination Rate

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| DS | 2 | 38.89 | 19.44 | 1.75 | 0.1952 |
| HD | 3 | 4230.56 | 1410.19 | 126.92 | 0.0000 |
| DS*HD | 6 | 27.78 | 4.63 | 0.42 | 0.8606 |
| Error | 24 | 266.67 | 11.11 | - | - |
| Total | 35 | 4563.89 | - | - | - |
| Grand Mean | | | 51.944 | | |
| CV | | | 6.42 | | |

Appendix 3 3 : Factorial ANOVA Table for Pollination Efficiency

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| DS | 2 | 84.43 | 42.216 | 13.93 | 0.0001 |
| HD | 3 | 806.62 | 268.874 | 88.73 | 0.0000 |
| DS*HD | 6 | 43.00 | 7.167 | 2.36 | 0.0616 |
| Error | 24 | 72.73 | 3.030 | - | - |
| Total | 35 | 1006.78 | | - | - |
| Grand Mean | | 9.7667 | | | |
| CV | | 17.82 | | | |

Appendix 3 4: Factorial ANOVA for Number of Fruits per Tree

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| DS | 2 | 397 | 198.4 | 0.07 | 0.9310 |
| HD | 3 | 198945 | 66315.0 | 23.99 | 0.0000 |
| DS*HD | 6 | 167 | 27.8 | 0.01 | 1.0000 |
| Error | 24 | 66343 | 2764.3 | - | - |
| Total | 35 | 265852 | | | |
| Grand Mean | | 285.06 | | | |
| CV | | 18.44 | | | |

Appendix 3 5: Factorial ANOVA for Average Fruit Weight

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| DS | 2 | 0.56 | 0.28 | 0.01 | 0.9851 |
| HD | 3 | 3858.71 | 1286.24 | 69.11 | 0.0000 |
| DS*HD | 6 | 33.27 | 5.55 | 0.30 | 0.9318 |
| Error | 24 | 446.66 | 18.61 | - | - |
| Total | 35 | 4339.20 | | | |
| Grand Mean | | 200.28 | | | |
| CV | | 2.15 | | | |

Appendix 3 6: Factorial ANOVA for Total Weight of Fruit per Tree

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| DS | 2 | 15.7 | 7.84 | 0.07 | 0.9362 |
| HD | 3 | 11768.3 | 3922.77 | 33.07 | 0.0000 |
| DS*HD | 6 | 4.1 | 0.68 | 0.01 | 1.0000 |
| Error | 24 | 2846.8 | 118.62 | - | - |
| Total | 35 | 14634.9 | | | |
| Grand Mean | | | 57.870 | | |
| CV | | | 18.82 | | |

**Appendix7**

**HAWASSA UNVERSITY**

**COLLEGE OF AGRICULTURE**

**DERPARTMENT OF ANIMAL AND RANGE SCEINCE**

Appendix 3 7: Survey Questioner; effects of honey bee on avocado production in Darra Otilcho District, Sidama Region, Ethiopia.

2021/2022

1. Back ground.

1.1. Village Name (PA) ____________________

1.2 .Farmer Name ________________

1.3. Farmer age____________________

1.4. Sex of farmer_____________________

1.5. Educational level________________

1.6. Do you keep livestock? Yes [ ] no [ ]

list:

1.7. Do you grow crops? Yes [ ] no [ ]

List:

1.8. What off-farm activities do you carry out?

1.9. Where do you get information about farming practices?

2. Pollinators, Pollination and Flowers

2.1 Do you keep Honey bee? Yes [ ] No [ ]

a. If yes, how many hives?

b. Are all hives colonized? Yes [ ] no [ ] how many un-colonized?

c. Where are your hives located?

2.2. Do you know bees other than honey bees which make honey? Yes [ ] No [ ]

b. Where do they live (nest)?

c. Do you harvest their honey? Yes [ ] No [ ] If no, reasons:

2.3. Do you know other bees which do not make honey?

a. If yes, list:

b. Do you know where they live (nest)? Yes [ ] no [ ] If yes, Where?

2.4. When do you start to notice bees visiting your crops?

a. Do bees prefer different crop flowers? Yes [ ] No [ ] List:

2.5. Are bees present all year round in the farm or in the surrounding shrubs? Yes [ ] No [ ]

2.6. Do you also notice other insects visiting the crops during flowering?

Yes [ ] No [ ]

List:

2.7. Do you know what bees collect from a flower? Yes [ ] No [ ] List:

2.8. Do you think the crop (or flower) benefits from the bee visits?

Yes [ ] No [ ] List:

2.9. Do you think that without flowers you can get fruits (avocado) or seeds?

Yes [ ] No [ ]

2.10. Do you know whether a flower **(**e.g., avocado**)** require fertilization to produce seeds/pods/ fruits?

Yes [ ] No [ ] I am not sure [ ]

2.11. List the top five fruit plant important food source for bees in your area?

List:

2.12. What are the major constraints related to avocado production in your locality?

List

2.13. Do you know the effect of honey bee on avocado fruit production?

Yes [ ] No [ ] I am not sure [ ]

If ye, list:

2.14. How much hectare of avocado orchard do you have?

2.15. Which month of the year avocado flower starts to bloom in your locality?

2.16. Which month of the year avocado flower start to set fruit in your locality?

2.17. Which month of the year avocado fruit is harvested in your locality?

2.18. How much number of avocado fruit per plant you harvest?

2.19. How much kg of avocado fruit per plant you harvest?

2.20 How much birr you sold 1 kg of avocado fruit?

2.21. How much birr you get from avocado fruit per one flowering season?

2.22. How much birr you get from avocado fruit per year?

3. The type of hive you used?

3.1. How many hives do you have?

3.2. How many kg of honey from one traditional hive per one harvesting time you harvest?

3.3. How much kg t of honey from one transitional hive per one harvesting time you harvest?

3.4. How much kg of honey from one modern hive per one harvesting time you harvest?

4. What are the major constraints facing you in beekeeping and Avocado farming integration?

Figure 7: Pollen analyses at Holeta Bee Research Center

Figure 8:  Counting avocado fruits per tree at the study area.

Figure 9: Avocado trees in the study area in 2022.