ESTIMATION OF NET CARBON SEQUESTRATION POTENTIAL OF CITRUS UNDER DIFFERENT MANAGEMENT SYSTEMS USING THE LIFE CYCLE APPROACH

BY

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A DISSERTATION SUBMITTED TO THE UNIVERSITY OF ZAMBIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN AGRONOMY

THE UNIVERSITY OF ZAMBIA

LUSAKA

2012

DECLARATION

I, Jackson Mwamba Bwalya, declare that this dissertation represents a genuine research I carried out and that no part of this dissertation has been submitted for any other degree or diploma at this or another university or institution.

……………………………… ………………………...………..

Signature Date

APPROVAL FORM

This dissertation of Mr. Jackson Mwamba Bwalya is approved as fulfilling part of the requirements for the award of the degree of Master of Science in agronomy (Plant Science) of the University of Zambia.

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Internal Examiners

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2. Name: …………..……………Signature: …………………..Date: …………………

3. Name: …………………………Signature: …………………..Date: …………………

DEDICATION

I dedicate this dissertation to my daughter, Chewe Bwalya, and my parents; Mr. Lackson Mwamba and Ms. Veronica Chewe and my siblings.

ABSTRACT

A study was conducted to determine the net carbon sequestration potential of citrus to mitigate climate change. Perennial crops such as citrus have the potential to absorb and sequester carbon dioxide from the atmosphere, save for the carbon released back through the application of agro-chemical inputs and use of fossil fuels in running farm machinery in the management of citrus production systems. The main objective of this study was to determine the net carbon sequestration potential of sweet orange (*Citrus sinensis* (L.) Osbeck), orchards under different management systems. The biomass densities and the carbon stocks (carbon sequestration) of citrus trees were determined and orchard carbon emissions estimated and converted to carbon equivalents. Carbon stocks were estimated using standard carbon inventory methods. Allometric equations were used to transform citrus tree diameter into biomass. Farmers from the ten fields used in this study analysis were asked over input application history to the orchards. Life cycle assessment based carbon foot-printing methods were used to determine citrus orchard carbon emissions. The carbon emission factors were calculated in conformity with PAS 2050. Results obtained showed that citrus trees carbon sequestration in biomass ranged from 23.99 Mg CO_2e/ha for young trees to 109 Mg CO_2e/ha for mature trees.

The carbon emissions from fertilizer, pesticides, water, electricity and fuels production, delivery and use was estimated to range from 0.22 Mg CO_2e/ha for low input orchards to 4.28 Mg CO_2e/ha for high input management. The net carbon sequestration potential were calculated to be between 15.35 Mg CO_2 eq/ha and 95.14 Mg CO_2 eq/ha for input application ranging from two years to 16 years. Continous application of agro-chemical inputs beyond the optimum fruit bearing age could result in net carbon emissions and is not justified. The carbon sequestered (biomass accumulation) in trees was observed to increase with age (r^2 = 0.55) and was not seen to increase directly with the increase in carbon emissions (r^2 = 0.44), but it was apparent that increase in inputs especially fertilizer, pesticides and electricity resulted in increased greenhouse gas emissions. An opportunity exist in the growing of citrus especially with low input management and under well managed high input management systems to mitigate climate change by reducing CO_2 from the atmosphere through carbon sequestration in citrus biomass.

ACKNOWLEDGEMENTS

I wish to avail my gratitude to Dr. Mebelo Mataa of Plants Science Department of the University of Zambia and Mr. Daud Kachamba of Bunda College of the University of Malawi, for their expert guidance and counsel from the time of developing a research concept and writing a research proposal and through implementation to reporting of the results by writing this dissertation and submission.

I am also elated to Mr. Yobe Nyirenda, a Senior GIS Technician of the Forest Department for assisting with the forestry inventory tools and equipment and in the actual data collection. It was not an easy task going round orchards scattered all over Lusaka collecting data. It required determination and dedication, that which can only be achieved with a selfless heart.

I am deeply indebted to Dr. Masuwa of the Ministry of Agriculture and Livestock head office and Mr. Pascal Chipasha at the Lusaka Provincial office for the assistance in the identification of the citrus farmers in Lusaka province. In the same vein I would like to thank all the agricultural extension officers of Lusaka province, with whom I worked on this study.

I acknowledge with thanks the financial and moral support I received from my employer, the Ministry of Agriculture and Livestock, North Western provincial office at Solwezi. In this regard I wish to thank Mr. Charles Sondashi; the Provincial Agricultural Coordinator, Mr. Amos Malumo; the Principal Agricultural Officer and the Provincial Accounts staff for having facilitated my studies. I wish also to thank all my workmates for moral support.

Lastly, but not the least, I wish to extend my appreciation to all my course mates. In a way unimaginable to each one of them individually and as a group, I unbelievably enjoyed their company and I derived a lot of encouragement to work hard.

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LIST OF ACRONYMS

CDM:	Clean Development Mechanism
CO:	Carbon monoxide
DBH:	Diameter at breast height (30 cm aboveground in this case)
EPA:	US Environmental Protection Agency
FAO:	Food and Agriculture Organization
GHG:	Greenhouse gases
GREET:	Greenhouse Gases Regulated Emissions, Energy and Transportation
GWP:	Global warming potential
ha:	Hectare
IPCC:	Intergovernmental Panel on Climate Change
ISO:	International Standards Organization
LCA:	Life cycle assessment
LHV:	Lower heating value
MACO:	Ministry of Agriculture and Cooperatives
MAL:	Ministry of Agriculture and Livestock
MMBTU:	10^6 British thermal unit (10^6 Btu)
PAS:	Publicly available specifications
UNEP:	United Nations Environmental Programme
UNFCCC:	United Nations Framework Convention on Climate Change
VOC:	Volatile Organic Carbon
WMO:	World Meteorological Organization

Chapter 1

1.0 INTRODUCTION

The emergence of extreme weather changes as result of climate change is expected to have great impact on plant development. The increase in global temperatures will result in higher water holding capacity of the atmosphere with precipitation expected to increase, (IPCC, 2001). However, potential evapo-transpiration is expected to exceed the summer precipitation with an increased frequency in droughts. The potential impacts of climate change on agriculture will be reflected most directly through the response of crops, soils, weeds, insects and diseases to the elements of climate to which they are most sensitive. Many weeds as well as plants are expected to benefit from increased carbon dioxide concentration through enhanced photosynthesis. Insect pests, fungal and bacterial pathogens of importance to agriculture production are sensitive to the effects of the changes in moisture and temperatures on the host susceptibility and the host-parasite inter-relations.

Climate Changes especially that involving high frequency in extreme events such as droughts, , flooding, storms and heat waves will impact negatively on the agricultural dependent rural livelihoods, threatening agricultural production systems that ensure food security and income generation, (Bockel *et al*., 2011).

Agriculture is a major source of GHG, contributing about 20 percent of total global emissions which rises to over 30 percent when combined with related changes in land use including deforestation; mainly driven by the expansion of agricultural lands, (Cole *et al*., 1997). Other causes of the increase in GHG concentration in the atmosphere include natural causes such as volcanic activity and changes in the composition of the earth's atmosphere. The high mitigation potential for climate change lies with agricultural sector in developing countries. The technical mitigation options available from agriculture, forestry and other land uses include reducing emissions of carbon dioxide through the reduction of the rate of deforestation and forest degradation. This could be through the adoption of improved cropland management practices (including reduced tillage, integrated nutrient and water management and conservation agriculture); reducing emissions of methane and nitrous oxide through improved manure and crop residue management and more efficient management of irrigation water on rice paddies. Further, improved synthetic fertilizer production and management and sequestering carbon (C) through conservation farming practices, improved forest management practices, afforestation and reforestation, agro-forestry; the growing of perennial tree crops, (Bockel *et al.*, 2011) are some of methods available for mitigation.

Citrus production is primarily an agricultural activity that is used to generate income for producers through the production and sale of fruits. However, given the amount of carbon dioxide that the trees fix through the plant dry matter it can play a role as a means of removing carbon from the atmosphere –commonly referred to as carbon sequestration. The amount of carbon dioxide removed from the atmosphere through sequestration is proportionate to the amount of biomass the plant accumulates over its life time, (Juwarkar *et al.*, 2011). However, the growing of citrus, like all other crops, as noted below requires additional external inputs which in turn release carbon dioxide to the atmosphere and therefore the ultimate value of such systems as a sequestration strategy will depend on whether the amount of carbon fixed exceeds that amount generated through establishing and maintaining these trees.

The application of agro- inputs do not only cost farmers money, but also cost the environment through an increase in greenhouse gases which eventually results in increased temperatures.

