ADDIS ABABA UNIVERSITY

SCHOOL OF G... E STUDIES

COMPAR... N OF GROW... D OF APPLE (M... domestic...) REE CULTIVARS AT ... A... N GAMO GOFA ZONE, SOUTH ETHIOPIA

By Kebede Jobir

... the School of Graduate Studies ... versity in Partial Fulfillment of the ... the Degree of ... Biology

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SCHOOL OF GRADUATE STUDIES

COMPARISON OF GROWTH AND YIELD OF APPLE (*Malus domestica* Borkh.) TREE CULTIVARS AT THREE ALTITUDES IN GAMO GOFA ZONE, SOUTH ETHIOPIA

By Kebede Jobir

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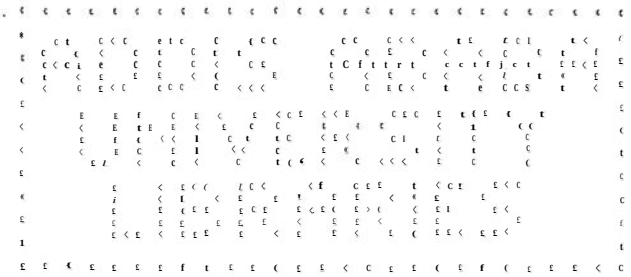

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Abstract

Growth and yield of seven apple tree *(Mains domestica* Borkh.) cultivars were compared in three-altitudinal zones in Game Gofa, at Chencha, Bonke and Boreda, Southern Regional State, Ethiopia. to relate crop growth and yield with altitude. The seven cultivars, BR-64, Granny Smith, Gala, Anna, Golden Delicious, Red Delicious and Crispin were of similar age, had identical rootstocks and were growing at the same site in each altitude under similar management practices. Data on new shoot growth, leaf area, height, stem diameter, number of fruits and fruit size were collected and 60 home gardens of the apple growers were surveyed. Interviews were conducted and questionnaires administrated in order to get information on the practice of apple growers and their perception. The result showed that, more than half of the area of home gardens of the apple growers were used for apple cultivation for income generation and for domestic consumption. Farmers indicated that the expansion of the crop was related to the high price of the fruit. in Chencha and Bonke the number of BR-64, Granny Smith and Gala was more than that of Anna and Golden Delicious. The latter cultivars were not widely planted due to their lower yield at the two sites. Anna and Golden Delicious were better in Boreda than in Chencha and Bonke. Farmers' selection of cultivars were based on experience on yield performances. On the other hand, most farmers showed limited knowledge of rootstocks used, cultivar selection at different sites, pruning and thinning activities. Further, management practices such as mulching and manuring at proper time of cultivars new growth and blooming at Fall *(tsedey)* was not performed. Similarly knowledge of apple diseases and pests that reduce yield was not apparant and little traditional methods of prevention were used

Of the seven cultivars BR-64, Granin Smith and Gala grafted on MM106 rootstock showed an increase with altitude in new shoot grow th, leaf area, stem diameter and fruit number. Both in Chencha and Bonke these cultivars shaded their leaves early in June and resumed blooming and leafing in September. For Anna and Golden Delicious the same parameters decreased with increase in altitude. The results indicate that while Anna and Golden Delicious were suited for warmer climates, BR-64. Granny Smith and Gala were more suited for colder climates.

Red Delicious and Crispin had moderate growth and did not show altitude preference. It is recommended that selection and distribution of apple seedlings should be altitude specific based on the preference of the cultivars.

1. INTRODUCTION

Apple is the most important pome fruit of genus *Malus* belonging to the Family *Rosaceae.* It has been cultivated and vegetatively propagated for over two millennia. Over 100,000 named cultivars exist and breeders worldwide create new selections annually, but only a few dozen types are widely produced in commerce today (Janick *et al.,*1996). The common domesticated apple is reported to be an interspecific hybrid complex, usually designated *Malus domestica* Borkh. (Korban and Skirvin, 1984). *Malus domestica* is now cultivated widely in temperate latitudes or at high elevations in the tropics on all continents except Antarctica. The fruits are eaten fresh, dried or canned or processed into juice, preserves or processed or are used for medicinal purposes (Luby, 2003).

Due to this and its other economic supremacy over other fruits, apples are widely grown in many countries such as China, USA, Japan, Australia, and others. According to Westwood (1993), a lot of research in most of the developed countries focuses on producing improved cultivars that have a better performance of yield, resistance to climatic and soil conditions, frost or diseases. On the other hand, commercial apple production is increasingly concentrated in countries and in growing districts that have a strong comparative advantage in apple production and marketing such as China and USA as a leading production countries (O'rourke, 1994). However, the development of more heat tolerant cultivars such as Granny Smith (Miklos, 1989) and advances in irrigation techniques have permitted apple production to expand successfully into lower latitudes with warmer climates.

Some of these economically important apple cultivars are grown in some regions of Ethiopia. Apple tree cultivars were introduced to Chencha in the 1950s by protestant missionaries. Few cultivars were distributed to some followers, who planted them in their home gardens. However, its use was not understood. During the Derg regime, the Church was closed and apple cultivation was interrupted. After the fall of the Derg, individuals, notable Theophillus Tesfaye in Chencha, started to grow apples, train others, and promote its distribution to other areas. As a result, apple is grown by many farmers in different areas near and around Chencha in Gamo Gofa. Such

farmers have benefited from the high price of the apple fruit which increased their income and improved the livelihood of their family. Nevertheless, apple growing could not develop and expand as it should for a number of reasons among which lack of knowledge on cultivars, absence of knowledge on cultivar characteristics requirements and their performance at different sites. In addition, agricultural extension workers indicate that the expansion of apple growing is hindered by lack of information on varietal differences, yield and production levels and rootstocks and scion types to be used. The present work attempts to address this need by studying the comparative growth and yield of seven cultivars of apple at three altitudes, and by gathering the experience and perception of farmers to asses and document their knowledge.

1.1. Objectives

1. 1. 1. General objectives

To compare the growth and yield of the seven apple tree cultivars cultivated at three altitudes and identify cultivars with better performances, and to asses experience and perception of farmers and document knowledge of farmers related to apple cultivation.

1. 2. 2. Specific objectives

- To compare growth and yield of apple tree cultivars at three altitudes of Boreda, Chencha and Bonke woredas.
- To distinguish the impact of management practices; disease and pests on the performance of apple tree cultivars in the three study sites.
- To examine the farmers husbandry, perception as well as attitude for apple cultivars and apple growing.

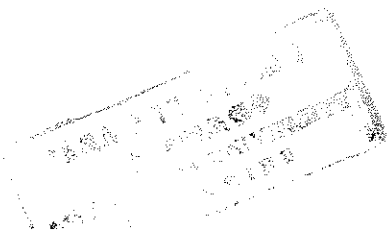
parameters within which apple fruits are produced and they may impose the limits of potential fruit production, these environmental factors must be properly managed to allow the cultivars to achieve its productive potential. In agreement with this John (1996) documented that the environmental factors affect growth by affecting the fundamental biological processes of apple fruit trees, the metabolic biochemical reactions and pathways such as photosynthesis and respiration. According to Way *et al.* (1990), the most important aspects of climate the apple fruit grower must consider in selection of site for cultivars grows are temperature, rainfall and wind. Of these temperature is the most crucial. Further more West wood (1993) indicated that, both low and high temperature can minimize growth or cause injury by affecting the physiological processes. On the other hand, temperature affect fruit size, quality, and thus ultimately their value and the economic return of the crop (Ryugo, 1988). Thus in the orchard ecosystem, the environment is an important component so as its components must be managed to the benefit of the grower.

As Miklos (1989) stated, at high latitudes apple requires a mild growing season (no extremes of sunshine, temperature or humidity), a sufficiently cold winter to break dormancy and well drained soil condition to limit stress as this would affect fruit quality and fruit size and floral development for next crop. Wind breaks are needed for exposed sites to prevent fruit blowing or pollinators (bees) movement (Duane, 1996). In the tropics, for an annual cycle there should be a prominent change of seasons, the growing season meeting adequate moisture (1600-3200 mm), temperature (16-27^{0}c), altitude(1000-300m), sunshine more than 50% of potential sunshine duration and good soil with irrigation facilities (Westwood, 1993; Morgan and Richards, 2002).

2. 2. *Malus domestica* Borkh.

2. 2. 1. General feature

Westwood (1993) described *Malus domestica* as small-medium sized tree or shrub mostly with spreading canopy, rarely with spiny branches, 2- 4 m tall, freely branching with long shoots and various types of short shoots (spurs) with a single trunk, tree size is heavily dependant on rootstock and training system, leaves are elliptic-ovate in shape and can have a size of up to 4-13 cm by 3-7 cm, rounded at base, margin irregularly saw toothed (serrate) dark green with light pubescence on underside, flowers largely terminal on spurs, in several flowered fascicles, pedicel



and calyx usually wooly, calyx persistent in fruit, petals 5, white to pinkish, falling off after anthesis, stamens 15-20, styles 5, ovary position is epigenous or inferior containing up to 10, ovules (2 per locule), fruit a pome, glabose, ellipsoid to obovoid, usually more than 5 cm in diameter, varying in color, sweet or acid, much longer than pedicel; endocarp coriaceous, fruit pulp without stone cells. Seeds brown, mostly 2 in each cell.

2. 3. Cultivar descriptions

2. 3. 1. Granny Smith

Granny Smith is a chance seedling discovered on the farm of Maria Ann and Thomas Smith of Ryde, New South Wales, Australia (Bultitude, 1989). The original tree was fruiting in 1868 (Bultitude, 1989). Granny Smith is chiefly a southern hemisphere apple (Avermaete, 1999). It has been grown extensively in Australia, Argentina, Chile, New Zealand and South Africa. It has become an important apple in world trade since 1950 (Warrington, 1998). The chilling requirement vary depending on the growing area (Barahone *et al.*, 1992; Ghariani and Stebbins, 1994).

Fig. 1. Granny Smith (Photo: field survey, 2005)

The botanical characteristics of Granny Smith as observed by the researcher in the grown area. and as described by several researchers, Stebbins (1980), Bultitude (1983), Khanizadeh and Cousineau, (1998), habit tree, large in size with up right spreading branches which can reach about 3.5 m; spur-type cultivar (Roy and George, 1987); lenticels conspicuous as gray dots: leaves are simple, alternate, elliptical in shape, margin serrate, apex acuminate, base acute-asymmetrical, surface under-neath light pubescent and can have a size of up to 7.4 cm by 4.2 cm long; venation pinnate; petiole are up to 3 cm long; inflorescence cymes, petals are 5, free with whitish pink colour and oblong shape which reach up to 20 mm long, calyx 5 with lanceolate shape up to 1-2 mm long and not fused; stamens free, number 16-20, pistils 5, fruit colour bright green or green sometimes flushed and striped with brown round conical shape, flesh greenish white as described by Dick *et al.* (1986).

2.3.2. Gala

Gala is the product of two generations of controlled crossing by amateur breeder, I. H. Kidd of Wairarapa, Newzeland (Bultitude, 1989). It is the offspring of a cross of Kidd's Orange Red X Golden Delicious made about 1934 (Bultitude, 1989). The apple was named Gala by Walli Gale in 1962. and released for commercial planting in 1965 (Tustin, 1990). Gala is an important cultivar widely grown in several areas. It is suitable for drying and has no significant storage disorders (Hempson and Kemp, 2003).

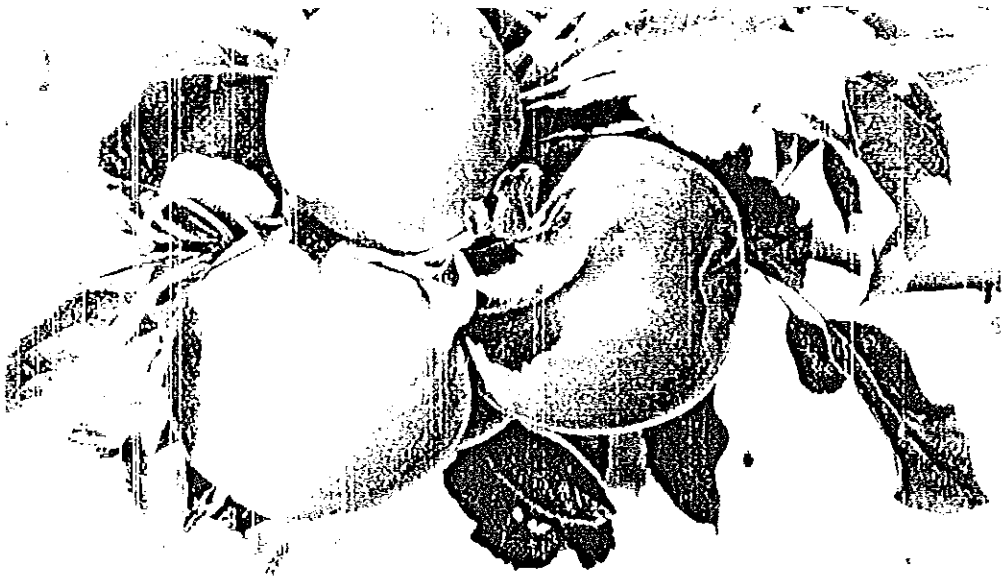


Fig. 2. Gala (Photo: field survey, 2005)

The botanical characteristics of Gala as observed in the grown area and as described by Bultiude (1989), it is a tree, medium in size with up right wide spreading growth which can reach up to 2.85 m long, tip and branching spur bearer, lenticels fairly conspicuous as gray russet dots; leaves are simple, alternate, ovate in shape, margin serrate, apex acuminate, base acute, surface pubescent, venation pinnate and can have a size of up to 7.2 cm by 3.73 cm long, petiole 3 to 3.5 cm long; inflorescence cymes. petal free, number 5 with whitish pink colour and an oblong shape and can reach up to 20 cm long, calyx 5 in number free with acuminate to ovate shape and can reach up to 2-3 mm long, stamen free, number about 19, pistil 5, fruit colour shiny red skin or yellow heavily flushed red with round shape, flesh cream.

2.3.3. Red Delicious

Red Delicious (also known as Delicious) arose unwanted in the field of Jesse Hiatt of Peru, Iowa USA, in about 1872 (Fear and Domoto, 1998). Mr. Hiatt cut the tree down twice before allowing it to persist. because it was not growing in the row. The parentage is unknown. a near by yellow bell flower tree may have been the seed parent (Khanizadeh and Cousineau, 1998), or Delicious may have arisen as a sprout from a seed or a seedling root stock, Mr. Hiatt was impressed by the fruit and named the cultivar Hawkeye. It was eventually purchased by Stark brother's nursery, who renamed it Delicious and introduced it commercially in 1895 (John *et al.*, 1991). It has long been the back bone of the US industry and is an important cultivar in Europe. China, Australia, etc.

Fig. 3. Red Delicious (Photo: field survey, 2005)

Botanical characteristics observed in the grown area and described by Roy and George (1987), habit tree, medium in size with spreading growth which can reach up to 3.5 m; lenticels moderately conspicuous; leaves are simple, alternate, ovate in shape, margin serrate, apex acuminate, base acute, surface very light pubescent and can have a size up to 7.1 cm by 3 cm long, venation pinnate, petiole up to 3.5 cm long, venation pinnate: inflorescence cymes, petal are 5, free with whitish pink colour and oblong shape and reach up to 20 mm long , calyx 5 in number with acuminate shape and 2-3 mm long; stamens free, with up to 20 in number, pistil 5, fruit colour red flushed with round shape, flesh cream, slightly green.

2. 3. 4. Crispin (Mutsu)

Crispin was raised in Japan in 1930 at Aomori Apple Experimental Station, as the offspring of a cross of Golden Delicious x Indo (Bultitude, 1989). Bultitude (1989) further stated that the cultivar was first fruited in 1939, named Mutsu in 1948 and renamed Crispin in UK for commercial reason in June 1968.

Fig. 4. Crispin (Photo: field survey, 2005)

In the grown area the botanical characteristics of Crispin observed and as described by Bultitude. (1989), is habit tree, large in size with central-spreading growth with up to 3.5 m height: tip spur bearer, lenticels very numerous and highly conspicuous grey russet dots ; leaves are simple, alternate, elliptical in shape, margin serrate (sharp), apex acuminate, base acute to asymmetrical, surface pubescent and can have a size of up to 8.85 cm by 4.29 cm long; petiole reach up to 3 cm long; inflorescence cymes, petal free, number 5 with whitish pink colour and have oblong shape, with up to 17 mm long, calyx 5 in number, free, with lanceolate to ovate shape reach up to 1-2 mm long; stamen free, number 15-17, pistils 5, fruit colour yellowish-green with round-oblong shape.

2.3.5. Golden Delicious

Golden Delicious is a chance seedling found by A.H Mullins, West Virginia, USA in 1980 possibly from seed of Grimes Golden and introduced by Stark Brothers in 1914 (Bultitude. 1989). It has less cold hardiness and requires warmer climate (Luby *et al.*, 1999).