Trees just like other plants are able to capture and fix carbon dioxide through the process of photosynthesis. Carbohydrates may temporarily be stored by plants in the form of sugars and polysaccharides such as starch and are permanently stored as cellulose and lignin which act as structural components of plant. The amount of carbon dioxide captured and fixed through the process of photosynthesis and stored by plants as structural components can be estimated from the amount of dry biomass produced by the plant. On the other hand the amount of carbon dioxide and other greenhouse gases released as a result of the application of external inputs by the farmers to the citrus trees can be determined by calculating the life cycle carbon footprint of each input.

Statement of the Problem

There is scientific empirical evidence that the concentrations of greenhouse gases are rising and that agriculture contributes about 20% of global emissions, (Cole *et al*., 1997 and Marble *et al*., 2011). Agriculture has also potential to contribute to carbon sequestration, especially through the growing of perennial crops such as oranges which produce large aboveground biomass. The net outcome regarding carbon emissions and sequestration in perennial plants is unknown and may differ depending on plant species, geographical location, level of management and utilization of external inputs.

Objectives

The main objective of the study was to determine the net carbon sequestration of orange (*Citrus sinensis (L.*) Osbeck) orchards under different management systems in Zambia.

Specific Objectives

- To determine the amount of carbon sequestered as biomass (above ground) under different management systems.
- To estimate the greenhouse gas emissions during production

Justification of study

The findings from this study will contribute to elucidating the relationship between carbon fluxes, orchard management systems and the effects on green house gases. This may assist in accessing opportunities for carbon trading, contribute to the development of sustainable agro-based community technologies to manage greenhouse gas emissions and global warming.

Chapter 2

2.0 LITERATURE REVIEW

2.1Global Climate Change

Climate change refers to any significant shift or variability in temperature, precipitation, humidity, light or wind. These changes can be of short or long duration covering decades or longer (IPCC, 2007). Notwithstanding the fact that climate is dynamic and has been changing through the ages, the recent emergence of extreme weather patterns is attributed to anthropogenic activities including burning of fossil fuels for transport, industrial practices, deforestation and agricultural activities.

The earth's atmosphere contains carbon dioxide (CO_2) and other green house gases such as methane (CH_4), nitrous oxide (N_2O) that act as a heat insulation layer resulting in progressive heat conservation by the atmosphere. This phenomenon results in the retention of heat that is critical for maintaining habitable temperatures, causing the planet to be warmer than it would otherwise been. There is irrefutable scientific evidence that the concentration of the three most important greenhouse gasses (carbon dioxide, methane and nitrous oxide) in the atmosphere have been increasing causing the temperature at the Earth's surface to rise, (IPCC, 2007). Fossil fuel combustion and land use change including deforestation, soil organic carbon emissions, biomass burning and drainage of wetlands have resulted in increased carbon emissions (IPCC, 2007). There are suggestions that global surface air temperature may increase by 1.4 ^{o}C to 5.8 ^{o}C at the end of the century (IPCC, 2001). The increase in surface air temperature level is more directly linked to the increase in the concentration of CO_2 in the atmosphere. The risk is that increasing global temperatures could negatively affect biological systems, (Lal, 2004). Higher temperatures may also cause higher sea levels due to melting of polar icecaps thereby disrupting the marine and fresh water ecosystems, increase heat related diseases, change rainfall patterns and increase the geographical spread of disease vectors, insect pests and invasive weeds, (IPCC, 2001; Douglas, 2004). The effect of rising temperature on agriculture could be more devastating. Shifts in precipitation and temperatures may hinder some cropping patterns while at the same time benefiting others. With rising global human population, any reduction in crop production due to rainfall or temperature pattern induced reduced yield or disease or pest attack could have devastating effect on food insecure families.

These potential impacts have raised concerns over potential global climate change with the international organizations and nations. The World Climate Conference organized by World Meteorological Organization (WMO) in 1979 led to the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988. Four years later, an international environmental treaty, called United Nations Framework Convention on Climate Change (UNFCCC), was formulated with the objective of reducing global greenhouse gas emissions. The UNFCCC's Kyoto Protocol, (UN, 1998) formulated in 1997 stimulated the amount of emission reduction by industrialized nations and recognized forests or vegetative growth as carbon sequestration or potential carbon storage (Brown, 2002).

The agriculture sector is one of the largest contributors to carbon emissions behind energy production (Johnson *et al*., 2007). Emissions from agriculture account for an estimated 20 per cent of the annual increase in global GHG emissions. When land use change involving deforestation or clearing of land for agricultural expansion, soil degradation and biomass burning, the agriculture contribution to emissions is raised to one-third of all anthropogenic emissions, (Cole *et al*., 1997). The biggest contribution to the increase in carbon dioxide concentration comes from burning of fossil fuel, but agriculture also contributes significantly from biomass burning and other land use changes. Agriculture is considered a major contributor of methane and nitrous oxide, (Cole *et al*., 1997). Methane is emitted from flooded rice fields, wet lands and from animal raring. The major source of nitrous oxide emissions is the large scale production and application of inorganic nitrogen fertilizers. A lot of studies have been focused on reducing the emissions from agriculture, (Cole *et al*., 1997; Lal *et al*., 1998 and Lal, 2004). However, it is believed that emission reduction alone will not be sufficient to curtail the impacts on the environment and therefore long term carbon sequestration is necessary.

Carbon sequestration involves the capture and storage of carbon dioxide produced by burning of fossil fuels and other anthropogenic activities from the atmosphere and storing it away in long-lived carbon pools, (Nair *et al*., 2009). Some of the potential carbon storage sites include depleted oil fields, sedimentary rocks and injecting carbon dioxide in the sediments below the ocean and that dissolved in the oceans. The other method is through the terrestrial biological plant carbon sequestration; above-ground plant biomass and below-ground biomass such as roots. Plants use energy from the sunlight to convert carbon dioxide from the atmosphere to carbohydrates for their growth and maintenance, via the process of photosynthesis. Plants being autotrophs are able to absorb light energy and carbon dioxide. Carbon dioxide in the presence of light and water is converted to glucose which is stored as carbohydrates. Carbohydrates are stored as part of the body structure of the plant biomass in the form of cellulose, lignin and other macromolecules (Losi *et al*., 2003 and Phat *et al*., 2004).

2.2 Biomass and assessment

The amount of carbon dioxide stored in a natural carbon sequestration infrastructure such as photosynthesizing citrus biomass can be determined by measuring the amount of biomass. Biomass has been defined as the organic material both above-ground and below-ground, and both living and dead, such as citrus trees, crops, grasses, and others (FAO, 2004a). The above-ground biomass consists of all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. Below-ground biomass consists of all living roots excluding fine roots (less than 2 mm in diameter). Biomass is measured in fresh weight and dry weight. In carbon sequestration biomass is measured as dry weight; Carbon is taken to account for 50% of dry weight, (Timothy *et al*., 2005; Losi *et al*., 2003 and Juwarkar *et al* 2011; IPCC, 2005).

Many biomass assessment studies conducted focused on determining the above-ground biomass in natural forest by use of allometric equations, (Juwarkar *et al*., 2011; Adhikari, 2005; Brown, 1997; Brown *et al*., 1989; Vermer and de Meer, 2010; Phat *et al*., 2004; Lasco *et al*., 2008; Segura and Kanninen, 2005; and Zemeck, 2009) and by use of remote sensing, (Torio, 2007). Some studies have also been carried out aimed at estimating and modeling carbon sequestration in aforestation, agro-forestry and forest management, (Hairiah *et al.,* 2001 and Masera *et al*., 2003), with other crop specific studies such as Cocoa (*Theobroma cacao*), (Isaac *et al*., 2007) and coffee (*Shorea javanica*), (Noordwijk *et al*., 2002). Allometric equations have been used in the determination of aboveground biomass of natural forest tree species and these equations relate biophysical properties such as diameter at breast height (DBH) and height to biomass, (Brown, 1997; de Gier, 1999; Ketterings *et al*, 2001; de Gier, 2003 and Zianis and Mencuccini, 2004). Few studies have focused on carbon sequestration in orchards, (Page, 2011 and Marble *et al*., 2011). Morgan *et al*, (2006) did a study to determine nitrogen and biomass accumulation in citrus (*Citrus sinensis* (L.)) using the destructive method of biomass determination. Orchard species have higher growth rates and thus accumulates large amount of carbon in the first stage, (14-20 years) of their life span (Manner *et al*., 2006) after which they virtually stop growing. On the other hand natural forest trees have higher specific gravity and are slower growing species which allows them to accumulate more carbon in the long term. Natural forest trees are reported to continue accumulating biomass over a longer period of time (Hairiah *et al*., 2001). Biomass is an indicator of carbon sequestration and hence the need to determine the biomass of perennial crops including citrus trees, mangoes and many other agro-forestry trees.