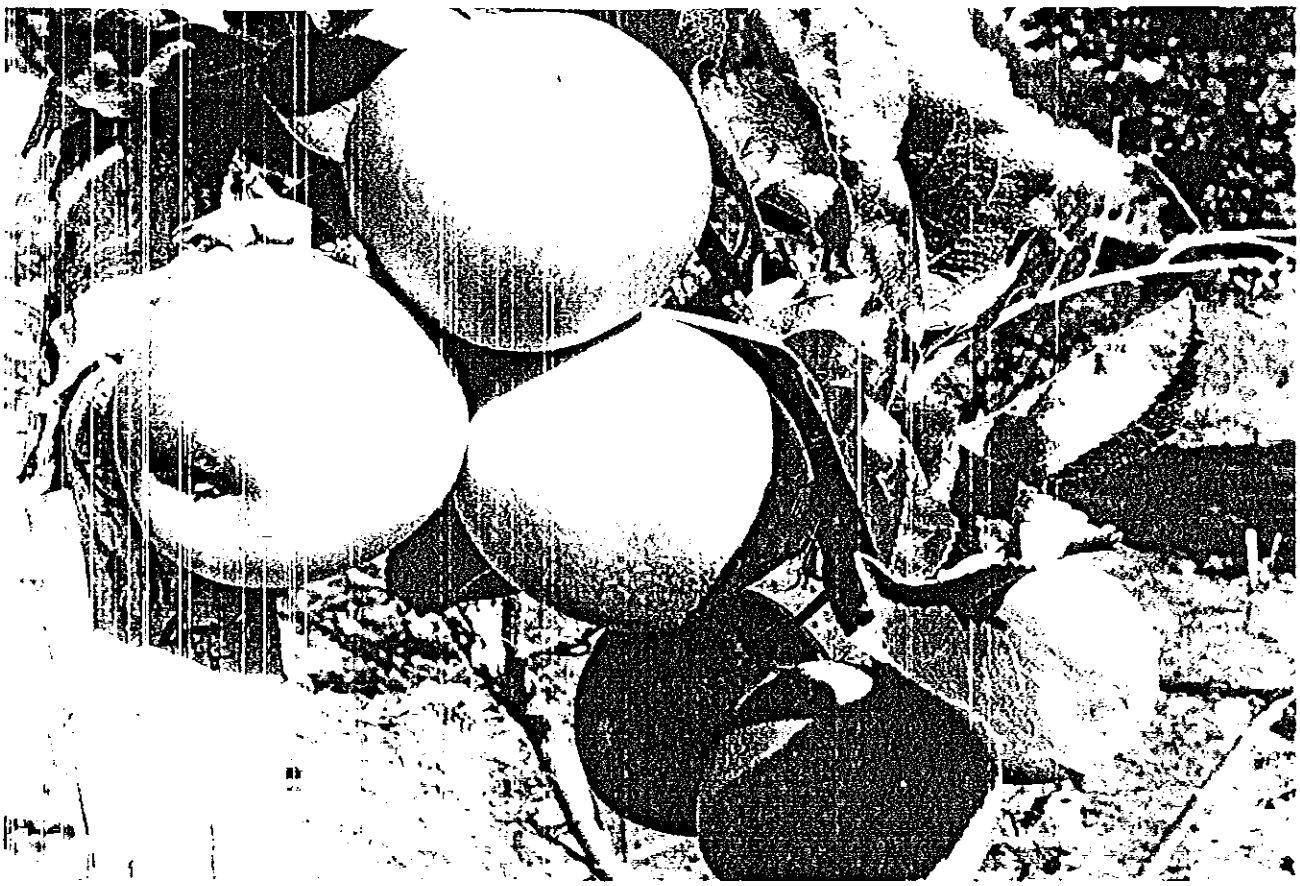


Fig. 5. Golden Delicious (Photo: field survey, 2005)

The botanical characteristics of Golden Delicious as observed in the study area and as described by Westwood (1993) is, habit, tree small in size with spreading growth which can reach up to 2.85 m; spur-type bearer; lenticels not conspicuous; leaves are simple, alternate, elliptical in shape. margin serrate, apex acuminate, base acute, surface pubescent and can have a size of up to 7.75 cm by 4.7 cm long, venation. petiole 1.5-2 cm long; inflorescence cymes, petals free. number 5 with reddish pink colour and oblong shape with up to 15 mm long, calyx 5 with acuminate shape up to 2-3 mm long and free, stamen number 15-20 and free, pistil 5, fruit colour yellow turning gold or golden yellow with round conical to oblong shape; flesh deep cream.

2.3.6. BR-64

The apple cultivar BR-64 based on one of the key informants, Theophillus Tesfaye, who lives in Chencha woreda, near *tolola* apple nursery site, and was one of the apple propagators and growers was brought to *tolola* by Bruce Bond (New Zealand) may be from the Institute of

Agricultural Research (IAR), or more likely from Kenya in 1964. The parentage of the cultivar and its original name is unknown. The present name was given by the nursery site technician Gota Goda in 1981. Theophillus remarks BR as Bond Red Delicious, and 64 represents the year the cultivar introduced to Chencha. Therefore, the cultivar was named BR-64 and released for commercial planting in 1981.

Fig. 6. BR-64 (Photo: field survey, 2005)

As observed in the study area BR-64 has the following botanical characteristics: habit tree, large in size with spreading growth which can reach up to 3.85 m; spur-type and tip spur bearer, lenticels not conspicuous, leaves are simple, alternate ovate in shape, margin serrate, apex acuminate, base acute surface pubescent, venation pinnate and can have a size of up to 7.68 cm by 4.79 cm long; petiole 3-3.5 cm long; inflorescence cymes, petals are free, number 5, with whitish pink colour oblong shape, size up to 12-15 mm long; calyx 5 in number, free, lanceolate to ovate shape with 1-2 mm length; stamen free, number 18, Pistils 5; fruit colour reddish yellow with round shape, flesh whitish cream colour.

2. 3.7. Anna (Apple Chinago)

Anna was a chance seedling developed by Mr. Abba Stein of Israel and was commercially planted in 1850 (Baker, 2000).

Fig. 7. Anna (Photo: field survey, 2005)

Anna botanical characteristics observed in the grown area and as described by Morgan and Richards (2002), habit tree, large in size with spreading growth which can reach up to 3.85 m; spur-type and tip spur bearer; lenticels not conspicuous; leaves are simple, alternate. ovate in shape, margin serrate. apex acuminate, base acute. surface pubescent, venation pinnate and can have a size of up to 7.68 cm by 4.79 cm long; petiole 3-3.5 cm long; inflorescence cymes, petals are free, number 5, with whitish pink colour oblong shape, size up to 12-15 mm long; calyx 5 in number, free, lanceolate to ovate shape with 1-2 mm length; stamen free, number 18. pistils 5; fruit colour blushed with long-conical shape and flesh whitish cream (Hessayon, 2000).

2. 4. Root stocks

The study conducted by several researchers indicated that apple trees are not grown on their own root but propagated on rootstocks that control production in the tree, directing its energy into fruit production (Cyrus and James, 1992; Elfving and Schechter, 1993; Westwood, 1993; Morgan and Richards, 2002). They revealed that the rootstocks determine the relative tree growth rate, ultimate size, anchorage, precocity, productivity and respond hazardous of the soil environment. Couvilloon *et al.* (1984) further reported that specific rootstocks are also known to reduce scion-chilling requirements. Therefore, selecting and planting a rootstock cultivars that is true-to-type is essential for apple growers. Thus before buying a tree it is essential to know which root stocks has been used.

Westwood (1993) reported that beginning 1912 the East Malling research station at Kent, England tested and characterized the paradise stocks of Europe, some of which had been used for centuries. These dwarfing stocks were introduced as Malling (M) series in 1917, each clone with Roman numerical (e.g. MI, MIV, MIX). Recently the number changed to Arabic and thus become M9, M27, etc.

The Malling-Merton (MM) series was developed jointly by the East Malling Station and the John Innes Horticultural Institute at Merton, England. The cultivar of stocks tested which are important for their character of resistance, vigorousity and then designated as MM104, MM106, MM111, etc. However, the work of several researchers on root stock performance revealed that the vigorous type of root stock of one area may not be effective in other area due largely to variation in climatic, soil conditions, altitude and tree managements (Westwood, 1993; Morgan and Richards, 2002: Simon *et al.*, 2002).

2. 5. Ecology

The domestic apple (*Malus domestica* Borkh.) tree cultivars are found in the South Western plateaus of Gamo Gofa zone with altitudinal range of 2300 to 3200 masl. Its local temperature zones are *dega* with mean annual temperature of 9^0 to 15.5^0C (GGZAD, 1990). Rice *et al.* (1990) indicated that the apple tree cultivars can grow at elevation of 1300 m and above with the temperature range of 5-10°C. In agreement with this Westwood (1993) reported that, temperate

fruits that are grown in lower latitudes based on the area and cultivar require a minimum elevation at which adequate chilling occurs, usually between 1000 and 3000 m. Besides elevation he further described that other factors such as, humidity, rainfall and fogs or clouds can be important in choosing the site for a cultivar.

The apple fruit producing cultivars are grown in the highlands of the study area that are prone to degradation and infertility. Consequently, they dispose several ecological significances, while possessing huge economic potentials to buffer and improve the economy of the communities living there. Thus, apple tree cultivars expansion in the study area and elsewhere improve soil conservation in such a way that their root systems are effective in reducing soil erosion thereby stabilizing soils. On the other hand the non-destructive harvest of apple tree fruits is also used for conservation of the cultivars and protection of the vast marginal degraded fragmented highland ecosystems.

3. DESCRIPTION OF THE STUDY AREA AND THE PEOPLE

3. 1. Geographical location

The study was carried out in the Southern Nations, Nationalities and Peoples Region (SNNPR) region, Gamo Gofa zone in three districts (woredas), Bonke, Chencha and Boreda.

Bonke is situated about 97 kms west of Arbaminch and Chencha and Boreda are situated 50 and 104 kms north of Arbaminch, respectively. The study area (Fig. 8) is located within Southern Ethiopia Rift Valley and is situated approximately from longitude 36^0 37' E to 37^0 85' E and latitude 5^0 57' to 6^0 71' N (GGZPED, 2001). The elevation of the study sites is in the range of 2300 to 3200 masl.

3. 2. Geology and soils

The Ethiopian highlands were formed in the late tertiary period by lava flows, which hardened in to a large basalt dome. Later, a huge block of land running along the crest of the dome dropped down ward to form the rift valley of East Africa (Jackson, 1969). From a structural point of view, the East African Rift system is a complex tectonic mega structure characterized by a serious of down faulted troughs, intense volcanic and seismic activity and an attenuated continental crust (Sagri, 1998).

In Ethiopia the rift valley divides the highlands in to two main segments lying roughly North West and South East of one another. The study sites are found in most area of Gamo highlands, which is the southern, most extension of the North Western block of Ethiopian highlands. According to GGZAO (1990) the general data of soil of characteristics of the three study sites are mainly related to the topography and parent materials. In most of the study sites the slopes are steep and the soils are shallow to moderately steep. The soils are clay in texture and have developed on schist and shales'. The dominant soil colour is reddish brown to dark brown. The major soil types identified in this area are Cambisols, Litisols and Leptosols. These soils are confined to severely eroded steeper parts of the woreda. These soils are very shallow and agriculturally unproductive (MOA, 1998).

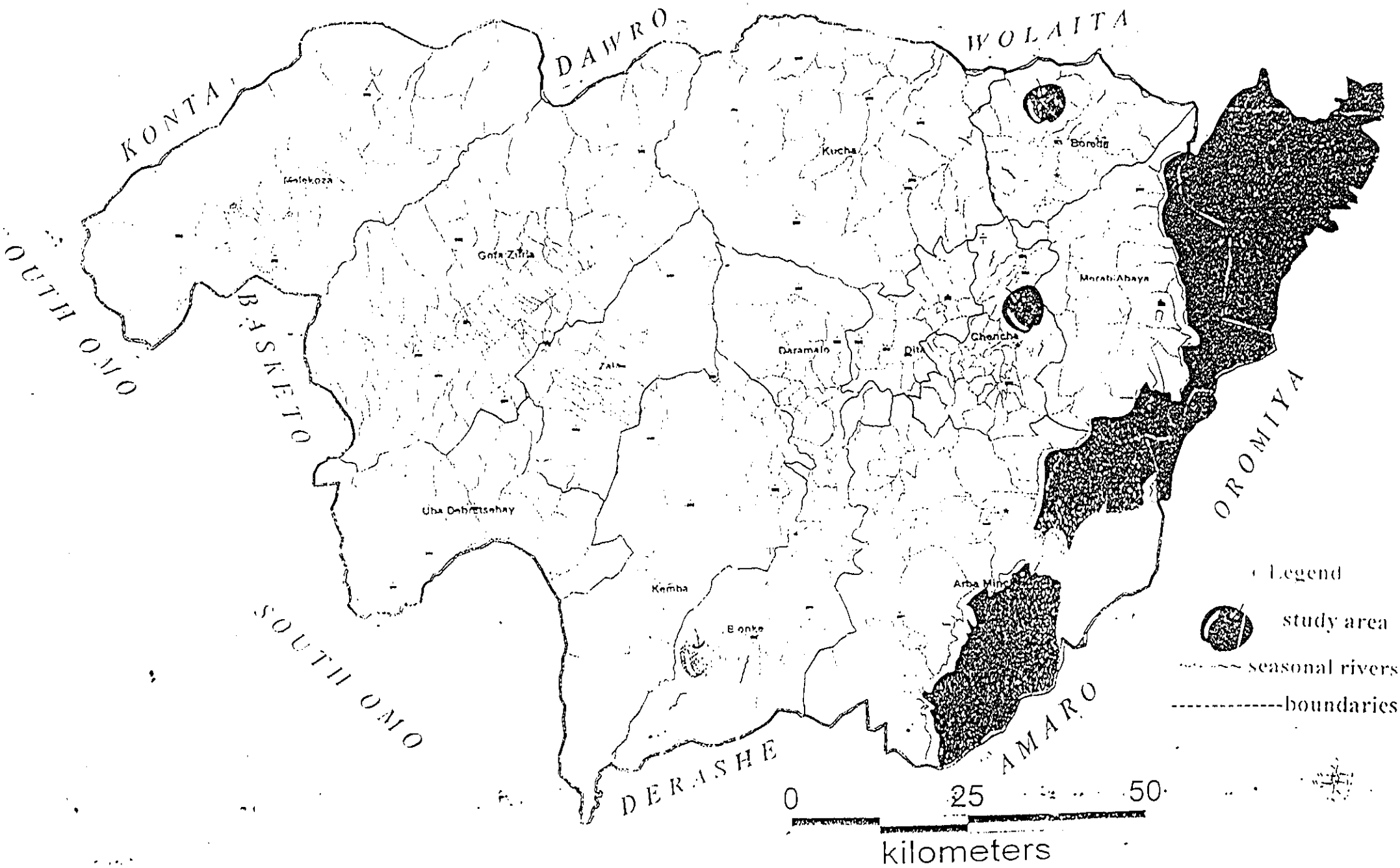


Fig. 8 Map of the study area

3. 4. Vegetation

The natural vegetation of the study area is highly depleted due to the continuous intervention of human beings for various purposes. But one can see remnants of forests in few hilly areas. These are not cut down due to traditional beliefs (key informants). As personal observation, in the area few forest trees including *Hagenia abyssinica*, *Ficus sur*, *Croton macrostachyus*, *Juniperus procera*, are commonly met including in the crop fields which may give clues to the kind of the original natural vegetation.

3. 5. The people of the study area

The people inhabiting the study area have mostly the characteristics high density of *enset* horticulturalists, and their strong economic reliance on their well-known weaving skills. It is well known that, the size, growth and spatial distribution of population influences the degree of utilization of natural resources, the level of economic development and level of socio economic services. Thus according to CACC (2003) the total estimated population of the Woredas, percent of all holders (croplands, livestock, etc), percent of non- holders (with no land, livestock or other) are shown in Table 1.

Table 1. Total population, percent of all holders and non-holders.

Woreda	Total population	Percent of female	All holders	All non-holders	Percent of holders	Percent of non holders	Percent of female non-holders
Bonke	121,919	49.80	24,480	97,439	20.10	79.90	60.10
Chencha	100,155	56.00	21,305	78,850	21.30	78.70	63.50
Boreda	55.872	50.40	11,453	44,419	20.50	79.50	60.10

(Source: CACC, 2003)

The people of the study area are settled farmers growing mainly the annual food crops such as barley, wheat, teff, etc. However the non- holders are mostly migrating to near by town of Arba-minch and other rift valley areas. Most of them become daily laborers or are involved in

deforestation by bringing logging. charcoal, thatched grasses to the town and get money in exchange. Few of them (non-holders) propagate apple cultivars on small plots of land or work as daily laborers in fruit nursery sites.

3.6. Land use system

The land use system in the study area is characterized by the combination of livestock rearing with crop cultivation. In all the three woredas of the study areas crop cultivation is mostly dominated by *enset*. Its major characteristics is the dominance of the home stead plots of *enset*, root crops, tree crops, and barley which is becoming more important at the *dega* zone of the study area. The population of the area is heavily dependent up on subsistence economy. Crop- livestock interactions are essential for the social, economic and ecological sustainability of smallholder farming system. This is because crop residue is used to feed livestock and livestock waste is used to fertilize cultivated fields and home gardens (Nori, 1998).

4. MATERIALS AND METHODS

4. 1. Selection of the study site

The study was carried out in three woredas of the 13 woredas of Gamo Goffa zone (Bonke, Chencha and Boreda), which are located in the southern extension of North West highlands. The three woredas were selected based on the expansion of apple tree cultivars and also based on their altitudinal variation. A reconnaissance survey was made in each woreda to select study site and from each woreda two *kebeles*, making a total of six *kebeles* were selected based on apple expansion. Sixty apple cultivar growers home gardens, were selected from all three woredas and six *kebeles*.

4. 2. Informant selection

Sixty informants, owners of apple tree cultivars were selected through discussion with informants and agricultural extension workers. The study involved 59 men and one woman informant. Informants were selected based on the number of apple trees in their home garden in such away that those with the largest size were selected. Interviews were conducted with usually owner of home garden . The informants were briefed on the objectives and aims of the study and assured that their names would appear in the document as key participants in the study. This is to encourage information exchange by making the resource persons more open and cooperative.

4. 3. Selection of domestic apple tree cultivars

A reconnaissance survey was made in each woreda, to select apple tree cultivars. It has been known that cultivars were propagated in the fruit nursery site of the kalehiwot (*tolola*) protestant church. The cultivars were grown in the three woredas, Boreda (2300 m) (*zefine kebele*). Chencha (2700 m) (*tolola kebele*), Bonke (3200 m) (*chosha kebele*) jointly with livestock production. Cultivars of the same rootstocks MM106, that are widely distributed in the area and adapted for more than 10 years were selected. For each cultivar a total of ten individuals of similar age, height, rootstock and similar management at site level were selected. Information obtained from the growers concerning their ages, rootstocks, was used in the selection process. A total of seventy individuals were selected at each study area.

4.4. Data collection methods

4.4.1. Botanical data

The seven apple tree cultivars characteristic features such as habit; leaves, shape, margin apex, base, size, etc, flowers; color, number, fruit; colour, shape, lenticels; etc was observed, measured in the field using ruler, described and recorded following Bultitude (1983).

Useful tree crops, vegetables, root tubers, etc in the home gardens of the apple tree growers were observed and described in the field and based on the informants their local name were identified and recorded.

4.4. 2. Growth data

Several researchers reported that apple cultivars that obtain adequate chilling during Summer (*kiremt*) cold season (June-August) develop, full bloom, increase in their new shoot (new wood) growth and good leafing in Fall (*tsedey)* (Sept-Nov) (Rice *et al.*, 1990; Westwood, 1993; Muntubani, 1999). The shoot growth performance of the seven apple tree cultivars in the three-altitudinal zone was measured and observed in the field.

The new shoot growth (new wood) which will bear next year's crop above the pruned scar or above the dormant bud of ten of the apple trees cultivars was randomly measured using ruler and the average height was taken following Hessayon (2000).

The leaf area estimates from non-destructive measurement of leaf length (LL) and leaf width (LW) offer reliable, inexpensive alternative to leaf area meters (Gamiely *et al.*, 1991; Westwood, 1993). Thirty leaf lamina of each of the seven apple tree cultivars (210 for each cultivar) averages LL and LW representing the range of leaf size present were randomly measured using ruler following Nesmith (1992).

Total height of ten apple trees, which were not affected by shading or by injury to the leaves, was measured using meter and their average height was recorded (Westwood, 1993).

The stem diameter of the apple tree cultivars at stamp height i.e., 30 cm above the ground was measured using diameter tape following Westwood (1993).