The procedure employed in the determination of aboveground biomass is outlined in Timothy *et al* (2005). The method involves randomly selecting sample trees, measuring the growth variables (i.e. DBH or tree height) and relating these variables to tree biomass.

There are two methods available for measuring sample tree biomass- these are the destructive and non-destructive. The conventional destructive method is done by felling the sample tree and then weighing it and this procedure is very laborious and costly. The non-destructive method does not require the trees to be felled. Biomass is determined from allometric equations that have been specifically developed for calculating biomass for dry tropical forests (Brown, 1997) for citrus and agro-forestry shade trees (Schroth *et* *al*., 2002) Andhra Pradesh Forest Department, (2010) and Segura *et al*., (2006) In this study a non-destructive method was used to determine biomass.

2.3 Botanical characterization of citrus

The *Citrus sinensis* (L.) species is in the family of Rutaceae which belongs to the order Sapindales in the Magnoliopsida and Magnoliophyta class and phylum respectively. The other popular members of the family Rutaceae include mandarin (*C. reticulata*), grape fruit (*C. paradisi*), lemons (*C. limon*) and the limes (*C. aurantifolia*), (Harley *et al.*, 2006). Common sweet orange varieties include the Washington Navel, Valencia Late, Delta and Midnight. Others are the Pineapple, Bahianinha, Hamlin and Oasis (FAO/MACO, 2007).

In Zambia, sweet oranges are grown as exotic evergreen medium sized trees. They are cultivated under varied agro-ecological conditions ranging from dry hot regions (Region I) to wetter subtropical regions (Region III). The water requirement range is from about 800 mm to 2000 mm per annum and they are commonly grown under irrigation in areas with lower amount of rainfall. Citrus grow well between a temperature of 13 ºC and 37 ºC and can be grown in a wide range of soils ranging from sandy loam or alluvial soils to clay loam or heavy clay soils (Manner *et al*., 2006). Citrus requires the external supply of essential nutrients (N, P, K) and protection against pests and diseases and weeds through the application of agro-chemical inputs. The supply of water is essential during the drier part of the year.

The citrus growth rates are enhanced by application of fertilizers. Young trees in the range of 5-10 years have higher growth rates. The optimum tree size is typically reached between 10 and 14 years after transplanting and reaches peak fruit bearing age between 20 and 25 years. The citrus trees, however can survive up to 250 years for ornamental trees (Manner *et al*., 2006). The application of agro- inputs do not only cost farmers money, but also impact negatively on the environment by increasing greenhouse gases which eventually results in increased ambient temperatures. It is postulated that increase in global temperatures will result in higher water holding capacity of the atmosphere with precipitation expected to change. The coastal areas are anticipated to experience increase in rainfall, whereas other areas would record decline in annual rainfall. Generally, potential evapo-transpiration is expected to exceed the summer precipitation with an increased frequency in droughts (IPCC, 2001). The potential impacts of climate change on agriculture will be reflected most directly through the response of crops, soils, weeds, insects and diseases to the elements of climate to which they are most sensitive. Many weeds as well as plants are expected to benefit from increased carbon dioxide concentration through enhanced photosynthesis. Insect pests, fungal and bacterial pathogens of importance to agriculture production are sensitive to the effects of the changes in moisture and temperatures on the pest or pathogen, on the host susceptibility and the host-parasite inter-relations as high moisture and temperatures favour the spread of pests and diseases.

2.4 Life cycle assessment method of assessing environmental impact

Greenhouse gas emissions due to the application of agro-chemical inputs and the energy use on the orchards can be assessed using carbon footprints based on life cycle assessment methods. Life Cycle Assessment (LCA) is defined as a quantitative process for evaluating the total environmental impact of a product over its entire life cycle, referred to as a cradle to grave approach. LCA focuses on the product, with emphasis on quantifying the environmental impacts (Heijungs, 1996). The LCA consists of four phases; namely goal definition and scope, inventory analysis, impact assessment and interpretation. The goal definition and scope phase includes identifying the product or function to be studied, the reasons for carrying out the study, defining the system boundary, and identifying the data requirements. Inventory analysis involves identifying the process involved in the system, defining the inputs and outputs of each process, and collecting data to quantify those inputs and outputs. Impact assessment defines impact categories and uses the results of the inventory analysis to calculate indicator results in those categories.

Finally, in the interpretation phase the results of the inventory analysis and impact assessment are interpreted in terms of the goal and scope definition; the results are checked for completeness, sensitivity, and consistency; and conclusions, limitations, and recommendations are reported (ISO, 1997). Further LCAs generally fall into two categories based on their purpose, that is, attributable and consequential LCAs. The former is focused on looking back on a product and determining what emissions can be attributed to it while the latter is directed on the environmental effects of what will happen due to a decrease or increase in demands for goods and services (Ekvall and Weidema, 2004).

Carbon Footprint is a measure of the exclusive total amount of carbon dioxide (CO_2) and other Greenhouse Gas (GHG) emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product and is usually expressed in kilograms of CO_2 equivalents, which may account for different global warming effects by different Greenhouse Gases. Carbon Trust (2007) also broadly defines Carbon Footprint as a methodology to estimate the total emission of greenhouse gases (GHG) in carbon equivalents from a product across its life cycle from the production of raw material used in its manufacture, to disposal of the finished product (excluding in-use emissions). Its also defined as a technique for identifying and measuring the individual greenhouse gas emissions from each activity within a supply chain process step and the framework for attributing, these to each output product. The greatest challenge facing sustainability of ecosystems and therefore human kind is the emissions of the major green house gases; Methane (CH_4), Nitrous oxide (N_2O) and Carbon Dioxide (CO_2) in the atmosphere (Millennium Ecosystem Assessment, 2005 and Watson *et al.*, 1998) which have different global warming potential. A Global Warming Potential (GWP) is an indicator that reflects the relative effect of a greenhouse gas in terms of climate change when a fixed time period, such as 100 years is considered (IPCC, 2007).

A number of studies have been conducted that aimed at modeling energy and material flows in citrus orchard production systems (Ozkan *et al.*, 2003; Dalgaard *et al.*, 2001 and Namdari *et al.*, 2011). Other studies have focused on carbon emissions from farm operations with emphasis on tillage operations and the associated emissions reductions from conventional tillage to zero tillage (Lal, 2004 and West and Marland, 2002). Studies conducted using the life cycle assessment approach include that of Wood and

Cowie (2004) which gave the emission factors associated with the production of chemical fertilizers-N, P_2O5 and K_2O. Life cycle assessment based carbon foot-printing of orchards have also been done by researchers with a focus on Kiwifruits and apples (Page, 2011), from which lessons were drawn during this study.

The emissions from inputs included the energy in the acquisition and use of agro-chemical inputs and the use of farm machinery and equipment. This includes the use of fossil fuels for running of tractors, electricity for running of water pumps and the emission due to the manufacture, packaging, transportation and use of inorganic fertilizers and pesticides. LCA approach has been used to calculate carbon footprints of sugar cane in Zambia (Plassmann, 2010).

2.5 Carbon emission associated with agricultural inputs

2.5.1 Fuel and electricity

The use of fossil fuels in agriculture results in CO_2 emissions from the combustion of the fuels and the additional emission associated with the production and delivery of fuels to the farm (West and Marland, 2002). Carbon emissions due to burning of fossil fuels are estimated using carbon emission coefficients. Carbon dioxide emissions attributable to electricity consumption are based on the fuels or energy used in power generation. The Carbon dioxide emissions are determined per kilo watt-hour (kWh) of electricity generated, transformed, distributed and used. The CO_2 emissions include emissions from the energy sources that fossil fuels (coal, oil and oil products and natural gas), that are consumed for electricity and heat generation in transformation and output of electricity and heat generated. The other sources of energy in the generation of electricity include nuclear energy, hydro-power, geothermal and solar energy. The carbon dioxide emissions per kWh vary depending on the source of energy and its environmental friendliness. Nuclear and hydro-power energy generated electricity has high carbon emissions during construction but low during operations (OECD, 2011 and Carbon Trust, 2011). Natural gas shows the least carbon emissions.