Similarly the circumference of ten matured fruits of each of the seven apple tree cultivars was randomly measured by centimeter and its average was converted to volume in spheres following Westwood (1993).

Furthermore the total fruit set (matured) per apple tree of ten individual for each cultivar was counted and average yield was recorded following Elfving and Schechter (1993) and Westwood (1993).

4. 4. 3. Phenology of apple

The performance of the seven apple tree cultivars at a mature stage in three-altitudinal zone to the climatic changes i.e., leaf shade, blooming, bloom shade, fruit set and maturity was observed and recorded at the peak of each season following Westwood (1993). The grower was interviewed and their response was documented.

4. 5. Data analyses and interpretation

Two way ANNOVA, Chi-square test, Spearman's correlation coefficient and descriptivestatistics were used to analyze the data. The data collected through measurements and semi-structured interview were analyzed using Computer SPSS.

5. RESULTS

5. 1. Cultivar, altitude, climate relationship

The domestic apple tree cultivation in most of the surveyed area was practiced in the home gardens of the growers and in nursery areas of the Kalehiwot Protestant Church. The total number of cultivars with age of 10 years and below counted in the study areas were shown in Figure 10. According to the interviewees cultivars were distributed to all study areas from Chencha (*tololа*) nursery site.

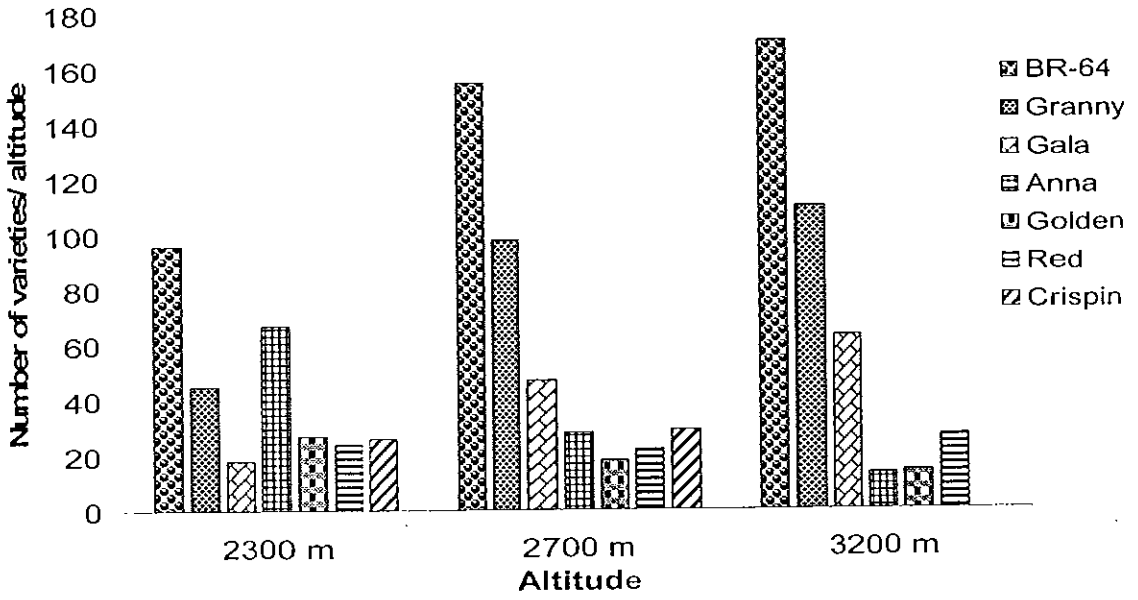


Fig. 10. Cultivar distribution along the altitudes.

As shown in Figure 10 total number of trees, BR-64, Granny Smith, and Gala increases with altitude, while the reverse is true for Anna and Golden Delicious. Red Delicious and Crispin was not affected.

5. 2. Home garden

The owners of apple tree cultivars grow the cultivars in their home gardens. Home garden is a sustainable production system where crops, vegetables, fruits and other plant species are integrated. In Bonke, Chencha and Boreda home garden is a distinctive system of agricultural

production carried out by the household and is one of the traditional means of food production, as also reported by Zemede Asfaw (1997).

The characteristic feature of home garden management is that each member of the family is involved in managing the home gardens. The prolonged cultivation and nursery activities related with apple plantation help members in developing knowledge on the cultivars.

5. 3. Impact of management practices, disease and pests

The growth and productivity of the apple tree cultivars is primarily based on the knowledge of the grower, to decide on geographical area (climate) that best suits with the cultivars and appropriate management practices such as mulching and manuring, pruning, thinning, type of rootstock and method of preventing or controlling apple diseases and pests. On the other hand very little or nothing is known about cultural practices, production and management techniques and nutritional requirements of deciduous fruit crops in Ethiopia (Godfrey and Berke Tsehai Tuku, 1986). In other cases during nursery propagation the grower has to know those suckers that are compatible with the scion. Incompatibility results in yield failure susceptibility to disease, etc.

5. 3.1. Mulching and manuring

The work of different researchers revealed that, insufficient nutrients reduce the fruit set of the cultivars, and affects harvest of the following year (Muntubani, 1999; Hessayon, 2000). According to the field survey about 70% of the growers in Chencha, 10% of Bonke and 65% of Boreda responded that, *tsedey* mulch of compost or rotted manure around the base of the trunks promotes a good crop later in the season and also encourages the production of new growth which will bear next years crop as described by Hessayon (2000). However 30% of Chencha, 90% of Bonke and 35% of Boreda did not know the appropriate time of mulching (Table 2).

Table 2. Response of farmers regarding duration of mulching and manuring.

Mulching and Manuring	Number of respondants			Total percentage
	Bonke	Chencha	Boreda	
Fall *(tsedey)*	2	14	13	48.30
Winter *(bega)*	3	0	0	3.30
Spring *(belg)*	0	0	0	0
Summer *(Kiremt)*	1	4	3	13.30
not using	15	2	4	41.70

5. 3. 2. Pruning

Pruning helps to grow regular crops with fruits of good size and quality, it is also used to obtain a measure of control over pests and diseases (Stebbins, 1980). The farmers response on knowledge of apple tree pruning is shown in Table 3.

Table 3. Response of apple growers regarding apple tree pruning.

Do you perform pruning?	Alternatives	Number of respondents			Total Percentages
		Bonke	Chencha	Boreda	
	Yes	6	16	13	58.30
	No	14	4	7	41.70
Excess pruning	Increase fruit set	11	7	9	45.00
	Decrease fruit set	2	10	8	33.30
	Not using	7	3	3	21.70
Season of pruning	*Tsedey* (Fall)	0	0	0	0
	Kiremt (Summer)	2	1	2	8.30
	Belg (Spring)	0	2	1	5.00
	Bega (Winter)	4	13	10	45.00

Most apple growers mentioned that *bega* (winter) pruning is done to remove dead, diseased and badly placed branches and also to maintain tree shape. However, 33.30% of the respondants mentioned that excessive pruning of BR-64 and Granny Smith apple trees results in high vegetative vigor. In agreement with this Miklos (1989) wrote that strong pruning in apple

increases growth and decreases flower bud formation. Furthermore Jules (1980) reported that increased pruning tends to decrease yield and red colour on fruit and delays fruit maturity, but increases fruit size.

To examine whether there is statistically significant variation in pruning performance by farmers among the study sites chi-square test was computed (Table 4).

Table 4. Chi-square test for pruning practices among the study woredas.

Response	Bonke		Chencha		Boreda		Chi-square
	Act	Exp	Act	Exp	Act	Exp	
Yes	6	11.7	16	11.7	13	11.7	cal = 10.80
No	14	8.3	4	8.3	7	8.3	tab = 5.99

Act = actual (observed), Exp = expected, cal = calculated, tab = tabulated

As noted in Table 4, the computed chi-square value (10.8) was more than the critical value (5.99) at 0.05 probability level, suggesting the presence of variation in the pruning practices among the surveyed apple growers in the three altitudes, indicates significant variation among cultivars in growth and yield performance due to the lack of proper pruning by farmers.

5. 3. 3. Thinning

As Miklos (1989) mentioned, one of the management practices that the grower has to do once the crop has set is thinning, in order to ensure that the apples are of good size and quality. The result of survey conducted on the knowledge of apple growers fruit thinning was shown in Table 5.

Table 5. Response of apple growers regarding apple fruit thinning.

Do you perform thinning?	Alternatives	Number of respondents			Total
		Bonke	Chencha	Boreda	
	Yes	1	4	3	13.00
	No	19	16	17	86.70

In this study, 95% of the respondants in Bonke, 80% in Chencha and 85% in Boreda responded that they do not perform fruit thinning. They mentioned that they don't know its use and method. On the other hand, in the field the apple tree can only support a limited number of large and well-shaped fruits. A heavy crop of apple trees such as BR-64 and Granny Smith need to be thinned. As observed in the field, the spurs of most of the cultivars contain more than 3 or 4 fruits, Crispin in Bonke contained more than 5 fruits of spur on some branches.

5. 3. 4. Disease and pests

According to the field survey, some of the major diseases and pests known in the study area based on informants, apple growers, observation and references are, Apple scab (*Venturia inaequalis*) (Rice *et al.*, 1990), Powdery Mildew (*Podosphaera leucotricha*) (Rice *et al.*, 1990) and Apple Aphids (Morgan and Richards, 2002). Apple scab is a serious air-borne fungus disease of apples, which can attack all parts of the tree (Halliwell *et al.*, 1982). As observed in the survey, brown spots or black scabs are visible on fruits and leaves, some fruits loss their shape and others are cracked. Most of the apple tree cultivars except Granny Smith in Boreda are attacked by apple scab (Table 6).

Powdery Mildew is a fungus which over-winters in dormant buds and is prevalent on hot dry conditions (Baker, 2000). During the field survey a white powdery coating which might be a fungus spore was observed emerging on shoot and young leaves. As mentioned by interviewees and observed in the field, this disease results in stunted shoot growth, diseased flowers which do not set and leaf fall as described by Hessayon (2000). Cutting infected shoots, flowers and mulching are the preventive measures reported by the apple growers of the area.

Table 6. Response of apple tree growers regarding apple diseases and pests.

AA = Apple Aphids; AS = Apple scab; PM =Powdery Mildew; R = Resistant; NR = Not Resistant

Cultivars	Types of disease and pests	R / NR	Number of respondents			Total percentage
			Bonke	Chencha	Boreda	
Granny Smith	AS	R	19	12	0	51.70
	AA, PM	NR	0	16	14	50.00
BR-64	AA, PM, AS	NR	19	15	17	85.00
Gala	AA, PM, AS	NR	0	17	10	45.00
Anna	AA, PM, AS	NR	0	19	16	58.30
Crispin	AA, PM, AS	NR	0	15	13	46.70
Red Delicious.	PM	R	19	3	10	53.30
	AA, AS	NR	0	13	15	46.70
Golden Delicious.	AA, PM AS	NR	0	15	18	55.00

The major apple pests in all the three study areas are apple aphids. As observed in the field survey colonies of aphid pests attack the apex causing leaf curling and distortion. Most apple growers are not familiar with these diseases and pests, so that they don't practice the traditional preventive methods such as smoking, spraying with milk, crushed onion as mentioned by informants in Chencha. Therefore, further studies in this area is recommended in identifying and controlling or prevention of these disease and pests.

Rootstocks

According to the respondents apples are not grown on their own roots for a number of reasons. Some will not root easily, some are prone to root troubles, and some make large unproductive trees as described by Cosets *et al.* (2001). To overcome these problems the domestic apple cultivars are propagated vegetatively on selected clonal rootstocks by means of cuttings in stool beds or layer beds. Each particular root stock affects the tree vigor and final tree size (Cyrus and James, 1992). *Malus domestica* scions maturity indices measured was significantly influenced by rootstock (Gerald and Dwight, 1992) in other case, for apple trees to be of desirable uniform size at maturity and yield the grower should know the type of rootstock that is compatible with the scion. At 2700 m incompatibility was observed in one of the growing cultivars in which the scion

overgrows the stocks. In line with this, when producing an apple tree the scion cultivars is budded on to the root stock up to about 15 - 30 cm above the soil line (Bruce, 1988). However cultivars with budded scion rooting was observed at 3200 m which may no longer remain dwarf but grow into full size tree in few seasons affecting performance of the tree (Warner,1991).

Based on the data in Table 7 chi-square test was calculated to examine if there was any significant variation in the knowledge of apple growers to the types of rootstocks among the study sites.

Table 7 . Chi-square test for knowledge of apple growers to the types of rootstocks used.

Response	Bonke		Chencha		Boreda		Chi-square value
	Act	Exp	Act	Exp	Act	Exp	
Yes	3	10	12	10	16	10	cal =18.20
No	17	9.70	8	9.70	4	9.70	tab = 5.99

The calculated value of x^2 (18.20) was found to exceed the tabulated value (5.99), at 0.05 probability level implying a significant variation in the knowledge of rootstock types used among the study areas. Therefore, this study provides evidence that there is a difference in knowledge of the apple growers on the type of rootstocks used. This reduces the yield performance of the cultivars and affect its expansion in the area. During the survey it was observed the root sprouts or suckers of matured apple cultivars were cut for developing rootstocks; however people did not know what type they were. Interviewees of Bonke respond that selection was based on the performance of matured apple trees. On the other hand, respondents of Chencha and Boreda mentioned that the rootstocks used in their study area are MM106, MM111, MM104, M27 and Local or CH (Table 8).

Table 8. Response of apple growers on the type of rootstock used.

Rootstocks types	Number of Respondents			Total percentage
	Bonke	Chencha	Boreda	
MM106	3	10	9	36.00
MM111	0	1	0	1.70
MM104	0	5	15	33.00
M27	0	2	1	5.00
Local (CH)	0	7	5	20.00

Farmers mentioned that root sprouting or suckering of all the root stocks is not a problem except M27 cultivars that develop very less root sprouts as described by Westwood (1993). Further the semi dwarfing MM106 rootstock does not tend to sucker so that it is more desirable than others. Thus, it has been known that most of the apple growers used MM106 (Table 8).

Theouflous (informant) describes local or CH as rootstock named in Chencha (*tolola* nursery site), the original name of the cultivars was unknown; due to this the apple growers in Chencha area for simple identification named it local rootstock or CH (Chencha). He further indicated that local rootstock (which probably is seedling rootstock) is deep rooted so that it withstands drought, performs better in rootstock propagation and is also disease resistance. However because it tends to grow root suckers apple growers don't choose it for production. The types of rootstock used and the response of the growers regarding the performance of different rootstocks are shown in Table 9.

Table 9. Response of apple growers regarding the effect of root stock used

GS = Granny Smith; RD = Red Delicious; GD = Golden Delicious; CR = Crispin; Cl = central leader; Sb = spreading branches; mt = meter

Rootstocks	Cultivars propagated	Height (mt_)	Age when fruit set (years)	Yield	Vigorousity	Precocity	Tolerance to climate, soil condition	Percentage
MM106	All seven	2.7-3.5	3-4	Very high	Moderately semi-dwarf	Grow as Cl	High	33.00
Local (CH)	All seven	2.5-3.5	3-4	High	Semi -dwarf	Grow as Sb	High	30.00
MM111	GS. RD, GD. CR	3-3.7	5-7	Low	Very high	Grow as large Sb	Moderate	6.70
MM104	GS. BR-64. Gala, Anna ,CR	2-2.8	3-4	Low	High	Grow as bushes	Very high	11.70
M27	BR-64, Anna	1-1.8	2-3	Very low	Very low	Grow as Cl	Very low	5.00

5. 5. The phenology of apple

According to Westwood (1993) adaptation of plants to changing seasons has occurred naturally over many thousands of years. He further stated that many domestic cultivars are adapted, but some are not ideally suited and their weakness must be recognized when attempting to grow them. Further phenology, the study of changes in plants attendant to the changing season, has helped to determine the degree of adaptation of the cultivars to a given climate. Moreover he reported that phenology of domestic apple cultivars is basic to determine the appropriate timing of many management operations including, propagation, pruning, thinning, mulching, manuring application and irrigation. As described by Westwood (1993), the apple phenological stages observed in sequence under the condition of the study area were leaf fall *kiremt,* bud break and flowering *tsedey*, fruit growth and maturation *bega* and *belg* respectively. In all the three-altitudinal zones rainfall is bimodal (Daniel Gamachu, 1977). From March to May the area obtains *belg* rain and the temperature becomes low (Fig.9). During this time most of the apple cultivars in the study areas were harvested (Appendix 5, 6, 7,). As described by Miklos (1989), harvested apple trees quickly

showed yellowing, senescent leaves and probably causes sharp build up of ethylene and absicic acid (ABA) in leaves and buds. In agreement with this we observed that, following harvest as *kiremt* approach most apple trees shade their leaves and enter their period of dormancy from June-August. Though mean temperature seem to be higher about 11^0C to 15^0C (Fig.9) at this time of the year chilling is more effective because of longer periods of overcast weather. The major period of vegetative growth, blooming and flower ending is in *tsedey*, fruit set and maturity in *bega* and *belg* which coincides with long dry seasons.

5. 5. 1. Apple leaf shading (dormancy)

As mentioned by Ryugo (1988) apple trees need to be exposed to chilling temperature during *kiremt* to satisfy their rest requirement and be able to resume growth the following *tsedey*. Frank and Dennis (1996) revealed that, leaves are receptors for short day or lowered temperature response that generates physiological changes to bring about defoliation. In agreement with this in this study those apple trees that obtain adequate chilling shade their leaves in *kiremt* (Fig. 11).

Fig. 11. BR-64 leaf shade (Photo: field survey, 2004)

The leaf fall performance of the seven apple tree cultivars to the seasonal change in Summer *(kirmt)* was displayed in Table 10. The result showed that the earliness and delay in leaf

defoliation is depend on the cold temperature condition of the altitude in which the cultivars were grown.

Table 10 . Leaf shade performance of the seven apple tree cultivars.

Cultivars	Leaf shade		
	Bonke	Chencha	Boreda
Granny Smith	June	June	July-Aug
BR-64	Mid-May	June	July-Aug
Red Delicious	Mid-June	July	June
Golden Delicious	Jul-Aug	July-Aug	June
Gala	Mid-Jun	June	July-Aug
Crispin	ND	June	June
Anna	NK	NK	June

*ND = No data *NK= not known

5. 5. 2. Flower development

The apple cultivar usually initiate flowers just after shoot growth ceases and when leaves are dropped (Frank and Dennis, 1996).The cultivars flower initiation and bud break depends on the adequacy of cold temperature in which the cultivar grows. Higher altitudes colder temperature fulfill the cultivars chilling requirements so as cell division will be maximal and hence more flower bud formations as described by Westwood (1993). In Anna both at 2700 m and 3200 m full defoliation of leaves was not observed. Some of the branches of this cultivar bear few fruits of different stages. Farmers reported that unlike in others Anna with bare branches were not observed. Thus the presence of fruit and leaves in *kiremt* indicates that the cultivar was un chilled and vegetative growth was continues showing that the cultivar may not be suited to climatic condition of the area. This agrees with study of Rice *et al.* (1990) who reported that, the presence of apple trees with vegetative leaves or flowers during the cold season indicates physiological disorder in the cultivars.

On the other hand, Chandler (1957) cited by Westwood (1993) documented that intermittent chilling (warm periods) in *kiremt* increase the chilling requirement because warm periods reverse

the chilling responses. Thus *kiremt* fogs of Bonke and Chencha may be beneficial in such away that they prevent warming of the buds during the chilling period.

It was found that floral initiation and development of flower buds occur during *kiremt* of one season and the flowering process occurring in early *tsedey* the next season in cultivars that grow in suitable area with adequate chilling (Miklos, 1989). Similar findings were observed in this survey in such a way that in *tsedey* when temperature raises growth and development of the flowers resume. For example, BR-64 cultivars at 3200 m and 2700 m and Anna at 2300 m blossom earlier in September than the other apple tree cultivars (Table 11). Therefore, the development of blooming earlier after cold *kiremt* season may indicate that, the apple tree cultivars receive sufficient chilling, while delayed blooming seems to be inadequacy of low chilling temperature which limits cell divisions and *tsedey* blossom and leafing development as described by Ryugo (1988).

Table 11. Blooming and leafing (months) performance of apple tree cultivars.

Cultivars	Blooming and leafing (months)		
	Bonke	Chencha	Boreda
Granny Smith	End Sep	Oct	Nov
BR-64	Sep	Sep	Nov
Red Delicious.	Oct	Oct	Oct
Golden Delicious	Nov	Nov	Oct
Gala	End Sep	Oct	Nov
Crispin	ND	Oct	Oct
Anna	NK	NK	Sep

*ND = No data *NK= not known

5. 5. 3. Fruit set and maturity

It has been known that apple cultivars flowering establish the potential for crop load. Fruit set and development determine how well that potential is realized, with pollination complete. Fruit set is accompanied by wilting of the petals and in many cases the shading of the anthers and calyx by natural ethylene hormone (Duane,1996). During cold and less frost climatic condition apple growers indicated that blooming and fruit set as well as quality of the fruit is high (Fig.12) whereas, at less cold *kiremt* and high cold frost *tsedey* season fruit set is very low, this may be due to flower and fruiting injury or may be due to the restriction of bees (common pollinizar) movement due to cold weather condition. It has been known from field observation and farmers' response that, most of the apple tree cultivars flower ending varies along the altitudinal zones (Table 12).

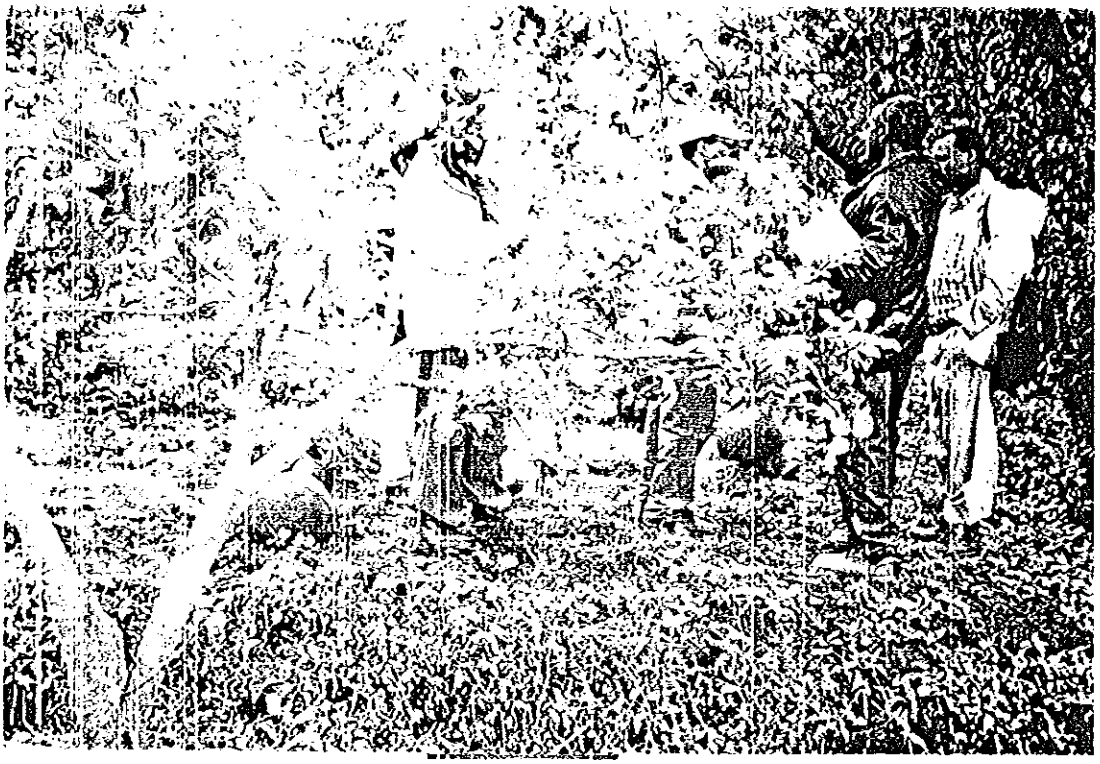


Fig. 12. Ripened BR-64 (Photo: field survey).

Table 12. Duration of blooming of apple tree cultivars.

Cultivars	Blooming shade (weeks)		
	Bonke	Chencha	Boreda
Granny Smith	2	2	3-4
BR-64	2	2	3-4
Red Delicious.	3-4	2	2
Golden Delicious	3-4	2	2
Gala	2	2	3-4
Crispin	ND	2	2
Anna	NK	NK	2

*ND = No data *NK= not known.

In this study blooming month of the cultivars and the month of first round harvest was recorded to estimate the bloom to harvest days of each cultivars (Table 13). Based on this apple cultivars that resume growth in *tsedey* are categorized into three in such away that those that bloom in September are considered to be early bloom (E), October mid season bloom (M) and November late bloom (L) as described by Westwood (1993).

Table 13. Apple cultivars of the study area and some of their hortieultural characteristics.

Cultivars	Bloom to Harvest (days)	Bloom time (a)			Fruit size (b)	Fruit colour
		Bonke	Chencha	Boreda		
Granny Smith	180-210	M	M	L	M-L	Green
BR-64	180	E	E	L	L	Reddish Yellow
Red Delicious	180-210	M	M	M	S	Red
Golden Delicious	180	L	L	M	M-L	Yellow golden
Gala	210	E	M	L	S-M	Red
Crispin	150-180	_	M	M	L	Yellow-green
Anna	120-150	_	_	E	M	Blushed

(a), E = early; M = midseason; L = late; (b), S = small; M = medium; L = large

5. 6. Apple shoot growth

The shoot growth performance of the apple tree cultivars that has similar age, rootstocks (MM106), same site in each altitude and same management at site level was studied. The study conducted by Curt (1991) indicated that the type of rootstock determines the size and general performance of the cultivar. This is in agreement with field survey study in such away that, in all study areas, cultivars with good performance in their growth, blooming, fruiting in general their types of rootstocks determined vigorousity.

5. 6. 1. New shoot growth

According to Stucky (1997) and Hessyon (2000), the size of new shoot growth (this year's growth) which will bear next years crop after the cultivars resume growth is used to estimate the adequacy of cold temperature of the area. Following their method ten of each cultivars new shoot growth which is available during *tsedey* season in the three-altitudinal zones was measured. The water shoot, which are rapid growing soft shoot, were excluded, because these shoots are unbranched and unfruitful so that they are removed by cutting as documented by David (1983). Thus, the new wood that develop from the tip of dormant bud that can easily be identified by its greenish colour and small flat growth bud, which produces a shoot was measured. Based on the data, the two-way ANOVA calculated was shown in Table 14.

Table 14. Two-way ANOVA for new shoot growth

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	37.26704	2	18.63352	2.115844	0.04159806	1.885293835
Columns	366.654	6	61.10901	2.996120378	0.03806119	0.379913
Error	1930.201	12	160.8501			
Total	2334.123	20				

As displayed in Table 14, the $F_{(row)}$ altitude, value 2.115 exceeds $F_{(critical)}$ 1.885 and $F_{(column)}$ cultivars, value 2.996 exceeds $F_{(critical)}$ 0.379 at $P = 0.05$ indicating the differences in the two treatments means is significant. In addition to this the data of new shoot growth (Fig.13) with 95% confidence interval, n = 10, and the new shoot growth of the seven apple tree cultivars along the altitudes was displayed in Figure 14 to 20.

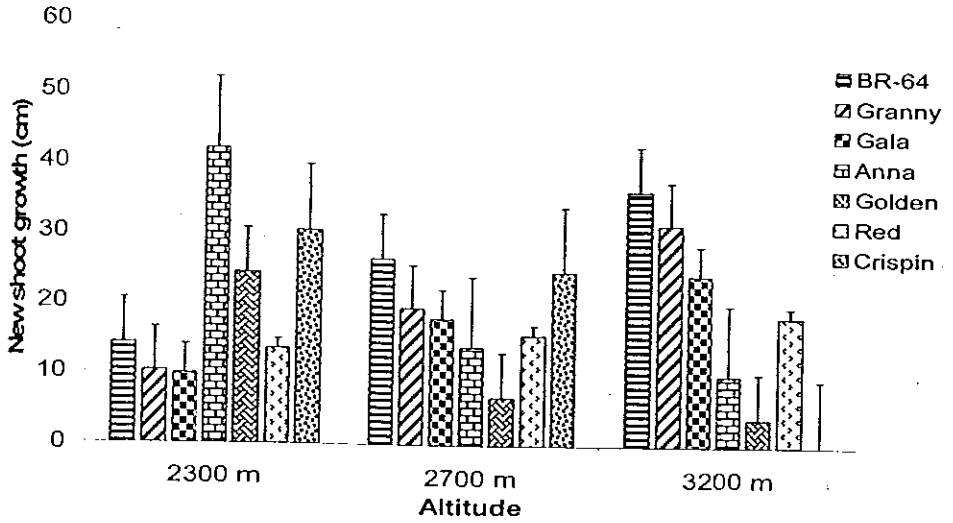


Fig. 13. New shoot growth (mean ± SE) of the seven apple tree cultivars.

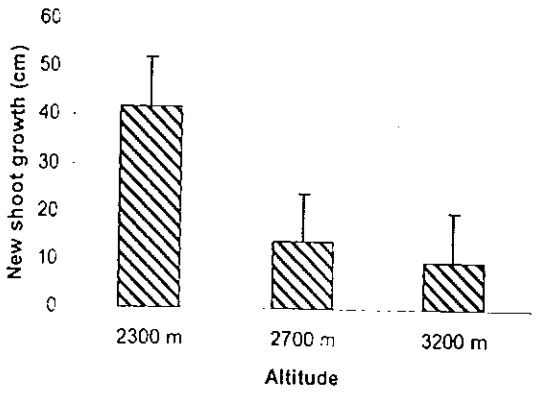


Fig. 14. Anna new shoot growth (mean ± SE).

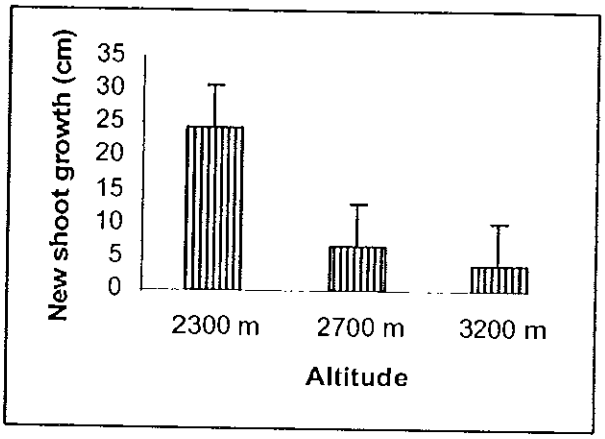
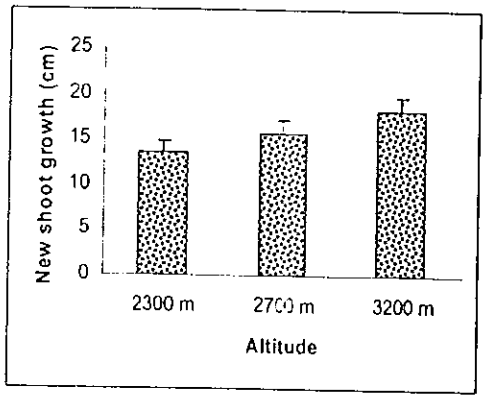


Fig. 15. Golden Del. new shoot growth (mean ± SE).



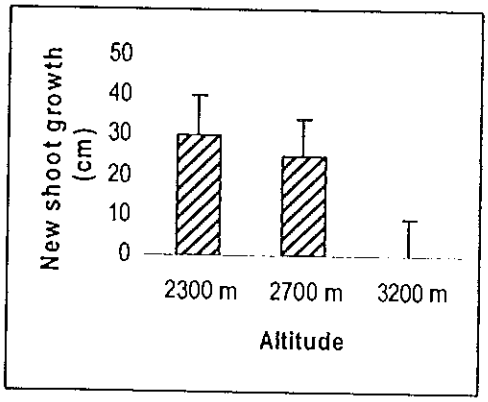


Fig. 16 Fig. 16. Red Delicious new shoot growth (mean ± SE). Fig. 17. Crispin new shoot growth (mean ± SE

Table 15. Two-way ANOVA for leaf area

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	28.79901	1	28.79901	0.4592841	0.528045	6.607891
Columns	1431.368	5	286.2736	5.0503291	0.030545	4.5654665
Error	313.5206	5	62.70413			
Total	1773.688	11				

The calculated two-way ANOVA for leaf area showed that the $F_{(column)}$ value 5.05 is greater than $F_{critical}$ 4.565 at P = 0.05 indicating significance differences in the leaf area of the cultivars in the three altitudes. But for the (altitude) there is no significant differenees. Similarly the difference in the leaf area of the cultivars along the altitude with 95% confidence interval, n = 30, is shown in Figure 21.

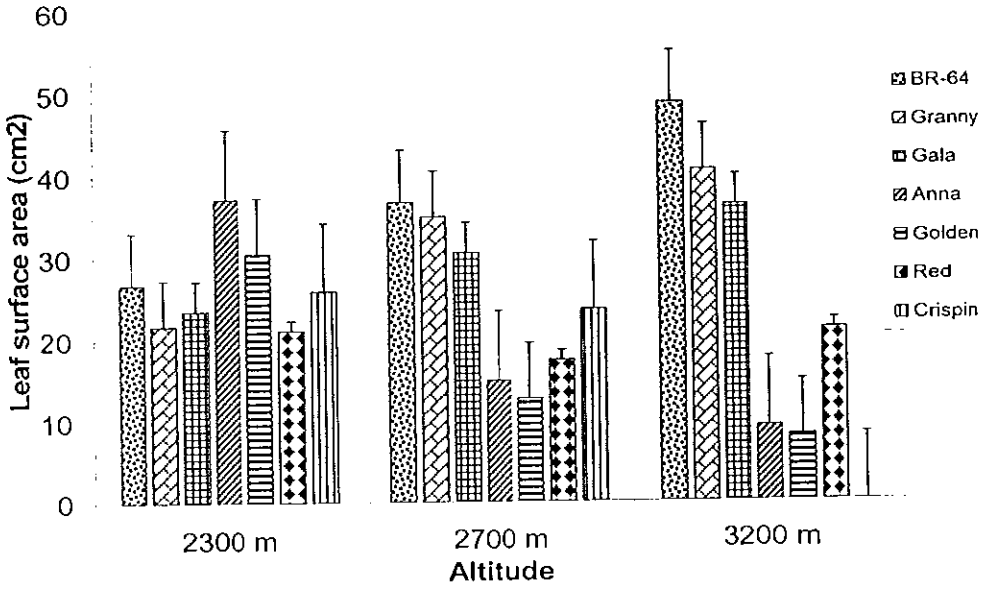


Fig. 21. Estimated leaf area (LA) (mean ± SE) of the seven apple tree cultivars.

In this study comparison was made between the leaf area and fruit size performance of the seven apple tree cultivars in the three altitudes. The result showed that there is a highly significant and direct relationship between blooming denseness and apple leaf area as described by Duane (1996).

Table 16. Influence of leaf area (cm^2) on fruit size (cm^3).

Cultivars	Altitudes					
	2300 m		2700 m		3200 m	
	Total leaf area cm^2	Fruit volume cm^3	Total leaf area cm^2	Fruit volume cm^3	Total leaf area cm^2	Fruit volume cm^3
BR-64	26.79	219.40	36.76	264.10	48.72	297.10
Granny Smith	21.70	115.90	34.95	219.40	40.60	273.70
Gala	23.50	108.80	30.50	156.50	36.20	205.70
Anna	37.10	197.70	14.90	83.00	10.30	62.90
Golden Delicious	30.47	154.30	12.70	135.00	8.16	107.00
Red Delicious	21.27	145.60	17.40	121.50	21.04	135.00
Crispin	25.90	192.50	23.60	167.90	ND	ND

*ND = no data

The comparison made between the leaf area and fruit size performance (Table 16) shows that the LA of cultivars is significantly related with fruit size. Hence, cultivars that are adapted to the climatic condition of the area such as BR-64, Granny Smith and Gala in Bonke develop high leaf area so as their fruit size is larger. The reverse is true for Anna and Golden Delicious (Table 16).

Based on the data obtained from the seven apple tree cultivars, LA and new shoot growth performance an attempt was made to compute the Spearman's rank correlation coefficient (r') between the two growths in all the three-altitudinal zones.

Table 17. Rank correlation coefficient of new shoot growth and LA (Boreda).

Cultivars	BR-64	Granny Smith	Gala	Anna	Golden Delicious	Red Delicious	Crispin
Ranks in new shoot growth	4	6	7	1	3	5	2
Ranks in LA	4	6	5	3	2	7	1

The calculated $r' = 0.91$ suggesting that, there is significantly strong positive correlation between the rankings. The new shoot growth rankings is related with the site of the area in which the cultivar grows. For example Anna, Crispin and Golden Delicious perform better at 2300 m so as they ranked high compared to BR-64, Granny Smith and Gala (Table 17).

Table 18. Rank correlation coefficient of new shoot growth and LA (Chencha).

Cultivars	BR-64	Granny Smith	Gala	Anna	Golden Delicious	Red Delicious	Crispin
Ranks in new shoot growth	1	3	4	6	7	5	2
Ranks in LA	1	3	4	6	7	5	2

In Chencha study area as shown in Table 18, the calculated $r'=1$ shows the correlation between ranks is perfect positive. This means there was proportional ranking of the performance between the new shoot growth and LA. As observed in the field BR-64, Granny Smith and Gala cultivars growth performance increases along the higher altitudes. Hence, their ranking is also high as altitude increases, while the reverse is true for Anna and Golden Delicious.