2.5.2 Chemical fertilizers

Chemical fertilizers are used to supply nitrogen (N), phosphorous (P) and Potassium (K) and in addition to other essential elements (West and Marland, 2002). In terms of climatic impact carbon dioxide emissions are considered as a result from the energy required for production of fertilizers and the energy required for their transport and application. The energy required to produce a unit weight of nitrogen and phosphorous differs considerably with the form in which the nutrient is supplied. The weighted average energy used for the production of nitrogen is estimated at 55.48 MJ/kg of N and the average energy requirement for phosphorous production is estimated to be 4.52 M J/kg of P_20_5 while that for potassium is estimated at 4.80 MJ/kg of K_2O (Bhat *et al.*, 1994). The lower heating value of diesel is 35.8 MJ/liter (ANL, 2009). Natural gas which is the major source of energy in fertilizer production has a lower heating value of 31.65 MJ/kg and a higher heating value[1] of 54.4 MJ/kg. The carbon emissions from the production of fertilizers include all emissions from the extraction of minerals, through the fertilizer manufacture to application, (Bhat *et al.*, 1994). Post production emissions are those from packaging, transportation and field application (Mudahar and Hignett, 1987). In the production of urea steam is credited to the production process (Bhat *et al.*, 1994).

2.5.3 Pesticides

Most modern chemical pesticides are produced from crude petroleum or natural gas products. The total energy input is thus both the material used as feedstock and the direct input of energy in the manufacture. Carbon dioxide emissions from post-production of pesticides include the formulation of the active ingredients into emulsifiable oils, wettable powders or granules, including those from packaging, transportation and application of pesticides formulations.

The Greenhouse Gases Regulated Emissions and Energy in Transportation, GREET Model (ANL, 2009) is used to calculate the upstream emissions associated with the production and delivery of electricity, diesel, fertilizers and pesticides. Direct emissions and those from the burning of fuel can be determined using factors given in 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines (IPCC, 2006b). Air pollutants namely Volatile Organic Carbon (VOC) and Carbon Monoxide (CO) are calculated from the formulas and emission factors given in the US Environmental Protection Agency's NONROAD MODEL (EPA, 2004, 2005, and 2010).

Calculated greenhouse gas emissions are converted to carbon dioxide equivalents using their global warming potential. Global Warming Potential (GWP) has been defined as an indicator that reflects the relative effect of a greenhouse gas in terms of climate change when a fixed time period, such as 100 years is considered (IPCC, 2007). The GWP_{100} of carbon dioxide is taken as the basic unit and the GWPs of other gases are compared to that of CO_2 equivalents. One kilogram of CO_2 is equal to one kg of CO_2e, one kg of methane CH_4 is equal to 25 kg CO_2e and one kg of nitrous oxide (N_2O) is equal to 298 kg of CO_2e PAS 2050 (2011). The air pollutants such as volatile organic carbon (VOC) and carbon monoxide (CO) are taken to have the GWP of 3.04 and 1.57 respectively.

The net sequestration (negative or positive) of carbon is dependent on plant species, management systems and other environmental conditions (Jana *et al.*, 2009). It is expected that high levels of external inputs reduce the net carbon sequestered. Older plants have a higher net carbon sequestered, as such, plants are expected to receive less external inputs beyond the optimum fruit bearing age is reduced or stopped.

Chapter 3

3.1 MATERIALS and METHODS

Plant materials

Fourteen citrus orchards in the three districts of Lusaka Province were chosen and visited to conduct the study and interview farm owners/managers. The study sites (orchards) were chosen based on availability after consultation with the Ministry of Agriculture and Livestock Lusaka province officers and also on the farm owner agreeing to have the study done in their fields. The visits were conducted between September 2011 and January 2012. To carry out the measurements on site of the tree biophysical parameters, the following tools/equipment were used. A tree diameter at breast height (DBH) tape and a Suunto Clinometer were used to measure the diameters and heights of the citrus trees respectively. A 30 m measuring tape and Garmin global positioning system (GPS) receiver were used to mark out size and position of the plots. A Casio digital camera was used to capture pictures. The measurements were recorded on pre-designed booking forms.

The study area

Lusaka province covers an area of 21,896 km^2 and lies between latitudes -14˚38.76'and -15˚57.48'South of the equator and between longitudes 27˚46.26' and 30˚24.6' E. This area lies in the central plateau with an average altitude of 1200 m above sea level (asl). Lusaka province lies in the agro-ecological Zone II with average annual rainfall between 800 mm and 1000 mm. The mean temperature of the area varies from 14.57˚C to 26.13˚C. The map (Figure 1) shows Lusaka Province from which research sites were selected (FAO LocClim, 2002).

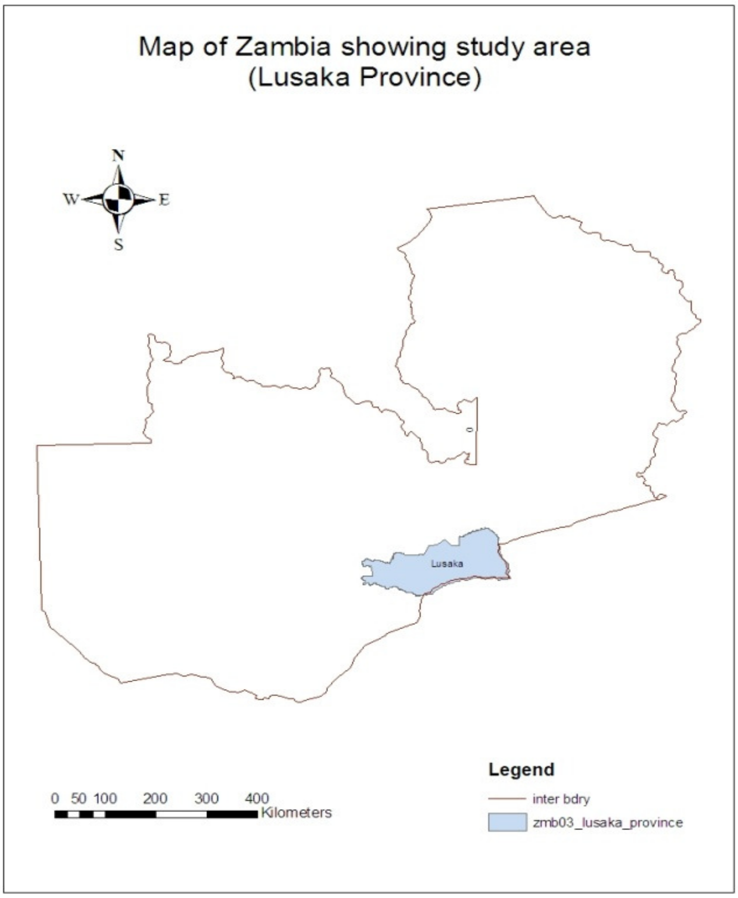

Figure 1: Map of the Republic of Zambia showing Lusaka Province

The research sites were selected orchards within selected areas within the province. The orchards were chosen from Chongwe, Kafue, Chilanga and Lusaka districts. The locations of the plots are shown in Table 1 and in Figure 2 where the coordinates as well as district camps where the plots were found were given.

Table 1: Location of the study plots within Lusaka Province

		Location			
Plot	Name of Farm/Area	District	Agriculture Camp	Longitude	Latitude
Plot 1	Auga (Fresh Farms)	Chilanga (Kafue)	Chilanga	28.241	15.621
Plot 2	Auga (Fresh Farms)	Chilanga (Kafue)	Chilanga	28.242	15.624
Plot 3	Auga (Fresh Farms)	Chilanga (Kafue)	Chilanga	28.243	15.639
Plot 4	Auga (Fresh Farms)	Chilanga (Kafue)	Chilanga	28.241	15.634
Plot 5	Auga (Fresh Farms)	Chilanga (Kafue)	Chilanga	28.243	15.631
Plot 6	Kabembe	Lusaka	Mitengo	-	-
Plot 7	Mulonga	Kafue	Chikupi	28.097	15.642
Plot 8	Mantimbe	Kafue	Chikupi	28.099	15.644
Plot 9	Palabana	Chongwe	Palabana	28.545	15.581
Plot 10	Sabonge	Kafue	Chikupi	28.098	15.645

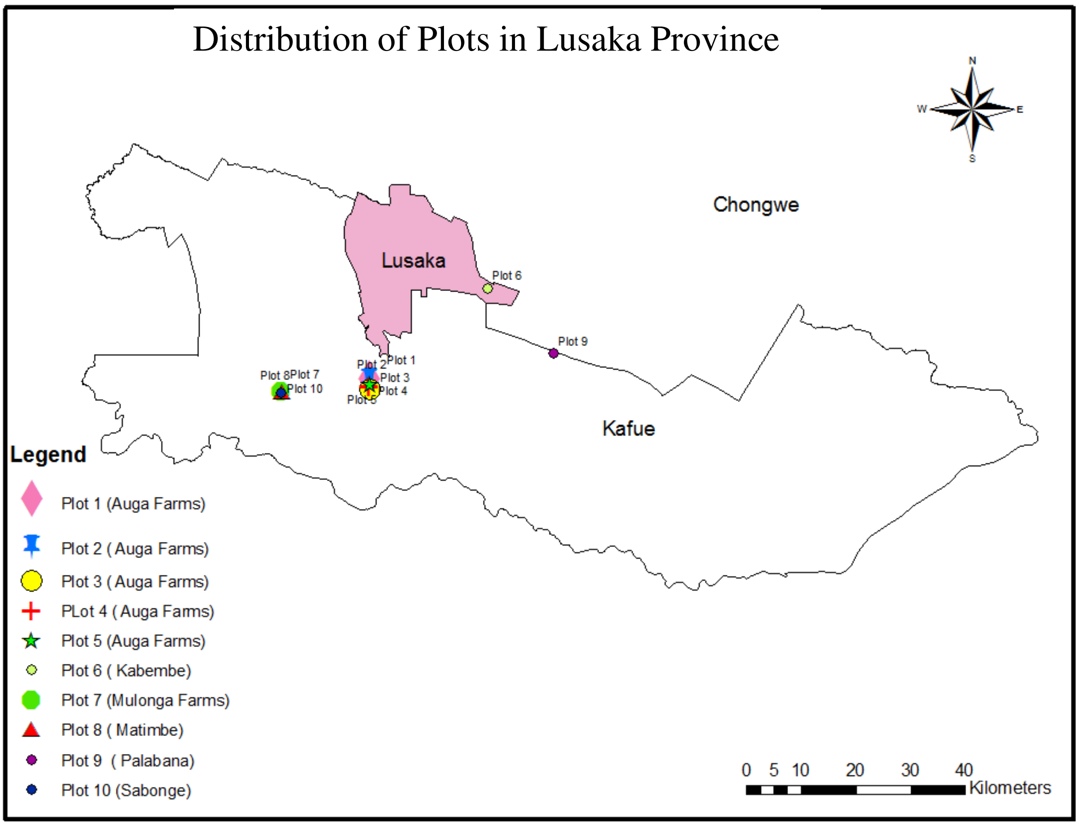

Figure 2: Study area-Map of Lusaka Province showing the distribution of the plots from the selected orchards.

3.1.1 Biomass determination

This study involved the non destructive method of aboveground biomass estimation by the use of allometric equations given by (Scroth *et al*., 2002; Brown, (1997); Andhra Pradesh Forest Department (2010); and Segura *et al*., (2006), to determine the aboveground biomass of citrus trees. Allometric equations (Table 2), which use the citrus tree diameter at breast height (DBH; normally taken to be 30 cm above the ground for oranges) was used to calculate the aboveground biomass of each tree in the plot. Measuring at this height avoids measuring the rootstock diameter that may be enlarged compared to the rest of the trunk/stem.

Sampling plots were located around the center of each orchard, and total enumeration was used for orchards which were smaller than 0.25 ha. The measured DBH was used to calculate tree biomass in kg/tree which was then converted to biomass per plot, carbon stock per plot and used expansion factor, to carbon per ha (Timothy *et al*., 2005).

Life cycle assessment based carbon foot- printing was used to determine the carbon emissions due application of inputs (Page, 2011; PAS 2050, 2011; OECD, 1999 and Kerckhoffs and Reid, 2007). The farmers were requested to give the history of the farm, highlighting the process of land clearing and the type of machinery used, agro-chemical inputs used, field management, and transportation of inputs and other farm requisites. The carbon footprints of inputs were then determined and converted to carbon dioxide equivalents. All the fields surveyed were not affected by the Land use and Land Use Change GHG emissions as they were cleared before the 31st December 1989 and there were reported no plans of expanding the fields into the natural forests.

Fourteen (14) orange orchards were selected from three districts of Lusaka province. Sampling plots in each orchard was done according to Timothy and others, (2005) and Hairiah *et al*., (2010). A minimum area of 20 m by 30 m plot size was sampled. For orchards smaller than 0.25 ha total enumeration was used. All the trees in each plot had their stem diameter (DBH) measured at 30 cm above the ground to avoid the grafted stem and the tree forking at 130 cm.

For trees that had multiple branches below 30 cm, each branch was measured as a separate tree and an equivalent DBH calculated (equation 2). Four allometric equations given by Brown, (1997); Andhra Pradesh Forest Department, (2010); Schroth *et al.*, (2002) and Segura *et al.* (2006), were used to estimate the aboveground biomass as per procedure. The results from the four equations were then averaged to improve the accuracy. The belowground biomass (roots) was calculated by dividing the aboveground biomass by four and the carbon content was calculated by dividing the total biomass by two and was then multiplied by 3.667 to convert biomass to CO_2 equivalents (Timothy et al., 2005; Hairiah *et al.*, 2010 and Juwarkar *et al.*, 2011).

To determine the type and amount of inputs used at each site, the farmer/manager was interviewed to obtain the history of the farm as regards the amount of inputs (energy/power sources, fertilizer and pesticides) used which contribute to GHG emissions. The interviewees were asked several questions aimed at establishing the cultural practices, the planting date, the amounts of external inputs and the period during which external inputs were applied and the responses recorded on a booking form. The GREET Model (ANL, 2009) was used to calculate the upstream emissions in the production and delivery of electricity, diesel, fertilizers and pesticides. Direct emissions from the burning of fuel were determined using factors given in 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines (IPCC, 2006). Air pollutants (Volatile Organic Carbon and Carbon Monoxide) were calculated from the formulas and emission factors used in the US Environmental Protection Agency's NONROAD MODEL (EPA, 2004, 2005 and EPA, 2010).

Table 2: Allometric equations for the calculations of aboveground biomass

No.	Allometric Equations	Source
1	Biomass = -6.64 + 0.279 x BA + 0.000514 x BA^2	Schroth *et al.*, (2002)
2	$V=0.184105-3.07474D+16.448494D^2-12.38362D^3$	Andhra Pradesh Forest Department, (2010)
3	Log_{10}Biomass = -0.834 + 2.223 (log_{10}DBH)	Segura *et al.*, (2006)
4	Y = exp(-1.996 + 2.32 ln (DBH)	Brown, (1997)

Biomass was calculated in dry weight of citrus tree in kg/tree
BA is basal area calculated from trunk diameter
V denoted volume of the tree in cubic meters
D was diameter at breast height (DBH) in meters measured at 130 cm, but for citrus DBH is measured at 30 cm aboveground
Y was expressed as tree biomass in kg/tree

3.1.2 System boundary

The life cycle approach of carbon foot printing of each product at the farm/orchard level was established and used to determine the total carbon emissions. The Life Cycle Assessment based carbon foot printing methods are applied to activities identified within a systems boundary (Figure 3). In citrus production the activities range from land acquisition up to the point before harvest. The systems boundary included emissions released per hectare of an orchard as a result of land preparation, application of external inputs such as fertilizers, pesticides, water and the use of electricity and machinery (EPA, 2010). The upstream boundary includes the emissions from the production of fertilizers, pesticides, fuels and electricity. The system boundary does not include the emissions due to the production of farm machinery, farm roads and farm buildings. The emissions associated with harvesting, transport and storage of the fruits were considered outside the system boundary (Figure 3). The activities enclosed by the doted lines, with the exception of seedling production, planting and harvesting, were considered in the determination of orchard GHG emissions.

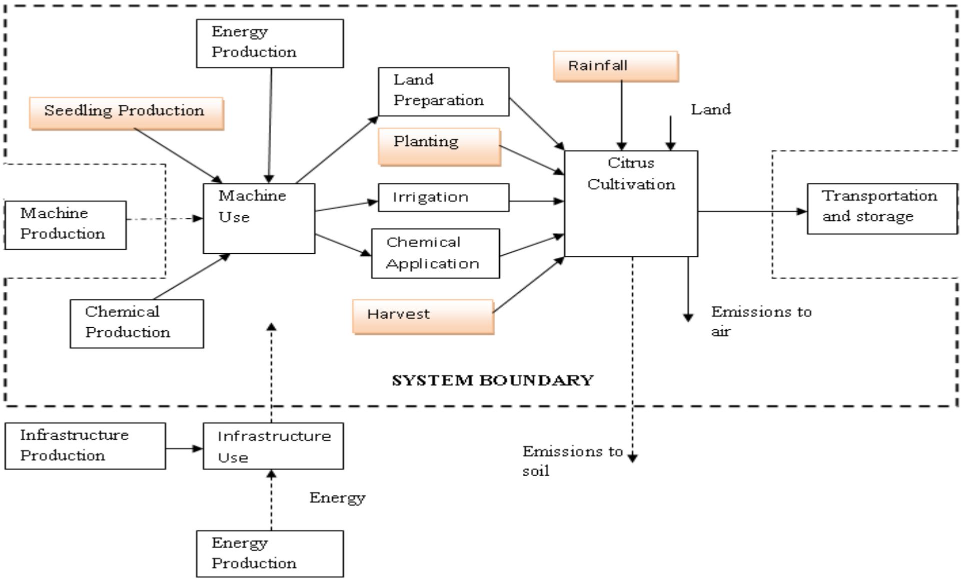

Figure 3: Systems boundary concept (Source: EPA, 2010).