Table 19. Rank correlation coefficient of new shoot growth and LA (Bonke).

Cultivars	BR-64	Granny Smith	Gala	Anna	Golden Delicious	Red Delicious	Crispin
Ranks in new shoot growth	1	2	3	5	6	4	ND
Ranks in LA	1	2	3	5	6	4	ND

In Bonke study area as displayed in Table 19 the calculated r'=1 shows the correlation between ranks is perfect positive. This means there was proportional ranking of the performance between the growth of new shoot and LA. Thus, at 3200 m BR-64, Granny Smith and Gala ranking is high while Anna and Golden Delicious is low, indicating that the former cultivars seem to be better adapted while the latter are not. Red Delicious in all sites ranks moderate, however its LA ranks least in Boreda.

5. 6. 3. Height and stem diameter

The height (H) and stem diameter (DM) of the apple tree cultivars was measured following Westwood (1993) who suggested that their results were correlated with the yield performance of the cultivars. Height and stem diameter of the apple tree cultivars measured, 95% confidence interval, n = 10 is shown in (Fig. 22) and (Fig. 23) respectively.

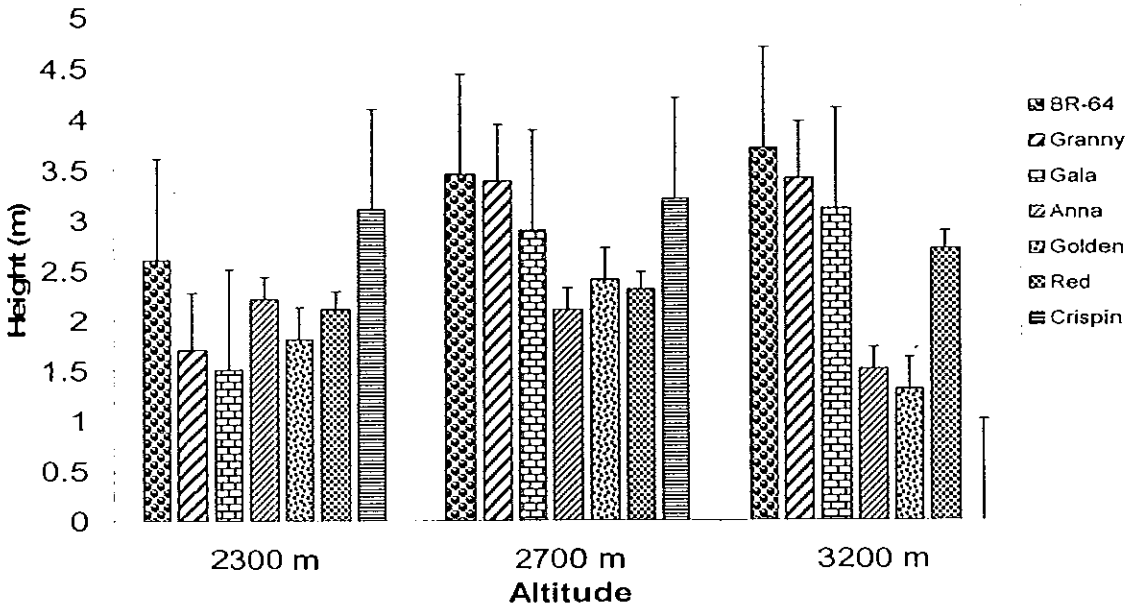


Fig. 22. Height (mean ± SE) of the seven apple tree cultivars.

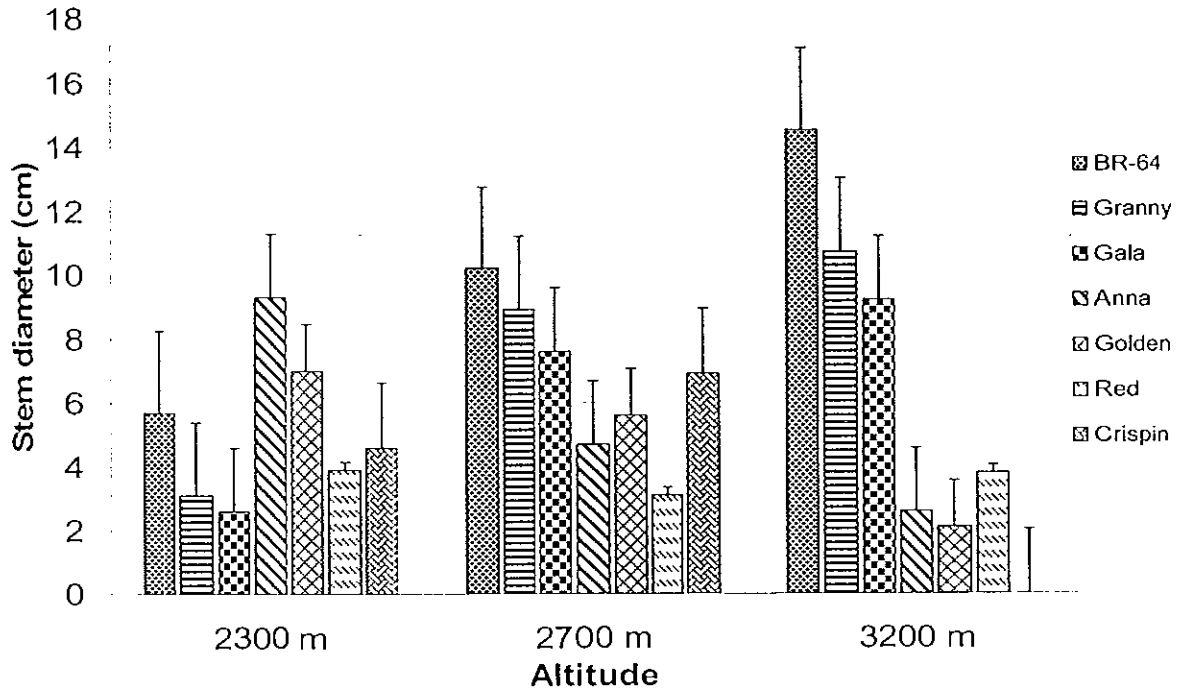


Fig. 23. Stem diameter (mean ± SE) of the seven apple tree cultivars

As shown in Figure 22 and 23 at 2300 m, Anna H (2.23 m.), DM (9.3 cm) and Golden Delicious H (1.9 m), DM (7.1 cm) are cultivars with highest DM performance whereas, BR-64 H (2.63 m), DM (5.7cm); Crispin H (3.05 m), DM (4.6 cm) and Red Delicious (2.18m), DM (3.93cm) had

moderate stem diameter growth. Granny Smith H (1.79m), DM (3.05 cm) and Gala H (1.59m). DM (2.6cm) are considered to be those cultivars with lowest H and DM performance.

As observed in the field and farmers response the pruning management practice of the grower was not uniform and regular, due to this there was the difference in H performance among the cultivars. Thus, the height of the cultivars along the altitude may not contribute for total height comparison. However, the total height available and visual observation of cultivars precocity was used. On the other hand BR-64, Granny and Gala were having low stem diameter compared to their performance in other study sites. This may be due to less moisture, inadequate cold temperature or soil conditions of the area (2300 m). The reverse was true for Anna. On the other hand similar to its other performances such as new shoot and LA, Red Delicious stem diameter is moderate, indicating cultivars wider adaptability in different areas (Fig. 23) as described by Fear and Domoto (1998).

In Chencha BR-64 H (3.46 m), DM (8.2 cm); Crispin H (3.39 m), DM (8.9 cm) and Granny Smith H (3.2 m), DM (5.8 cm) are those cultivars with highest H. Similar to Boreda due to farmer's irregular pruning, H may not be used for growth comparison. However stem diameter of BR-64. Anna and Crispin was similar as that of Granny, Gala and Golden Delicious. In general as shown in Figure 22 and 23, the H and DM performance of all cultivars at 2700 m seem more or less similar which might be due to rootstock performance, climatic or soil conditions of the area.

In Bonke study area, BR-64, Granny Smith and Gala have more H than Anna, Golden and Red Delicious (Fig.22, 23). However, stem diameter of BR-64, Granny Smith and Gala is highest in ranking order than all the study sites. This might be due to high moisture, sufficient cold temperature, soil conditions or rootstock performance. On the other hand Anna and Golden has least DM compared to other study site (2300 m), indicating that their performance is not matched with the altitude (3200 m). The stem diameter of Red Delicious is more or less similar as that of other parameters such as new shoot and LA indicating its moderate growth performance in all the study sites.

5. 6. 4. Estimation of apple fruit yield and size

5. 6. 4. 1. Estimation of apple fruit yield kg/ tree

Fruit count of ten of the seven apple tree cultivars were done and the average number of total count was taken. Five of visually observed larger fruit, six of moderate and seven of smaller are considered as one kilogram, to estimate the yield kg / tree performance of the cultivars in the three altitudinal zones following Westwood (1993) and Elfving and Schechter (1993) method.

Table 20. Two-way ANOVA for yield kg/ tree

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	127.6864	2	63.84321905	3.885294	0.033696	1.069653
Columns	1323.996	6	220.6660413	3.697122	0.025713	2.99612
Error	716.2307	12	59.68589127			
Total	2167.913	20				

The result showed that $F_{(rows)}$(altitude) 3.885 exceeds $F_{critical}$ 1.069 and $F_{(column)}$ (cultivars) 3.69 exceeds $F_{critical}$ 2.99 at P = 0.05 indicating that the null hypothesis which states there is similar yield in both rows and columns must be rejected. In other words, the yield difference among the means are significant and so are the difference among the means obtained for the altitudes.

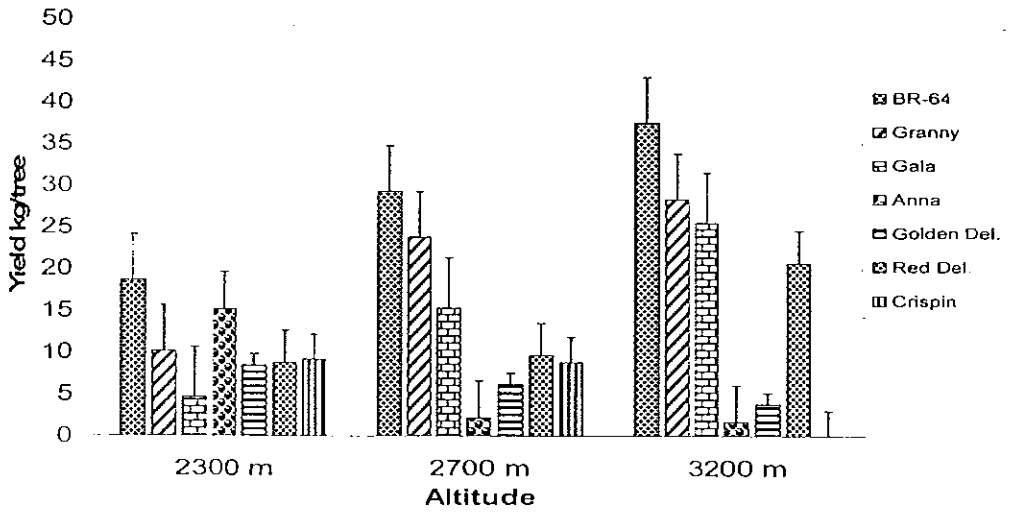
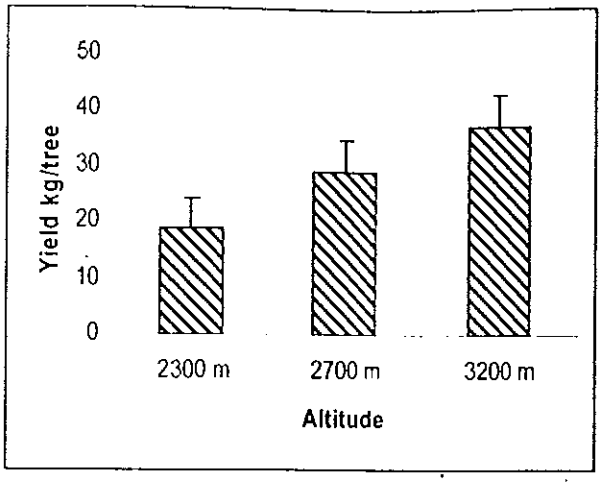


Fig. 24. Yield performance (mean ± SE) of the apple tree cultivars

Figure 24 with 95% confidence interval, n = 10 displays, the yield performance of BR-64, Granny Smith, and Gala increases as altitude increases among which BR-64 is a cultivar with vigorous high yielding performance.



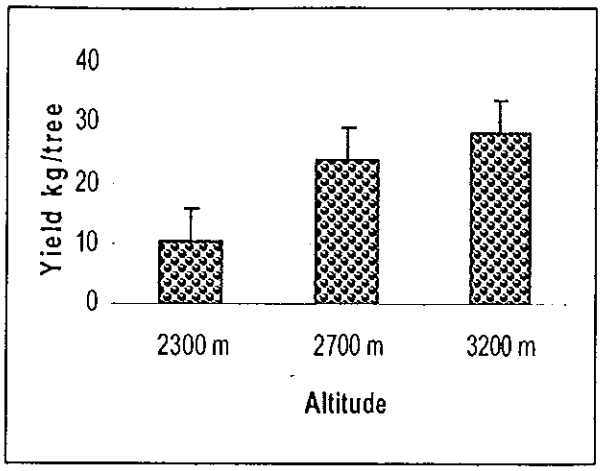
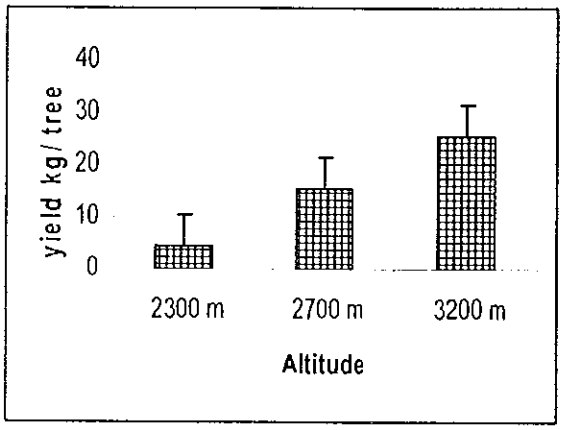


Fig. 25. BR-64 yield performance (mean ± SE). Fig.26. Granny Smith yield performance (mean ±SE).



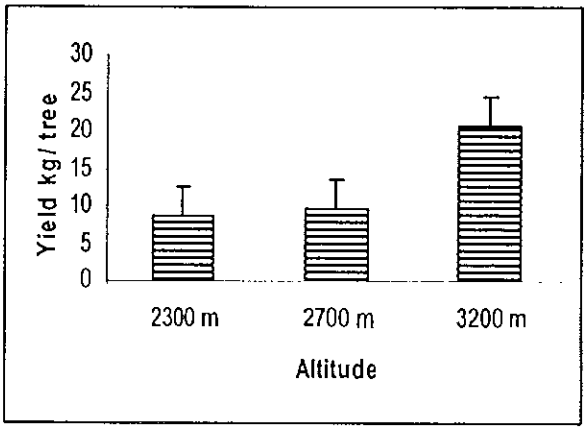
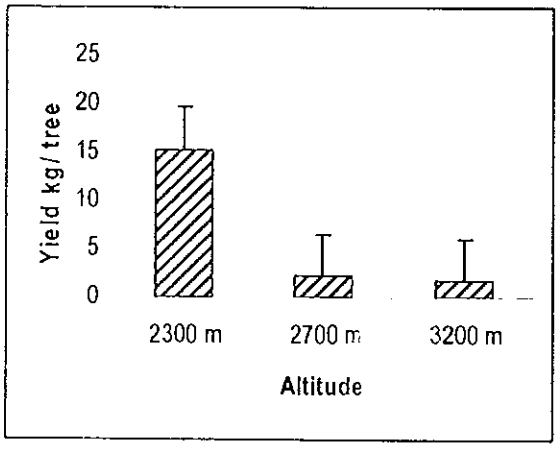


Fig. 27. Gala yield performance (mean ± SE). Fig. 28. Red del. yield performance (mean ±SE).



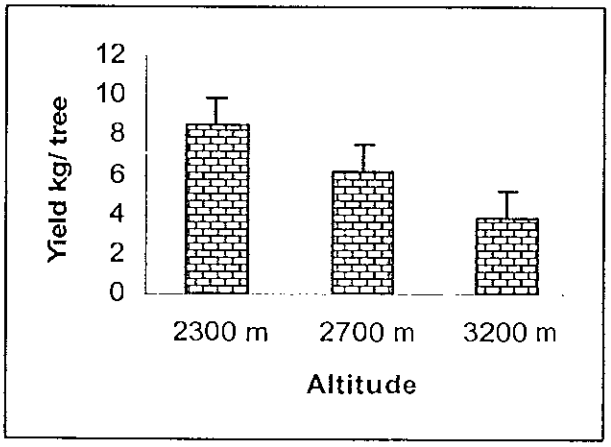


Fig. 29. Anna yield performance (mean ± SE). Fig. 30. Golden yield performance (mean ± SE).

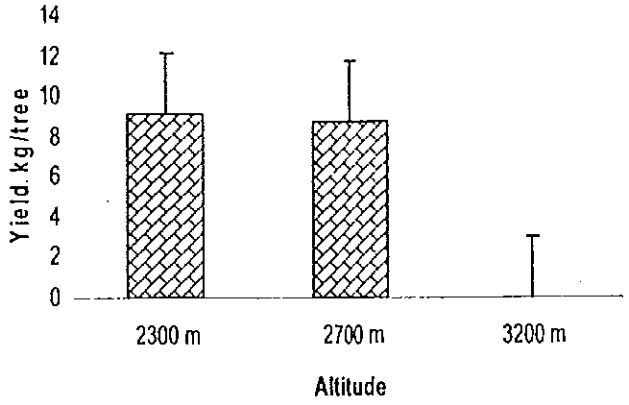


Fig. 31. Crispin yield performauce (mean ± SE) along altitude.

Based on the yield kg/ tree data shown in Figure 24, an attempt was made to calculate the chi-square test so as to examine the yield performance of the cultivars along the altitudinal zones. Based on apple growers, cultivars with yield performance of 20 kg/ tree and above are considered to be high. those within the range of 10 to 20 kg/ tree are moderate whereas, those below 10 kg/ tree are considered low yielding. Based on this, chi-square test was calculated to examine if there was any significant variation in the yield performance of apple tree cultivars along the three-altitudinal zones (Table 21).

Table 21. Chi-square test for yield performance of apple tree cultivars.