3.2 TABULATION EQUATIONS

3.2.1 Biomass determination (carbon sequestration)

Aboveground biomass

The aboveground biomass was determined using allometric equations given in Table 1 for *Citrus sinensis* and agro-forestry crops as shown in equations 1 to 4.

$$AGB_{Tree} = -6.64 + 0.279 \text{ x BA} + 0.000514 \text{ x} BA^2 \quad \text{.......................................1}$$

$$AGB_{Tree} = (0.184105 - 3.07474D + 16.448494 * D^2 - 12.38362 * D^3) * \rho \quad \text{.........2}$$

$$AGB_{Tree} = 10^{(-0.834 + 2.223 * logDBH)} \quad \text{..3}$$

$$AGB_{Tree} = \exp\,(-1.996 + 2.32 * \ln(DBH)) \quad \text{..4}$$

Where AGB_{Tree} is the aboveground biomass per tree (kg/tree), DBH is trunk diameter at 30 cm aboveground (cm), D is DBH (m), ρ is average density of trees for Equation 2 and BA is basal area.

The basal area was calculated from the following equation;

$$BA = \pi \frac{DBH^2}{4} \quad \text{..}5$$

Where DBH is the orange tree diameter at 30 cm above the ground

For forked orange trees that have two or three branches emerging below the 30 cm mark, the DBH_i of each branch was measured separately and then the equivalent combined diameter and calculated as in the equation below.

$$DBH = \sqrt{DBH_1^2 + DBH_2^2 + DBH_3^2} \quad \text{..}6$$

Where DBH_1, DBH_2, DBH_3 are diameters of forked branches

The total aboveground biomass (AGB_{Plot} kg) per plot was calculated by summing the aboveground biomass per tree (AGB_{Tree} kg) of all the trees in the plot as shown below.

$$AGB_{Plot} = \sum AGB_{Tree} \quad \text{...}7$$

The total aboveground biomass (AGB_{ha} kg/ha) per hectare was calculated from the following relationship;

$$AGB_{ha} = AGB_{Plot} * \frac{10{,}000\ m^2}{Area\ of\ plot\ in\ m^2} \quad \text{...}8$$

Estimation of the Belowground Biomass

The belowground biomass (BGB_{ha}, Mg/ha) was estimated from the ratio of the shoot to root ratio of 4:1 (Hairah *et al.*, 2010). From this relationship, the BGB_{ha} can be calculated as follows;

$$BGB_{ha} = \frac{AGB_{ha}}{4} \quad \text{.........9}$$

The results obtained from this equation can be compared with the BGB_{ha} calculated using the regression equation for the belowground biomass for tropical trees, as shown below (Timothy *et al*, 2005);

$$BGB_{ha} = \exp\left(-1.0587 + 0.8836 * lnAGB_{ha}\right) \quad \text{.........10}$$

Where BGB_{ha} is the belowground biomass density, and AGB_{ha} is the aboveground biomass density (Mg/ha)

Estimation of the total biomass

The total biomass ($Biomass_{ha}$, Mg/ha) was obtained by adding the aboveground and belowground biomasses.

$$Biomass_{ha} = AGB_{ha} + BGB_{ha} \quad \text{.........11}$$

To estimate the amount of carbon content (Mg C ha^{-1}) from biomass, the following relationship was used:

$$C = \frac{Biomass_{ha}}{2} \quad \text{.........12}$$

The Carbon estimated to be sequestered per hectare was then converted to carbon dioxide equivalents (CO_2e.) as follows; the carbon equivalent per plot calculated as the average of the four allometric equations (equations 1, 2, 3 and 4).

$$CO_2e = C * \frac{44}{12} \quad \text{.........13}$$

3.2.2 LCA BASED CARBON FOOTPRINTS OF ORCHARDS

The initial activity in establishing an orchard involves preparing land for planting tree seedlings. Land is plowed to loosen the soil to facilitate root growth, remove weeds and form beds or basins that helps tending operations and irrigation. Irrigation and drainage systems are also created at this time. After planting several activities follow that include mechanical or chemical weeding, pruning and maintenance. Although citrus can live up to 100 to 250 years, a conservative 40-year life-span for the orchards was assumed. The GHG emissions from the initial land clearing and preparation activity were amortized at the rate of two and half percent per hectare per year. It was assumed that four percent of established orchard of old, less productive (less than 50% of expected production), or diseased trees were removed per year and the land is reworked in preparation for the re-planting of new trees on annual basis, (Muraro, 2008a). The existing trees are removed and the land plowed, harrowed and the beds formed in readiness for replanting of new trees. The removed trees were assumed to be burnt resulting in the release of GHG emissions.

Some of the equipment/machinery reported to be used in the above mentioned operations included tractors of different sizes, plows and harrows. It was however, difficult to establish the amount of fuel consumption from the information given by the farmers. Literature from Ministry of Agriculture and Cooperatives Farm Management guide (MACO/FAO, 2007) and publication by Hinson *et al.*, (2006) were used to determine the missing information.

The summary of the GHG emissions considered for each of the ten orchards in this study included the following;

i) Direct emissions due to burning of fossil fuels including emission of air pollutants such as volatile organic carbon and carbon monoxide,

ii) Burning of replaced trees (four percent of the plant biomass per hectare),

iii) Emissions from electricity production and use for the electricity used in the pumping of water for irrigation,

iv) Upstream emissions from energy used in the production of fuels-diesel,

v) Upstream emissions from energy used in the production, packaging and transportation of fertilizer and pesticides and

vi) Nitrous oxide emissions due to application of fertilizers and emissions from crop residue.

The above listed emissions were summarized, converted to their respective global warming potentials and summed up. All carbons emissions were considered negative (carbon sources) and carbon sequestration as positive (carbon sinks) in the data analysis.

i) Direct emissions due to burning of fossil fuels

Greenhouse gas emissions from burning of diesel fuel were estimated using the IPCC emission factors (IPCC, 2006a). At diesel lower heating value (LHV) energy content of 35.8 MJ/litre, the default carbon dioxide (CO_2) emission rate for agricultural diesel operations is 2650 g CO_2, for methane (CH_4) is 0.149 g and 1.02 grams for N_2O per liter of diesel combusted, (ANL, 2009; NONROAD Model (EPA, 2004; 2005 and Hinson *et al.*, 2006).

Emissions of air Pollutants

During the operations of agricultural machinery air pollutants such as volatile organic carbons (HOC), carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM), and sulfur dioxide (SO_2) are released to the air due to fuel (diesel, petrol and others) combustion. This report only considers HOC and CO emissions which eventually convert to CO_2, a major contributor to global warming. And these emissions were calculated from the formulas and emission factors used in the US Environmental Protection Agency's NOROAD model (EPA, 2004). For a diesel internal compression ignition (CI) engine, the VOC and CO exhaust emission factors were calculated as follows:

$$EF_{adj\,(HC,\;CO,\;NOx)} = EF_{SS} * TAF * DF \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 14$$

Where; EF_{adj} is the final emission factor adjusted to account for transient operation and deterioration in grams per horsepower-hour (g/hp-hr), EF_{SS} is the zero-hour, steady state emission factor (g/hp-hr), *TAF* is the transient adjustment factor and *DF* is the deterioration factor.

To determine *DF* and EF_{SS}, the model year, age, horse power size and technology of the engine has to be known.

The emissions of the particulate matter (PM) are dependent on the sulfur content of the fuel the engine is burning. To calculate PM, equation 14 was adjusted to account for the differences in sulfur content of the fuel and is written as follows;

$$EF_{adj\,(PM)} = EF_{ss} * TAF * DF - S_{PMadj} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 15$$

Where; S_{PMadj}, defined in the equation below, is the adjustment to PM emission factor to account for variations in fuel sulfur content (g/hp-hr), PM and SO_2 being the only diesel pollutants that are dependent on fuel sulfur content and EF_{SS}, *TAF* and *DF* were defined in equation 16. Particulate matter (PM) emissions were not considered in this study.

$$DF = 1 + A * (age\ factor)^b \qquad for\ age\ factor\ \leq 1 \ \ldots\ldots\ldots\ldots\ldots\ldots 16$$

$$DF = 1 + A \qquad for\ age\ factor\ > 1 \ \ldots\ldots\ldots\ldots\ldots\ldots 17$$

Where; *age factor* is the fraction of median life expended is the $\frac{cumulative\ hrs * load\ factor}{median\ life\ at\ full\ load, in\ hours}$ and *A* and *b* are constants for a given pollutant/technology type; $b \leq 1$.

Calculation of air pollutants

For a diesel internal compression ignition (CI) engine, the volatile organic carbon and carbon monoxide exhaust emission factors were calculated as shown below. An 80 HP tractor and assumed to have been manufactured before 1990 with tier 1 technology and taken to be at its median life (half of life span) in 1990 was considered. The results of the calculations were shown in Table 20 and Table 21.

For diesel engines, b = 1

Activity hours = 475 (EPA, 2010)

Load factor = 0.59 (EPA, 2010)

Expected Engine life = 4667 hours (EPA, 2010)

Cumulative hours = 2375 hours

The emissions factors are calculated using formulas and tables (Tables; A1, A2, A3 and A4) from EPA report, (EPA, 2004).

$DF = 1 + A*(2375*0.59)/4667$, $A_{(HC, CO)} = 0.047, 0.185$

$DF_{(HC, CO)} = 1.014, 1.055$

$EF_{SS(HC, CO)} = 0.5213, 2.3655$

$TAF_{(HC, CO)} = 1.05, 1.53$

$EF_{adjHC} = 0.5213*1.05*1.014 = 0.555$ g/hp-hr

$EF_{adjCO} = 2.3655*1.53*1.055 = 3.818$ g/hp-hr

$EF_{adjHC} = 7.36$ g/litre

$EF_{adjCO} = 50.62$ g/litre

Emissions of VOC and CO from land maintenance activities

The calculation of the emissions of VOC and CO for land preparation was also done for land maintenance using emission factors and formulas, (EPA, 2004).

ii) Burning Replaced Citrus Tree

The old trees that were removed from the orchards were assumed to be burned. The amount of the dry matter to be burned depends on the amount of biomass per tree per hectare. This was determined by the number of trees replaced per hectare. And the emissions that are released to the atmosphere during tree burning contain a number of gaseous species many of which may contribute to net greenhouse emissions and air pollutant levels. The total emissions released depends upon the amount of matter that was available to be burned, the fraction that is actually burned and the emission factor for each species, (Muraro, 2008a and Futch *et al* 2008). The amount of dry matter that was estimated to be burnt in the fields studied was taken to be four percent of the amount of biomass per ha. This means that smaller amounts of biomass was burnt for smaller trees. The emission factors for different species of GHGs were used, (Andreae and Merlet, 2001 and IPCC, 2006b).

Amortization of emissions

The investment in initial land preparation and the associated carbon emissions was spread over an assumed life span of the orchard (40 years) at the rate of two and half percent per annum. The emissions due to tree burning and land maintenance activities were also treated as being four percent of the total emissions per hectare.

Cultural Activities

The orchard tending activities, although very necessary contribute to carbon emissions. The main aims of performing cultural operations are to maintain the orchard in a weed-free environment, to protect the trees and fruit from damaging insects, microbes and nematodes, and to provide the plants with adequate water and nutrients. Pruning of the citrus trees is also done to keep limbs (bearing branches) away from the ground, and to reduce the amount of vegetative growth and to control the shape and height of the tree to enhance hand harvesting and allow more light into canopy for attractive colour of fruits. There are slight differences in the management of young trees (within the first five years of planting) than with mature ones. The management of weeds was reported to have been done through mechanical cultivation, slashing and the application of herbicides. Although herbicides are said to be effective and easier in weed control, it was noted that if not properly applied could affect the quality of the fruits. This however, has not reduced the importance of herbicides as tools available to the citrus farmer in management of unwanted plants. The weed population needs to be minimized in order to eliminate plants that could compete with the shallow-rooted citrus trees for both water and nutrients. In addition, weeds tend to reflect solar energy, which prevents the underlying soil from heating up during the day.

Carbon Emissions from cultural practices

The emissions from the cultural practices were calculated from the emissions factors given in the IPCC guidelines, (IPCC, 2006a).

VOC and CO emissions from cultural activities

The emissions of VOC and CO were calculated using emissions and formulas in US EPA (EPA, 2004). The calculation of these emission factors depend on the tractor model technology, the annual activity cumulative hours and the load factor and expected engine life.

iii) Emissions from electricity used in pumping water for irrigation

The orchards numbered as Plot 1, Plot 2, Plot 3, Plot 4 and Plot 5 were irrigated by pumping water from boreholes using two pumps powered by three phase electricity from the main Zambia Electricity Supply Cooperation grid supply lines. The two pumps were Mono Pumps rated 30 horse power and each of them running for adequate time per day for every 14 days from April to mid November each year. The pumps were used to pump the water into reservoir. For Plot 10 water was pumped from a shallow well and irrigation water for plot 6 was pumped from a stream. The energy consumption is calculated from the equation 18 given below.

$$P_{ir} = hp * \frac{0.7457}{\eta_{fl}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 18$$

Where; P_{ir} is the input power at full rated load in kW, hp is the nameplate horse power, η_{fl} is the efficiency at full-rated load (75%).

iv) Energy for the production of liquid fuels

There is energy that is expended in the acquisition of energy. Electric energy was used to run pumps, while diesel was used to run tractors. The energy used in the production of electricity and diesel were calculated from the emission factors given by Argonne National Laboratories' GREET Model (ANL, 2009).

Emissions from the Production of electricity and Diesel

Energy related emissions, including emissions from the energy used in the production of fuel and electricity were calculated using the Greenhouse gases Regulated Emissions and Energy in Transport (GREET Model: 2011) program developed by the US Environmental Protection Agency (EPA). The program calculates the energy carbon emissions associated with the production of fuel and its transportation from the oil field to the Pump (Filling Station) known as Well to Pump (W-T-P) and are given in grams per mmBtu. The Model can also calculate the carbon emissions associated with the use of the fuel commonly referred as well to wheals (W-T-W) which is given in grams per mile. Using the GREET Model: 2011database, (ANL, 2009; EPA, 2010 and GREET Model, 2011), the emission factors due to the production of fuels and electricity, after converting the units to grams per mega joules.

Agro-chemical inputs

To maintain healthy and productive citrus plants, nutrients, pesticides water are applied to the orchard. The fertilizers Calcium Ammonium Nitrate and Ammonium Nitrate were used as a source of nitrogen, while Potassium Sulphate was used to supply potassium. Several insecticides, fungicides and herbicides were used to control insects, diseases and weeds respectively. A Sprayer boom was used to apply the pesticides for small low input orchards.

v) Energy in-puts in fertilizer and pesticide production

The amount of energy consumed in the production of agricultural chemicals (fertilizers and pesticides) is significant. The upstream energy for the production, packaging and transportation of fertilizers are taken from Bhat *et al*. (1994). The upstream energy for the manufacture, formulation, packaging and transportation of pesticides were also taken from Bhat *et al*. (1994), which is the most comprehensive literature found on the upstream energy for the production of agro-chemical inputs. The GREET model (ANL, 2009) is used to determine the values of carbon emissions associated with the manufacture and transportation of fertilizers and pesticides.

Upstream Emissions from production of fertilizers

The source of energy in the production of fertilizer is derived from Natural gas and electricity, while that for transportation is usually from diesel in the proportions given by Bhat *et al*., (1994). The carbon emissions were determined using the GREET Model, (ANL, 2009; GREET Model: 2011) and thus apportioned accordingly.

vi) Nitrous oxide emissions due to fertilizer application

Direct greenhouse gas emissions are also released as a consequence of using fertilizers. The rate at which the emission occurs can be determined using the IPCC guidelines (IPCC, 2006b). In considering only nitrogen fertilizer application, the rate of direct N_2O emissions can be calculated from the following equation;

$$N_2O_{fert.\ emissions} = N_{mass\ applied} * EF_{applied} * \frac{N_2O_{mw}}{2*N_{aw}} \quad \ldots\ldots\ldots\ldots 19$$

Where; $N_2O_{fert.\ emissions}$ is the mass of annual nitrous oxide emissions per unit area due to fertilization [kg/unit area], $N_{mass\ applied}$ is the mass of nitrogen fertilizer, as nitrogen, applied annually per unit area, $EF_{applied}$ is the emissions factor for added nitrogen, taken to be 0.01 per IPCC guidelines (IPCC, 2006b) and $N_2O_{mw}/(2*N_{aw})$ is the conversion factor for nitrogen to nitrous oxide, equal to 44/28.