Yield	Bonke		Chencha		Boreda		Chi-squar value
	Act	Exp	Act		Act	Exp	
High	4	1.8	2	2.1	0	2.1	cal = 8.30
Moderate	0	1.2	1	1.4	3	1.4	tab = 9.488
Low	2	3	4	3.5	4	3.5	

Thus the calculated result (8.3) was found less than the critical value (9.48) at 0.05 probability levels, leading the survey to provide evidence that the yield kg/ tree performances of the apple tree cultivars are determined on the altitudinal condition in which the cultivar grows. Therefore, knowledge of apple growers on cultivar performances at different sites is important.

5. 6. 4. 2. Estimation of apple fruit size.

As mentioned in Westwood (1993) the actual size obtainable in specific apple fruit will depend up on climate, soil type, and depth, irrigation, manuring, pruning and fruit set. He further noted that to obtain accurate apple fruit growth, the best method is to measure circumference or diameter and converting to volume (cm^3). Furthermore Elfving and Schechter (1993) indicated that cultivars rootstock and tree vigour are factors influencing the performance of apple fruit growth. In agreement with this findings an attempt was made to observe the fruit growth performance of the seven apple tree cultivars at three-altitudinal zones. Ten fruit circumference of each of the seven apple tree cultivars was randomly measured by centimeter and the average volume of fruit as sphere (cm^3) was calculated using $V= 4/3\pi r^3$, following Westwood(1993). The data obtained was analyzed using two way ANNOVA (Table 22).

Table 22. Two-way ANOVA for apple fruit size

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	351.6585	2	175.8292	0.038946	0.961924	3.8852938
Columns	50977.11	6	8496.184	2.9961204	0.045414	1.881897
Error	54176.3	12	4514.691			
Total	105505.1	20				

The calculated two way ANNOVA showed that $F_{(column)}$ value 2.99 is greater than $F_{critical}$ 1.88 at $P = 0.05$, indicating significant differences among the means obtained for fruit size of different cultivars in three altitudes. In other words, the cultivars (columns) fruit size depends on the altitudes (rows) in which the grow. However, for the row (altitude) there is no significant differences. Further the fruit size of the cultivars performance at three altitudes at 95% confidence interval. $n = 10$ was displayed in Figure 32.

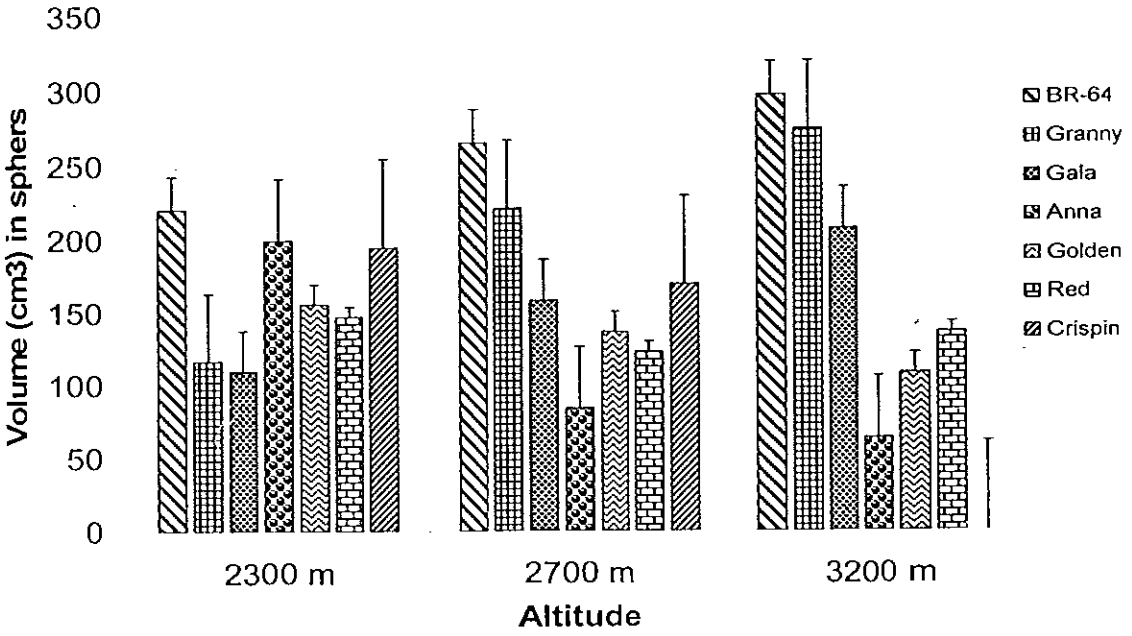


Fig. 32. Estimation of apple fruit size (mean ± SE).

As shown in Figure 32, the fruit growth performance of BR-64, Granny Smith and Gala increases as altitude increase (Fig. 33, 34, 35), in contrast to Anna and Golden Delicious in which the fruit growth decreases, may be due to cold injury as described by Frank and Dennis (1996) (Fig.36, 37). This shows that the increase in fruit size of the former in higher altitudes of 2700 m and 3200 m seem to be related to adequate chilling temperature of the area. Similar findings was reported by Westwood (1993) who documented that if apple tree is fully chilled, cell division will be maximal so as fruit size will be larger.

On the other hand the fruit growth performance of Crispin and Red Delicious (Fig.39, 38) is moderate indicating no altitude preferences or better adaptability to wider altitudinal zones. As observed in the field, study sites with sufficient moisture such as Bonke, and management practices such as mulching and manuring of *tolola* nursery site (Chencha), results in cultivars larger fruit size as described by (Berman and Dejong, 1996) whereas, the reverse is true for smaller fruit size in Boreda. Hence, irrigation as well as mulching and manuring is essential for sizing fruits in arid areas (Frank and Dennis, 1996).

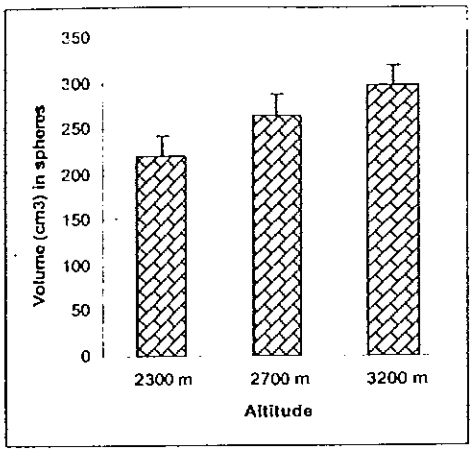


Fig. 33. BR-64 fruit size (mean ± SE).

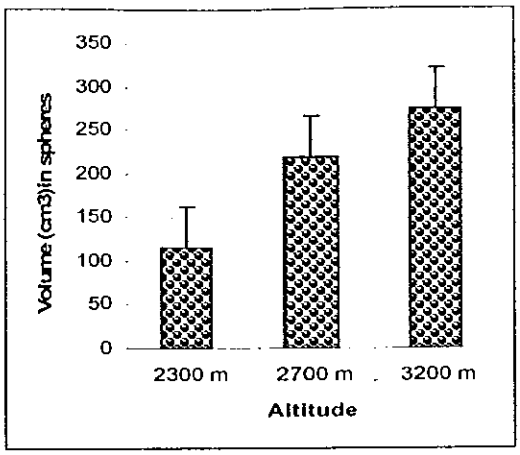


Fig. 34. Granny Smith fruit size (mean ± SE).

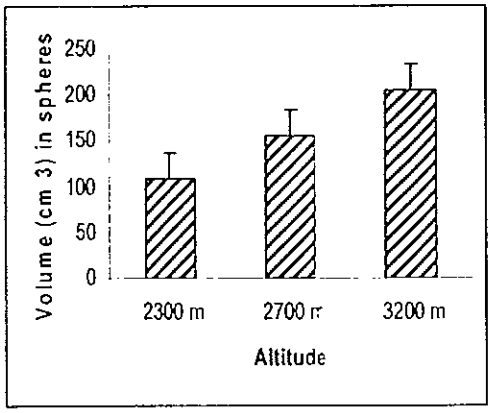


Fig. 35. Gala fruit size (mean ± SE).

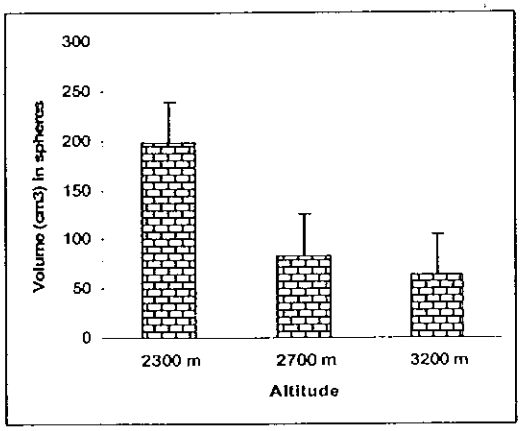


Fig. 36. Anna fruit size (mean ± SE).

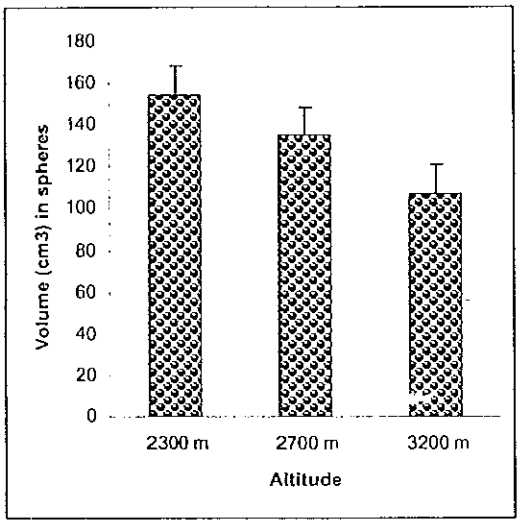


Fig. 37. Golden del. fruit size (mean ± SE).

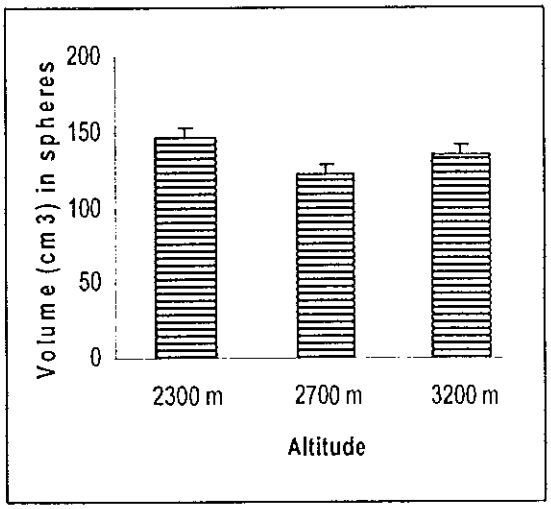


Fig. 38. Red del. fruit size (mean ± SE).

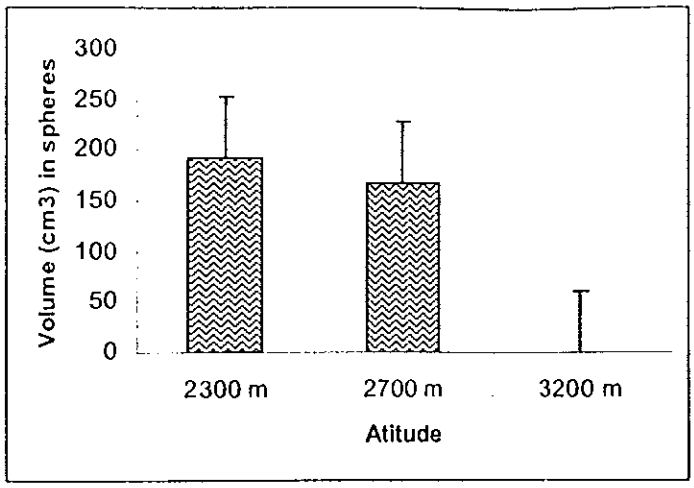


Fig. 39. Crispin fruit size (mean ± SE).

Based on the data obtained from the seven-apple tree cultivars fruit size and fruit load performance an attempt was made to compute the Spearman's rank correlation coefficient (r') between the two performances in all the three-altitudinal zones. The result of ranking of fruit size and fruit load at 2300 m was shown in Table 23.

Table 23. Rank correlation coefficient between fruit load and fruit size (2300 m).

Cultivars	Granny Smith	Gala	Golden Delicious	Red Delicious	BR-64	Anna	Crispin
Ranks in fruit size (cm^3)	6	7	4	5	1	2	3
Ranks in total fruit load	3	6	7	4	1	2	5

The calculated r'= 0.57 suggests that the correlation between the rankings is some how moderate, indicating the fruit volume and fruit load of the cultivars agree moderately. Granny Smith which ranked 6^{th} in fruit size ranks 3^{rd} in fruit load, indicating that, the fruit quality of this cultivar seem to be low at 2300 m, whereas the reverse was true for Crispin. Gala with heavy fruit load and size at 2700 m and 3200 m was the least ranked in Boreda which might indicate that the area is not favorable for this cultivar. On the other hand Anna with least rank in Chencha and Bonke ranked 2^{nd} in Boreda, showing that this geographical area is more favorable for this apple tree cultivar.

Table 24. Rank correlation coefficient between fruit load and fruit size (2700 m).

Cultivars	Granny Smith	Gala	Golden Delicious	Red Delicious	BR-64	Anna	Crispin
Ranks in fruit size (cm^3)	2	4	5	6	1	7	3
Ranks in total fruit load	2	3	6	4	1	7	5

In Chencha as shown in Table 24 the calculated r'= 0.82 indicate that, the two sets of ranking show significantly high correspondence. The ranking was different from Boreda except for BR-64. It seems that the performance of the cultivars changes at 2700 m. For example, Gala which was ranked least at 2300 m become 3rd at 2700 m, whereas, Anna ranked 2nd at 2300 m but ranked 7th at 2700 m. This shows that performance of apple tree cultivars depend on the suitability of the site that the cultivar grows.

Table 25. Rank correlation coefficient between fruit load and fruit size (3200 m).

Cultivars	Granny Smith	Gala	Golden Delicious	Red Delicious	BR-64	Anna	Crispin
Ranks in fruit size (cm^3)	2	3	5	4	1	6	ND
Ranks in total fruit load	2	3	5	4	1	6	ND

ND = no data

As Table 25 displays, in Bonke the calculated r'=1 shows the correlation between the rank is perfect positive. Thus BR-64 which is ranked 1st in fruit load ranked 1st also in fruit size. Thus, this study shows that as altitude of study site increases the significance of correlation between the two rankings is high and become perfectly positive at 3200 m. Therefore, BR-64, Granny Smith and Gala growth and yield performance are properly matched with growing sites of Chencha and Bonke, similar to Anna, Crispin and Golden Delicious of Boreda, whereas, Red Delicious moderately perform in all study sites.

6. DISCUSSIONS

6. 1. Cultivar, altitude, climate relationship

The presence of all the seven apple tree cultivars in all study sites as shown in Figure 10 indicates that there is lack of knowledge on cultivars used, so as Anna and Golden Delicious with low growth and yield were grown at 2700 m and 3200 m, similar to Gala at 2300 m. However the increase in the number of apple cultivars with better yield such as BR-64, Granny Smith and Gala at higher altitudes and the decrease in those with lower yield such as Anna and Golden Delicious in the home gardens of apple growers (Fig.10) shows, farmer's experience of cultivar selection was improved. On the other hand in lower altitude (Boreda), the number of Anna, Golden Delicious and BR-64 is increasing while that of Gala was decreasing. This indicates that farmers yield experiences in selection of cultivars seem to be improved.

6. 2. Impact of management practices

6. 2.1. Mulching and manuring

It has been reported that mulching keeps down weeds and conserves moisture status of soil by reducing evaporation and improving infiltration rate and enhances blooming and leafing of apple tree cultivars (Skroch and Shribbs, 1986). Similarly study of Wesley *et al.* (1991) and Hessayon (2000) revealed that mulched cultivars bloomed significantly more than non-mulched apple trees. This is in agreement with the field observation, where in Chencha (*tolola* nursery site) area Granny Smith. Crispin, Gala, BR-64 mulching produced more bloom than the same cultivars not mulched. As displayed in Table 2 even though most apple growers of Bonke did not perform proper mulching and manuring the growth and yield performance of BR-64, Granny Smith, Gala and Red Delicious were known to be high compared to other study sites. In Boreda due to the relatively lower altitude the area is warm. Although apples need to be mulched and manured, those cultivars with higher growth and yield performance such as Anna, BR-64 and Golden Delicious are not properly mulched.

6. 2.1. Pruning

According to the result of this study, 58.30% of the respondents mentioned that, pruning increases apple fruit yield and quality (Table 3). However, 41.70% responded, the yield of

cultivars after pruning of all branches or few was low so as they fear not to perform similar activity on others. However, researchers reported that apple tree pruning is a commonly used method to form the desired tree shape, size, fill the space available and obtain balanced growth (Halliwell *et al.*, 1982). In the field it was observed that in most of apple growers garden, there are un pruned cultivars with excessive growth, but with less blossom than the same cultivars that are pruned. This improper management may cause inadequate light penetration within the tree shade and might limit yield by reducing fruit number, size, and quality.

6. 2. 2. Thinning

Thinning fruits to one or two per spur by hand as soon as possible following blooming improved the yield and quality of apple fruits (Morgan and Richards, 2002). In Chencha where the farmers perform fruit thinning it was observed that the size and quality of thinned BR-64 is very attractive than others which are not thinned. This agrees with study of Hessayon (2000) who reported that thinning reduces competition among fruits, thereby increasing fruit size. However the management practices of thinning in all the study area was negligible (Table 5). Therefore we suggest that cultural factors including pruning, thinning, mulching and manuring which have an impact on fruit size and yield may merit more consideration in producing quality processing apples. Thus, the growers must adjust apple management practices to satisfy marketable quality size in order to obtain high profit.

6. 3. Rootstocks

As shown in Table 9 most apple growers used MM106 and Local (CH) rootstock. According to the respondants cultivars grafted on MM106 rootstock are semi-dwarfing, they bear fruits within 3 to 4 years and they are tolerant on a wide range of soils, altitudes and moistures. In agreement with this David (1983) and Hessayon (2000) described MM106 as the most widely used of all rootstocks and is nearly always used for the weaker cultivars. As observed in this study the cultivars propagated on MM106 rootstock are usually productive, good anchorage and favors good framework and central leader like BR-64, Granny Smith and Crispin. Furthermore study conducted by Wesley *et al.* (1991) documented that MM106 rootstock performed well across all areas suggesting a wider than expected adaptability. Morgan and Richards (2002) reported

MM106 is better in performance, because it is a type rootstock that has hardy very spreading-penetrating root system and produces better fruit and yield.

The vigorousity of Local or CH rootstock is similar or more than MM106 as indicated by informants. For example in Chencha, Granny Smith grafted on local root stock had good branching, dark green leaf, generally better performance than the same cultivars grafted on MM106. Similar observation was found in Boreda. However it was observed and farmers further indicated that the yield as well as fruit size of Granny Smith, Gala and BR-64 grafted on local or CH is not better than MM106. This is in agreement with the study of John *et al.* (1991) who revealed that different types of root stocks used to propagate same cultivars influence yield potential in apple in part by altering spur density of the scion.

As respondants mentioned and observed in the field, cultivars grafted on MM111 root stock have increased in height, but low fruit load and are slow to fruit. This is in contrast with the study of Morgan and Richards (2002) who reported MM111 as a high yielding rootstock. Informants further responded that apple cultivars grafted on MM106 and Local (CH) bear fruits with in 3- 4 years and have high yield in comparison to other rootstocks, whereas M-27 bear fruits with in 2-3 years, but with very poor yield (Table 9). This is in contrast with study of Westwood (1993) who recorded, yield efficiency of M-27 is highest of all rootstocks. It was observed in the field that BR-64 and Anna grafted on M-27 (Table 9) in Chencha and Boreda are very dwarf, stunted and had deformed leaves and mostly inviable blossom and few fruits. This seems to be either due to scion incompatibility, soil conditions, climatic factors or some other reasons, which may require further study under the study site condition. As indicated by John *et al.* (1991) and Simon *et al.* (2002) rootstock of one area might not be effective in other areas due to climate, soil and other management variations. Further Eric and Ronald (1989) reported failure of rootstock, adequate mineral and water absorption due to change of areas.

As displayed in Table 8, most of the apple growers in Boreda used MM104 rootstock. They mentioned that it is more drought tolerant and do not require more water. In agreement with this Rice *et al.* (1990) reported MM104 as a rootstock tolerant to drought and different soil conditions. In Boreda farmers responded that, BR-64, Anna, and Crispin grafted on MM104

rootstock (Table 9) had vigorous growth with few scattered fruits that are medium to smaller in size comparative to the same cultivars grafted on Local or MM106 rootstocks. This agrees with Westwood (1993) and Hessayon (2000) who reported MM104 as a rootstock that has vigorous growth but with low yield and poor anchorage. Thus, it was found that among the rootstocks used MM106 have good anchorage, resistant, and perform high yield in all study sites followed by Local (CH) rootstocks.

6.4. Apple leaf shading (dormancy)

According to the result of this study among the seven apple tree cultivars at 2300 m (Boreda) Anna shade its leaves fully in June. In this area the phenology of this cultivar is known by the respondents. It seems that lower altitude and warmer climate may contribute for better performance of Anna in Boreda study site. In agreement with this Blankenship (1987) earlier described Anna, as Israeli cultivar with lower chilling requirement that have better performance in warmer climate. Similar to Anna, except BR-64, Granny Smith and Gala, all other cultivars shade their leaves beginning from June to mid of July. BR-64, Granny Smith and Gala leaf shade begins in July and extends to August. In both Bonke and Chencha BR-64, Granny Smith and Gala shade their leaves earlier than others (Table 10). The delay in defoliation may indicates that cultivars are under stress condition due to inadequacy of cold *kiremt* temperature.

At 2700 m (Chencha) study site BR-64, Granny Smith, Gala and Crispin shade most of their leaves beginning from June (Table 10). The high growth and yield of these cultivars may indicate adequacy of cold *kiremt* temperature. On the other hand, Red Delicious and Golden Delicious delay defoliation up to July to mid of August (Table 10), and thus may require manual defoliation as suggested by David (1983). This may indicates that cultivars are stressed or injured by insufficient cold *kiremt* season so that they do not fully shade their leaves. In agreement with this Rice *et al.* (1990) reported that where cold is lacking the apple trees will suffer from a physiological disorder called delayed defoliation. Similarly Duane (1996) revealed that inadequate coldness delay the defoliation of apple tree leaves, causing a delay in blooming and leafing in *tsedey*.

As observed in the field. Anna remain vegetative, some branches produce flowers, others scattered fruits and a few form leafing in *kiremt* while the rest of the cultivars in the area shade their leaves. As respondents indicated Anna try to produce fruiting twice a year. However after blooming and fruiting about three fourth of the fruits get dropped so that there is little or no yield. This could be either due to climatic constraints rootstock performance or some other reasons which needs further study. Farmers indicated that the exact time of blooming and fruiting of Anna was not known (Table 10). Thus, 2700 m is not suited for Anna in such away that cultivars proper chilling requirement was not fulfilled. This condition was observed by failure of leaf shading and blooming time unlike others so as growth and yield is little. On the other hand Golden Delicious and Red Delicious leaf shade begins from July to August. However the yield and growth of Red Delicious was more than Golden Delicious. It seems that at 2700 m, Golden Delicious may be injured by *kiremt* coldness hence, it had weak growth and yield performance. In agreement with this Luby *et al.* (1999) reported Golden Delicious as a cultivar with less cold hardiness.

At 3200 m (Bonke) BR-64 (mid-May), Granny Smith, Gala, and Red Delicious shade their leaves beginning from mid June. Golden Delicious shades its leaf from July to August, its growth was stunted and had deformed leaf, showing that it was not suited to the area. Anna in Bonke posses few fruits that have deformed shape. Respondents mentioned that most of the excess flowers are injured and immature fruits are dropped, damaged blossom and fruits are observed during the survey. Thus Anna cultivar in both Chencha and Bonke seem to be injured by cold stress condition of the area, less adaptive to higher altitude, rootstock, soil condition or some other constraints and thus become unproductive. Some apple growers of both areas as observed in the field cut the cultivar and remove from their gardens.

According to field survey study and interviewees response leaf shading of the apple tree cultivar mostly begin from June or mid of June when the low temperature become 10 to 11^{0}C or lower and ends in about 60 to 75 days. Thus the chilling requirements of most cultivars seem to be about 1400-1800 hrs or above; which agrees with study of Miklos (1989) who recorded that in the area above 7^{0}C in apple tree the chilling requirement is about 200 to 2000 hrs. This study shows that apple tree cultivars that shade their leaves in June such as Anna, Golden Delicious,

Crispin and Red Delicious at 2300 m seem to obtain adequate chilling for good growth and yield, similar to BR-64, Gala, Granny Smith, Red Delicious and Crispin of Chencha and Bonke.

6. 5. Flower development

As shown in Table 11 in Boreda blooming of BR-64, Granny Smith and Gala is delayed to November with the latter having very less blossom. In agreement with this (Godfrey and Berke Tsehai Tuku, 1986) reported that lack of sufficient *kiremt* chilling temperature induce a physiological condition characterized by delayed flowering. On the other hand Bonke seem to be favorable to fulfill chilling requirement of Granny Smith so as the blossoming of the cultivars is earlier at end of September than Chencha and Boreda (Table 11). It was observed in the field that the blossom denseness of this cultivar increases as altitude increases. However blossom performance of BR-64, Granny Smith and Gala is delayed, is low in denseness and even dropped flower buds were observed in Boreda (2300 m). This agrees with study of Westwood (1993) who reported that inadequate *kiremt* chilling causes the flower buds simply to drop from the apple tree. On the other hand as observed in the field, BR-64, Granny Smith and Gala have scattered less blossoming, fruiting and leafing. In general they have weak precocity at 2300 m compared with 2700 and 3200 m. Simillar to this study Jules (1980) and Rice *et al.* (1990) earlier recorded that when there has not been enough cold, blooming of apple trees and leaf production will be sporadic. Thus it can be concluded that, BR-64, Granny Smith and Gala that had dense blooming and leafing at higher altitude (2700 and 3200 m) seem to be stressed by insufficient *kiremt* coldness at 2300 m.

At 2700 m altitude the blooming performance of BR-64 resembled that at 3200 m, but with moderate blossom. Others cultivars, Crispin, Red Delicious, Gala and Granny Smith developed flowers in October and Golden Delicious in November. The blooming performance of Anna was not known. As observed in the field blooming and leafing denseness of BR-64, Granny Smith, Gala, Red Delicious and Crispin at 2700 m was more than at 2300 m indicating that they had obtained adequate chilling making the area favorable for these cultivars. Golden Delicious blooming was delayed to November, few and scattered leaf and blossom was observed. Thus, 2700 m may not suited for this cultivar.

At 3200 m BR-64 blossom early in September followed by Granny Smith and Gala (end Sep). Golden Delicious and Red Delicious are delayed to November. The earliness in defoliation (mid June and July) doesn't contribute for early blooming of Golden Delicious and Red Delicious, it seems that the delay in blooming (November) may be due to cold temperature injury of these cultivars (Luby *et al.*, 1999). effect of rootstock, soil condition or some other reasons. As observed in the field and farmers response, BR-64, Granny Smith and Gala produce dense full blossom at 3200 m than in other study areas. Thus, these cultivars are favored by sufficient chilling of the area so as they resume growth and bear dense blooming and leafing early in *tsedey*.

6. 6. Fruit set and maturity

Several researchers reported that apple tree cultivars that obtain adequate chilling shade their flower after blooming within two weeks whereas, those stressed by insufficient cold temperature blossom shading is delayed from 3 to 4 weeks (Ryugo, 1988; Rice *et al.*, 1990; Westwood, 1993). In agreement with this, our study shows that, BR-64, Granny Smith, and Gala at 2300 m seem to be stressed by inadequate *kiremt* coldness similar to leaf shading and blooming (Table 10 and 11), hence, bloom shading ends within 3 to 4 weeks (Table 12). This indicates that the area is not matched with these cultivars. Hence, their growth performance is weak compared to the higher altitude of Chencha and Bonke. The reverse was true for Anna, Golden Delicious and Crispin.

According to the result in Table 13 the seven apple tree cultivars bloom to harvest is within the range of 120-210 days. Earliness in blooming and maturation is related with adequate chilling while delay or late in blooming and maturation is due to insufficient or stressed cold temperature (Westwood , 1993; Rice *et al.*, 1990). This agrees with this study in such a way that in Boreda those cultivars with vigorous yield in Bonke such as BR-64, Granny Smith and Gala delay in blooming and maturation compared to Chencha and Bonke. For example, the first round harvest of these cultivars at higher altitudes was in March whereas, in Boreda it was in April. On the other hand, Crispin bloom to harvest is about 180 days in Chencha whereas, it takes about 150 days as Anna of Boreda which requires 120-150 days. This indicates that warmer climate and relatively lower chilling seems to hasten the duration of blooming to harvest of both cultivars

6.7. New shoot growth

The calculated two way ANNOVA (P = 0.038) showed that the new shoot growth of the seven apple tree cultivars was significant, indicating the new shoot growth was dependant on the altitudes. On the other hand, there is a difference in new shoot growth among the cultivars in the row (altitude) (Table 14). Therefore cultivars new shoot growth is not the same for the altitudes and also i.e. not the same for the seven cultivars.

Furthermore, as displayed in Figure 13 at 2300 m study area the apple tree cultivar with high performance of new shoot growth was Anna (42 cm). The spur with healthy blossom and developing fruit was observed during the field survey. It has been known from observation that, unlike Bonke blooming and fruiting are more and the yield is also good. It seems that Anna perform better in lower altitudes with relatively warmer climates. Golden Delicious (24.3 cm) with less new shoot growth performance at 2700 and 3200 m is better at 2300 m (Fig. 15). The result of study conducted by Gerald and Dwight (1992) recorded similar findings in such away that, warmer or sunny climatic condition is favorable for Golden Delicious cultivar. Crispin (30.5 cm) is more vigorous having good new growth than BR-64 (14.2 cm) and Granny Smith (10.3 cm), which might be due to the lower altitude climatic condition. Gala (9.83 cm) and Red Delicious (13.5 cm) new growth is more or less similar. However, Gala cultivar has the least new growth performance compared to other study area. It seems that the growth of Gala was stressed by warmer climatic condition as described by Tustin (1990). On the other hand BR-64, Granny Smith and Gala new shoot growth performance seems to be less may be due to warmer temperature stress or probably due to inadequacy of cold *kirmt* seasons (Fig. 18, 19, 20). As observed in the field at 2300 m, leaf defoliation of Granny Smith, BR-64 and Gala was delayed up to July-August (Table 9). The delay in defoliation of these cultivars seem to be due to insufficient coldness so as the cultivars are stressed during the time of leaf shading (*kiremt*). This inadequacy can be recognized by the failure of the cultivars to produce sufficient new growth in *tsedey* as described by Rice *et al.* (1990) and Westwood (1993).

In Chencha study area (2700 masl), the new shoot growth of Crispin (24.8 cm) and BR-64 (26.5 cm) was high, it seems that they obtain adequate chilling while Granny Smith (19.5 cm) and Gala (18 cm) seem to be moderate. On the other hand, Anna (14 cm) with high new shoot growth

performance in Boreda is less in Chencha. The cultivars may be stressed by Chencha *kiremt* cold season, soil condition or some other factors. Red Delicious (15.7cm) have more or less similar new growth performance as Bonke, while Golden Delicious (6.83 cm) that have better new growth performance in Boreda seem to be stressed, so as it have the least new growth performance as compared with other cultivars (Fig. 15).

In Bonke study site (3200 m), BR-64 (36.4 cm), Granny Smith (31.5 cm) and Gala (24.3 cm) new wood growth is high, this seems that the cultivars obtain relatively adequate chilling during the *kiremt* season so that they resume growth in *tsedey* and perform high new shoot growth (Fig.18, 19, 20,) as described by Rice *et al.* (1990) and Hessayon (2000).

As observed in the field the new shoot growth of BR-64, Granny Smith and Gala is long with healthy dark green leaves. The increase in the size of new shoot growth along the altitude indicates that cultivars obtain adequate chilling and perform better growth at higher altitudes (2700 m and 3200 m). On the other hand Red Delicious (18.3) new shoot growth is more or less similar to other study areas (Fig.16). This cultivar has better growth performance at 3200 m. Hence. this seem that lower altitude with warmer climate may contribute for the better fruit quality of Red Delicious as described by Gerald and Dwight (1992). This may be the cause for its comparable distribution in all study sites (Fig.10). The cultivars with least new growth performance in Bonke are Golden Delicious (3.90 cm) and Anna (10 cm). On the other hand both Anna and Golden Delicious has better new growth at 2300 m. Thus the weak new shoot growth performance at 2700 and 3200 m indicates that the cultivars may be injured by *kiremt* cold temperature or some other reasons. Hence, both area probably might not suited for their growth.

6. 8. Estimation of leaf area

The two way ANNOVA calculated ($P = 0.030$) showed that there is significant difference of leaf area growth. In other wards, cultivars leaf area depend on the altitude in which they were grown whereas, differences obtained for altitudes (rows) were not significant (Table 15). Therefore the result showed that the size of leaf area depend on the altitude in which the cultivar grows.

Similarly according to the result displayed in Figure 21 in Boreda , Anna (37.10 cm^2), Golden Delicious (30.47 cm^2) and Crispin (25.90 cm^2), are having the highest LA in ranking order. As observed in Boreda, leaf area of BR-64 (26.79 cm^2), Granny Smith (21.70 cm^2) and Gala (23.50 cm^2) were low. Leafing and blossoming was scattered, and spurs of few branches develop fruits. This indicated that the cultivars were stressed by insufficient cold temperature of the area so as their chilling requirement was not fulfilled and hence, they perform weak growth of LA similar to their new shoot growth as described by Ghariani and Stebbins (1994). Therefore, it seems that they are not suited to 2300 m. On the other hand LA performance of Red Delicious (21.27 cm^2) was more or less similar with Bonke and Chencha. Anna during field survey in Boreda was at the stage of blooming and dense fruit. The leafing, blooming and fruit set performance of this cultivar was better at 2300 m than 2700 m and 3200 m.

In Chencha study area BR-64 (36.76 cm^2), Granny Smith (34.95 cm^2), and Gala (30.5 cm^2) are those cultivars that have high leaf area, indicating that the apple trees may obtain sufficient *kiremt* cold temperature. As observed in the field the cultivars are having dark healthy green leaves, however, BR-64 had more dense leaves than the others. Crispin (23.60 cm^2) had high leaf area similar to Boreda. On the other hand Red Delicious (17.40 cm^2) LA was almost similar to its performance in Bonke and Boreda. However during the survey the cultivar has very few leaves of small size that were scattered on the branches. Anna (14.90 cm^2) and Golden Delicious (12.70 cm^2) LA was the lowest of all the cultivars in Chencha study area (Fig.21.). Anna as observed in the field has curled (damaged) darker leaf with deformed shape.

In Bonke, BR-64 (48.72 cm^2) Granny Smith (40.56 cm^2) and Gala (36.2 cm^2) have more or less high leaf area growth performance (Fig. 21).The presence of high leaf area contribute for high photosynthetic products during photosynthesis. These carbohydrate are moved to storage areas of apple trees such as fruit and root system. Hence increase in root growth results in high absorptive, vigorous growth and yield performances of the cultivars. As observed in the survey these cultivars were having good canopy, dense blooming, fruit set, dark green leaves and generally good precocity. This is in agreement with Bruce and Bonnie (1990) who reported that apple tree high flower bud formation was associated with a maximum leaf area. Thus this study shows that BR-64, Granny Smith and Gala are more adapted and perform good growth in Bonke compared

with Boreda, indicating that the climatic condition of Chencha and Bonke seem to be suited for these cultivars. Red Delicious (21.04 cm^2) LA is moderate, its precocity and leafing is also moderate. Similar to its new growth performance this apple tree seems to have wider adaptation under the study area. On the other hand Golden Delicious (8.16 cm^2) and Anna (10.30 cm^2) LA are the least of all cultivars (Fig. 21), the general growth of these cultivars in Bonke seems to be stunted, with unattractive smaller spur terminal buds and fewer buds mixed with scattered leaves. this is in agreement with Jackson and Palmer (1977) who documented that weak growth of cultivars leaves affect the vegetative spurs characteristics. Thus the cultivars weak growth of LA and new shoot growth shows, both Golden Delicious and Anna are not suited to geographical area of both Chencha and Bonke.

6. 9. Estimation of apple fruit yield kg/ tree

Two way ANNOVA calculated for the yield performances of the cultivars (columns) P = 0.025 showed that there is significant differences and the difference for altitudes (rows) are significant (Table 20). Therefore, this result showed that cultivars yield performances differs and also is not the same for the three altitudes.

In addition to this similar performance of yield difference within the cultivars and along the altitudes was displayed in Figure 24. The result showed that, BR-64, Granny Smith and Gala have a better yield performance at higher altitude (2700 m and 3200 m) with more humidity, cold *kiremt* temperature, fogs and soil conditions (Fig. 25, 26, 27). On the other hand. Anna and Golden Delicious increase in fruit load performance in lower altitude (2300 m) with less coldness, humidity, fogs and warmer climatic condition (Fig. 29 , 30). Anna has the highest fruit load compared to other study sites . The yield of Red Delicious and Crispin (Fig. 28, 31) are moderate at 2300 m and 2700 m. On the other hand BR-64, Granny Smith and Gala, which are high yielding cultivars at both 2700 m and 3200 m were less in fruit load (yield) performance at 2300 m indicating that the cultivars seem to be stressed by lower altitude inadequate cold *kiremt* temperature. This is in agreement with the study of Oukabli *et al.* (2003) who documented that apple cultivars produce low yield when grown in regions with inadequate *kiremt* chilling temperature. They further indicated that the cultivars unsatisfactory development is attributed to the lack of climatic adaptations, which causes some abnormalities in flower bud differentiation

CONCLUSION AND RECOMMENDATION

Our work was intended to screen apple tree cultivars with their suitable rootstocks based on, their growth and yield performances in the three altitudes and to document the knowledge of apple tree growers about selection of cultivars, rootstocks used and management practices of apple (*Malus domestica* Borkh.). Seven of the apple tree cultivars were selected and 60 home gardens of the apple growers was surveyed. The result showed that, more than half of the home gardens of the apple growers were used for apple tree cultivation and farmers used apple for income and source of food. However, the knowledge of farmers' management practices in mulching and manuring at proper time of cultivars new growth and blooming at Fall (*tsedey*) was not performed. Furthermore, it was observed that pruning and thinning activities which improve cultivars yield are neglected by most of the growers. They mentioned that they do not know the method and its use. Similarly knowledge of apple diseases and pests that reduce cultivars yield was not known so as traditional methods of prevention were not performed.

It was observed that, apple tree cultivars perform best when they are propagated on suitable rootstock and grown in the area that properly matched with their performances. However, farmers' knowledge of rootstocks used and cultivars selection at different sites was little. Due to this the seven apple tree cultivars propagated on different rootstocks such as MM104, MM111, MM106, M27, Local (CH) were found in all study sites. On the other hand, the climatic condition of the area that determines cultivars performance was different along the elevation of the sites.

The growth and yield performance of cultivars were dependent on the *kiremt* cold temperature of the area in which the cultivar grows. As farmers indicated, at high cold *kiremt* and less frosty condition they obtain high yield, whereas less coldness and frosty climate results in little yield. Hence, according to our observations and apple growers responses, cultivars that obtain adequate chilling during *kiremt* satisfy their rest (dormancy) requirement by fully shading their leaves and resume new shoot growth and blooming the following *tsedey*. Under this condition flower ending and fruit set lasts within two weeks so as fruit maturation and ripening is early. On the other hand inadequacy of chilling temperature was observed by delayed defoliation (July-August), blooming (November) and flower ending (3 - 4 weeks).

This study shows that at 2300 m, Anna, Golden Delicious, Crispin and Red Delicious leaf shade were early in June. Blooming and new shoot growth resumes in September-October and bloom shading were within two weeks, indicating that the performance of the cultivars were suited to the climatic condition of the area. Hence, new shoot growth, stem diameter, leaf area, yield kg/ tree and fruit size of these cultivars

grown in this area is high; whereas, BR-64, Granny Smith and Gala shade their leaves at July-August, delayed blooming and new shoot growth (November) so as growth and yield performance is low comparative to other sites indicating that, 2300 m is less suited for these cultivars.

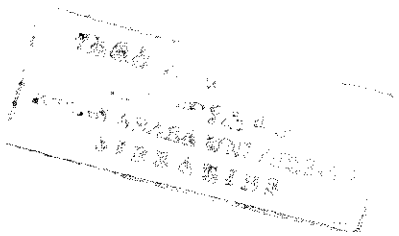
At 2700 m and 3200 m, BR-64, Granny Smith and Gala leaf shading was in June and new shoot growth and blooming was early in September. In this area flower ending is within two weeks so as cultivars very high growth and yield performance was observed. The reverse was true for Anna and Golden Delicious.

On the other hand the growth and yield of the cultivars were determined by the type of rootstock used. Among the rootstocks used in the study sites, MM106 has the highest performance in all sites than all the others followed by Local (CH). In areas of lower altitude (2300 m) where there is scarcity of moisture and poor soil fertility (degraded areas) MM104 seems to be better than MM111 and M27.

The result of this study conducted on the comparisons of growth and yield of apple tree cultivars at three altitudes therefore showed that, BR-64, Granny Smith and Gala grafted on MM106 rootstock has high new shoot growth, stem diameter, leaf area, yield kg/ tree and fruit size performances at higher altitudes (2700 m and 3200 m) whereas Anna and Golden Delicious, on MM106 root stock is better in lower altitudes (2300 m). Red Delicious and Crispin have moderate yield performance in all the study areas.

In these woredas, apple cultivars are an important source of income and have largely contributed to improve the livelihood of the growers. However, information studied on these cultivars under the Ethiopian condition is limited or not available. Therefore, we recommend further study on;

1. Growth and yield performances in lower and higher altitudes.
2. The rootstock, so as to develop types used in wider areas.
3. The effect of pruning on yield performances of the apple tree cultivars.
4. Apple diseases and pests.
5. Means of introduction in to other regions of the country having similar agroecology as it helps a lot in raising the local economy and poverty alleviation.



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Appendix 1. The guide questions used during the performance of apple trees data collection.

This questionnaire was prepared together knowledge of apple growers of the Gamo Gofa zone three districts (woredas) in cultivation of the seven apple tree cultivars as part of a research conducted for the fulfillment of the masters thesis on the problem entitled comparison of growth and yield of apple (*Malus domestica* Borkh.) tree cultivars in three altitudes at Gamo Gofa, South Ethiopia.

Status of interviewee

Region----------SNNPR Zone -----Gamo Gofa

1. Sex 1. Male---------- 2. Female----------
2. Marital status 1. Single--------- 2. Married-------- 3. Divorced--------4. Widow (er)----------
3.Occupation 1. Farmer--------2. Merchant-------- 3. Daily laborer------4. other (specify) .....
4. Religion... 1.Christian---------2. Moslem--------- 3. Other(specify) ----------
5. Family size 1. 1-2----------2. 3-5---------- 3. 6 and above----------
6. Educational status 1. Illiterate-----2. 1st cycle------- 3. 2nd cycle---- 4. Diploma and above-----

7.What proportion of your home garden is covered with apple trees?1. Less than half----------
2. About half---------- 3.Greater than half---------- 4.Other (specify)----------
8. What purpose do you use apple for? 1. Food---------2. Means of income---------3. other--------

9. Would you please enumerate the apple trees in your garden that shade their leaves in *Kiremt* (June-Aug) 1. BR-64----------2. Granny--------3. Gala---------- 4. Anna----------
5.Golden Delicious----------6. Red Delicious---------- ---7. Crispin----------
10 .List the apple trees months of leaf shade.

Cultivars	Months		
	June	July	August
BR-64			
Granny			
Gala			
Anna			
Golden Delicious			
Red Delicious			
Crispin			

11. Is there any apple tree that doesn't shade its leaves in *kiremt* unlike the others?
1.Yes---------- 2. No----------

12. If the answer in question no. 11 is yes would you please list the name (s)? ----------
---

13. Do you know when these cultivars of your answer in question 13 shade their leaves?

1.Yes ----------2. No ----------

14. Would you please enumerate the months of blooming of apple trees in your garden in *tsedey* (Fall)?

Cultivars	Months		
	September	October	November
BR-64			
Granny			
Gala			
Anna			
Golden Delicious			
Red Delicious			
Crispin			

15. Which apple tree(s) blooming month is not known?----------
16. Would you please rate in ranking order the apple trees based on dense blooming Performance? 1. BR-64----------2. Granny--------3.Gala.----------4.Anna-------
5. Golden Delicious---------- 6. Red del. ----------7.Crispin----------
17. What is the weather condition of the area in *tsedey* (Fall) season? 1.Very cold frost----------
2. Moderate frost----------3. Less frost----------
18. Which apple tree cultivars blooming or fruit are damaged (affected)by *tsedey* frost?
---
19. Would you please kindly rank the apple trees in your garden based on their yield?
1.BR-64-------- 2. Granny----------3. Gala----------4.Anna----------5.Golden Delicious---------
6. Red Delicious---------- 7. Crispin----------

20. Total no. of apple trees, rootstocks used and yield kg/tree

Cultivars	Total no.	Rootstock	yield/ tree
BR-64			
Granny Smith			
Gala			
Anna			
Golden Delicious			
Red Delicious			
Crispin			

21. Do you know the type of rootstock used in your garden? 1.Yes----------2. No----------

22. If your answer in question 21 is yes would you please enumerate the types and cultivars propagated?----------
---

23. A crop (fruit) with high cost in your area. 1. *Enset*----------2. Tubers---------3. Apple----------

4. Barly----------

24.Which crop (fruit) can substitute apple? 1. no crop can substitute---------- 2. *Enset*------
3.Barley---------- 4.Tubers----------5.Other (specify)----------
25. How much do one kg. of apple fruit costs? 1.----------2.----------

26. Is apple cultivation increasing? 1. Yes------ 2. No----------

27. If your answer in question no.26 is yes would you please enumerate the reasons?
1. high cost-------2. easy to cultivate-------3. once fruit set production is perennials------
4. all are possible reasons----------
28. How would you select apple tree cultivars before buying the seedlings? 1. From other-------
experiences ----------2. no selection ----------3. buying low cost seedlings----------
4. other(specify)----------
29. Do you know application of manuring (compost) season? 1.Yes------- 2. No----------

30. If your answer in question no.29is Yes would you please enumerate the season(s)?
1. *kiremt*----------2. *tsedey*----------3. *bega*----------4. *belg*.----------
31. Do apple cultivation cause the declining of *enset* cultivation? 1.Yes-------2. No--------

32. Would you please list the crops used as source of food according to its priority?----------
---
33. Do you know the name of apple tree in your area with good yield? 1.Yes----2. No-----

34. If your answer in question no. 32 is yes would you please enumerate the name?----------
---
35. Do you perform pruning? 1. Yes----------2. No----------

36. If the answer in question no.35 is yes mention the season. 1.*kiremt*-------2. *tsedey*-------3.
bega---------- 4.*belg*----------
37. Do you perform apple fruit thinning? 1. Yes----------2. No----------

38. If your answer in question no. 37 is No, what is the reason? 1. don't know its use ---------
2. do not know the method---------- 3. other(specify)----------

39. Do you know the name of apple tree disease and pests with their symptoms?
1. Yes----------2. No----------
40. If the answer in question no.39 is yes would you please enumerate the name of disease and
pests? ----------
---
41. How do we control this apple diseases and pests?----------
---
42. How can we improve apple cultivation?----------

Appendix 2. LIST OF KEY INFORMANTS

Theophillus Tesfaye
Israel Cheto
Eyasu Mathewos
Asfaw Jafaro
Kefiyalew Kacho
Gida Ginbare
Mathewos Goda
Dare Galjama
Malele Asamo
Bopana Boche
Elias Wogasso
Malebo Maja
Ofache Onchre

Appendix 3. List of useful plant species of the Gamo Gofa people encountered in home gardens, in the six study sites (kebeles) used as food and income.

Chosha, Kutta (Bonke); Tolola, Doko (Chencha) ; Chilashe, Zafine (Boreda).

+ = present: 0 = absent, * = income & food, # = income

Scientific Name	Family	Local name in Gamogna	Bonke		Chencha		Boreda		Parts used
Allium sativuum L.	Alliaceae	Shinkurto	+	+	+	+	+	+	Bulb *
Allium cepa L	Alliaceae	Tumo	+	+	+	+	+	+	Bulb*
Artemsia afra Jacq. Ex willd	Asteraceae	Natra	+	+	+	+	+	–	Bulb*
Brassica carinata A.Br.	Brassicaceae	Sansee	+	+	+	+	+	–	Leaf *
Brassica oleracea L	Brassicaceae	Unibuosanse	+	+	+	+	0	0	Leaf *
Beta vulgris (L.) Moq.	Chenopodiaceae	Keyisire	+	+	+	+	+	–	Leaf *
Cymbopogon citrates (DC.) stapf.	Poaceae	Chajisare	+	+	+	+	+	–	Leaf =
Plectranthus caninus Roth.	Lamiaceae	Gadedono	+	+	+	+	+	–	Root =
Daucus Carota L.	Apiaceae	Karotte	+	+	+	+	+	–	Leaf *
Ensete Ventricosum (Welw.) Cheesman	Musaceae	Utsa	+	+	+	+	+	–	Root = & leaf
Malus domestica (Borkh.)	Rosaceae	Appilee	+	+	+	+	+	–	Fruit *
Nicotiana tacum L.	Solanaceae	Tamboo	+	+	o	O	+	o	Fruit =
Ruta chalepensis L.	Rutaceae	Tselotte	+	+	+	+	+	–	Leaf =

Appendix 1. cont...

Rhamnus prinoides L'He'rit	Rhamnaceae	Gesho	+	+	+	+	+	+	Leaf, # Fruit
Solanum tubersom	Solanaceae	Asmaradon	+	+	+	+	+	+	Stem*
Capsicum anum L.	Solanaceae	Banbaree	0	0	0	0	+	+	Fruit *
Coffea arabica L.	Rubiaceae	Tuke	0	0	0	0		+	Seed, leaf *
Coriandrum sativum L.	Apiaceae	Debo	0	0	0	0	+	+	Leaf #
Cucurbita pepo L	Cucurbitaceae	Yelehiya	0	0	0	0	+	+	Fruit *
Ocimum sanctum L.	Lamiaceae	Koffee	0	0	0	0	+	+	Leaf, Fruit #
Catha edulis (vahl) forssk. exEndl.	Celasraceae	Catiya	0	0	0	0	+	+	Leaf #
Beta vulgaris. Cicla (L.)Moq.	Chenopoddiaceae	Kosta	0	0	0	0	+	+	Leaf *
Ipomoea batatas Lam.	Convolvulaceae	Sukarea	0	0	0	0	+	+	Root *
Saccharum officinarum L.	Poaceae	Shonkora	0	0	0	0	+	+	Stem *
Chenopodium ambrosioides L.	Chenopoddiaceae	Agupee	0	0	0	0	+	+	Leaf *

Appendix 4 . Characterization of the seven apple tree varieties.

T= tree; Cl = central leader; Sb = spreading branches; Al = alternate; Pub = Pubescent; Acu = acuminate; Pin = Pinnate; WP = whitish pink; RP = reddish pink ; fr = free; El = elliptic; Ser = serrate; Ob = oblong; S = simple; Cy = cymes; Sy = symmetrical; lan =lanceolate; Ar = arrangement; mt = meter; mm = millimeter; cm = centimeter, M = medium, L= large, S = small

Varieties	Habit	Height mt	Canopy	Leaf	Arrangement	Leaf shape	Margin	Apex	Base	Surface	Venation	Size (cm)	Petiole length (cm).	Inflorescence	Petal	Petal colour
Granny Smith	T	3.5	Cl	S	Al	El.	Ser.	Acu.	Acu - Sy	Pub (less)	Pin.	7.4 by 4.2	3	Cy.	5,fr	WP
Golden Delicious	T	2.85	Sb	S	Al	El	Ser.	Acu	acute	Pub	Pin	7.7 by 4.7	1.5-2	Cy	5,fr	WP
BR-64	T	3.85	Cl	S	Al	ovate	Ser	Acu	acute	Pub	Pin	7.6 by 4.7	3-4	Cy	5,fr	WP
Crispin	T	3.5	Cl	S	Al	El	Ser	Acu	Acu - Sy	Pub	Pin	8.8 by 4.2	3	Cy	5,fr	WP
Red Delicious	T	3.5	Sb	S	Al	Ovate	Ser	Acu	acute	Pub (less)	Pin	7.1 by 3	3-3.5	Cy	5,fr	WP
Anna	T	3	Cl	S	Al	Ovate	Ser	cuspidate	acute	Pub	Pin	6.2 by 3.4	3.5-4	Cy	5,fr	WP
Gala	T	2.85	Cl	S	Al	ovate	Ser	Acu	acute	Pub	Pin	7.2 by 3.7	3-3.5	Cy	5,fr	WP

Appendix 4. cont...

Petal size (mm)	Petal shape	Calyx	Size (mm)	Shape	Stamen	Pistil	Fruit colour	Shape	Flesh	Size	Lenticels
20	Ob	5,fr	1-2	lan	16-20, fr	5,fr	Green	Round-conical	Greenish-white	M-L	Conspicuous
10-15	Ob	5,fr	2-3	Acu	15-20, fr	5,fr	Yellow-golden	Round-oblong	Deep cream	M-L	Not conspicuous
12-15	Ob	5,fr	1-2	lan	18, fr	5,fr	Reddish-yellow	Round	Whitish-cream	L	Not conspicuous
17	Ob	5,fr	1-2	lan	15-17, fr	5,fr	Yellow-green	Oblong	Pale-yellow	L	Highly conspicuous
20	Ob	5,fr	2-3	Acu	20, fr	5,fr	Red	Round-conical	Cream	S	Moderately conspicuous
17	Ob	5,fr	1-2	Acu	18 ,fr	5,fr	Blushed	Conical-oblong	Pale-cream	M	Moderately conspicuous
20	Ob	5,fr	2-3	Acu	19 ,fr	5,fr	Red	Oblong-conical	Cream	S-M	Fairly conspicuous

Appendix 5. Apple tree phenological data

Woreda ---------- Boreda **Altitude ---------- 2300 m**

Varieties	Leaf shade		Blooming & Leafing		Bloom shade		Fruit set	Fruit harvest
	Begin	End	Begin	Full bloom	Begin	End	Begin	
Granny Smith	July	Aug	Nov	Nov	Dec	Dec	Dec	Apr
BR-64	July	Aug	Nov	Nov	Dec	Dec	Dec	Apr
Red Delicious	Jun	Mid- Jul	Oct	Oct	End of Oct	Nov	Nov	Mar
Golden Delicious	Jun	End of Jun	Oct	Oct	End of Oct	Nov	Nov	Mar
Gala	July	Aug	Nov	Nov	Dec	Dec	Dec	Apr
Crispin	Jun	End of Jun	Oct	Oct	End of Oct	Nov	Nov	End Jan
Anna	Jun	End of Jun	Sept	Sept	End of Sep	Oct	Oct	Jan

Appendix 7. Apple tree phenological data.

Woreda---------- Bonke **Altitude ---------- 3200 m**

Varieties	Leaf shade		Blooming		Bloom shade		Fruit set	Fruit harvest
	Begin	End	Begin	Full bloom	Begin	End	Begin	
Granny	June	July	End of Sep.	Oct	End of Oct	Nov	Nov	End-Mar
BR-64	Mid- May	June	Sep	End of Sep.	End of Sep.	Oct	Oct	Mar
Red Delicious	Mid June	July	Oct	Oct	Nov	Nov	Dec	Mar
Golden Delicious	July	Aug	Nov	Nov	End of Nov	Dec	Dec	Mar
Gala	June	July	End of Sep	Oct	End of Oct	Nov	Nov	Apr
Crispin	----	-----	----	---	----	-----	----	----
Anna	Nk	Nk	Nk	Nk	Nk	Nk	Nk	NK

Nk = not known