Carbon dioxide emissions due to urea application

The application of urea fertilizer to orchards as a source of nitrogen produces emissions of CO_2 as well as N_2O. Urea CO(NH2)2 in the presence of water, reacts to form ammonium ($NH4^+$), hydroxyl ion (OH^-), and bicarbonate (HCO_3^-). The bicarbonate ion then reacts further to form CO_2 and water. During the manufacturing of urea, CO_2 from the atmosphere is consumed which is released from the urea upon use. From the IPCC guidelines it was assumed that all of the carbon in the urea is oxidized to CO_2 and released as emissions to air. The CO_2 emissions are calculated as shown in the relations on the conversion of carbon to carbon dioxide;

$$CO_{2emissions} = M_{urea}*12/28*44/12$$

Where; $CO_{2emissions}$ is the mass carbon dioxide emission as result of applying urea, converted from the nitrogen to carbon dioxide and M_{urea} is the mass of urea applied to a unit area.

Nitrous oxide due to residue from trimmings left on the field

The exact amount of biomass pruned and left on the ground was not determined. Five percent (5%) of standing biomass is pruned from citrus trees annually (UNFCCC/NUCC, 2011). The amount of nitrogen in pruned residues is estimated at

0.5% of the total biomass, (IPCC, 2006b). Equation 20 below was used to calculate the nitrous oxide emissions from the crop residues.

$$N_2O_{CR} = M_{CR} * FRACTION_{NResidues} * EF_{NResidues} * \frac{N_2O_{mw}}{2*N_{aw}} \text{ ....20}$$

Where; N_2O_{CR} is the mass of annual nitrous oxide emissions due to pruning residues per hectare [kg/ha], $M_{CR, N}$ is the mass of the trimmings as calculated from the average of the allometric equations, $FRACTION_{Residues}$ is the fraction of nitrogen in the pruning residues, estimated to be 0.005 for a mixture of leaves and twigs, $EF_{N\ Residues}$ is the factor for crop residue nitrogen, taken to be 0.01, as per IPCC guidelines, $N_2O_{mw}/(2*N_{aw})$ is the conversion factor for nitrogen to nitrous oxide, taken to be equal to 44/28.

Nitrous Oxide due to volatilization for the application of urea

In addition to N_2O emissions that are released directly from fertilized cropland, indirect emissions occur either when N volatilized as NH_3 or oxides of nitrogen (NO_X) and subsequently deposited either in its gaseous form or as $NH4^+$ and NO_3^- onto soil, water, or plant surfaces or through the process of nitrification and denitrification by which N_2O is formed and released to the atmosphere. Sources of nitrogen that contribute to indirect emissions of N_2O from citrus farming include chemical fertilizer application and crop residues (tree trimmings left on the ground after pruning), EPA, (2010). The nitrous oxide indirect emissions are accounted for using IPCC guidelines (IPCC, 2006b), as shown in the equation 21 (due to volatilization) and equation 22 (due to leaching) below.

$$N_2O_{volatilization} = N_{mass} * FRACTION_{volatilization} * EF_{volatilization} * \frac{N_2O_{mw}}{2*N_{aw}} \text{ ....21}$$

Where; $N_2O_{volatilization}$ is the mass of annual nitrous oxide emissions per unit area produced from atmospheric deposition of nitrogen volatilized from crop land [kg], N_{mass} is the mass of nitrogen fertilizer, as nitrogen, applied annually per unit area [kg], $FRACTION_{volatilization}$ is the fraction of the synthetic fertilizer that volatilizes, assumed to be 0.1 in accordance to IPCC guidelines (IPCC, 2006b), $EF_{volatilization}$ is the mass of annual direct nitrous oxide emission per unit area due to the application of nitrogen fertilizer which is taken to be 0.01 (IPCC, 2006b) and $N_2O_{mw}/(2{*}N_{aw})$ is the conversion factor for nitrogen to nitrous oxide, taken to be equal to 44/28.

Nitrous Oxide due to leaching for the application of urea

$$N_2O_{leach} = (N_{fert} + N_{biomass}) * FRACTION_{leach} * EF_{leach} * \frac{N_2O_{mw}}{2*N_{aw}} \quad \text{................22}$$

Where; N_2O_{leach} is the mass of annual nitrous oxide emissions per unit area produced from leaching and runoff of nitrogen from crop land [kg], N_{fert} is the mass of nitrogen fertilizer, as nitrogen, applied annually per unit area, $N_{biomass}$ is the mass of nitrogen in biomass remaining on the ground per unit area (0.5% of biomass), $FRACTION_{leach}$ is the fraction of added nitrogen that volatilizes, taken to be 0.30 (IPCC, 2006), EF_{leach} is the mass of annual direct nitrous oxide emission per unit area due to the leaching of nitrogen; assumed to be 0.0075 as per IPCC guidelines, (IPCC, 2006b) and $N_2O_{mw}/(2{*}N_{aw})$ is the conversion factor for nitrogen to nitrous oxide, taken to be equal to 44/28.

Calculation of Nitrous Oxide emissions due to fertilizer application

$N_2O_{fert.\ emission}$ = 289.5*0.01*44/28 = 4.55 kg/ha

Carbon dioxide emissions due to urea application

$CO_{2emissions}$ = 0*12/28*44/12 = 0 kg/ha

Nitrous oxide due to residue from trimmings left on the field

N_2O_{CR} = 1550.33*0.005*0.01*44/28 = 0.122 kg/ha

Nitrous Oxide due to volatilization for the application of urea

$N_2O_{volatilization}$ = 289.5*0.1*0.01*44/28 = 0.455 kg/ha

Nitrous Oxide due to leaching for the application of urea

N_2O_{leach} = (289.5+7.75)*0.3*0.0075*44/28 = 1.051 kg/ha

Energy Requirements for the production of pesticides

As noted from section 3 above, the upstream energy in the production of pesticides was taken from Bhat *et al*., (1994). The unit energy consumed in producing active ingredients of herbicides, insecticides and fungicides are calculated as 214.93, 245.06 and 356.39 MJ/kg respectively. The active ingredients (a.i.) are formulated into usable forms before being released into the market. The forms into which pesticides are formulated into include emulsifiable oils, wettable powders and granules. Green (1987) estimated that formulation into emulsifiable oil, wettable powder and granules requires an additional energy of 20, 30 and 10 MJ/kg, respectively. In addition the energy required for packaging and distribution of pesticides was estimated to be about 2 MJ/kg. The energy used for transportation depends on the distance pesticides are distributed. If the pesticides are domestically produced and used, distribution energy is estimated to 1 MJ/kg. The energy used in the distribution is 5 MJ/kg for pesticides imported from other countries, (Bhat *et al*., 1994).

Green house gas emissions from the production of pesticides

The emission factors were calculated using the GREET Model: 2011. The actual emissions were then calculated by multiplying the emission factors of particular energy source in grams per Mega Joule by the amount of upstream energy, (ANL, 2009) (The GREET Model: 2011).

Converting LCA results to Carbon equivalents

For purposes of determining the net carbon sequestration potential of orchards, each of the greenhouse gases was converted to its carbon dioxide equivalents using their respective 100 year global warming potentials (PAS 2050, 2011). These factored emissions were then summed up to give the total emissions in terms of carbon dioxide equivalents. Volatile organic carbon gases and carbon monoxide are assumed to be readily oxidized to carbon dioxide and volatile organic carbon gases have a relatively low molecular weight consisting of 83 wt% carbon, (EPA, 2010). Therefore, the sum of the masses of greenhouse gas emissions as expressed in terms of carbon equivalents are given as shown in the equation 23 below:

$$GHG_{Total\,CO2e} = \sum_i m_i * GWP_i + (m_{CO} * \frac{CO_{2\,mw}}{CO_{mw}}) + (0.83 * m_{VOC} * \frac{CO_{2\,mw}}{C_{aw}}) \quad \text{.........23}$$

Where; $GHG_{Total\ Carbon\ Equivalents}$ is the sum of the greenhouse gas emissions expressed as carbon dioxide equivalents, m_i is the mass of emissions of greenhouse gas species i (e.g. CO_2, CH_4 or N_2O), GWP_i is the 100 year global warming potential for greenhouse gas i, m_{CO} is the mass of carbon monoxide emissions, CO_{2mw}/CO_{mw} is the conversion factor for CO to CO_2, taken to be equal to 44/28, m_{VOC} is the mass of VOC emissions and CO_{2mw}/C_{aw} is the conversion factor for C to CO_2, calculated to be equal to 44/12.

Chapter 4

4.0 RESULTS

4.1 BIOMASS DETERMINATION: HIGH-INPUT ORCHARD SYSTEMS

4.1.1 Biomass Determination (Carbon sequestration) for Plot 1 in Kafue district

A 30 m by 60 m (1800 m^2) sampling area was marked out in the middle of a commercial orchard. It consisted of a total of fifty one (51) 35-year-old citrus trees of the variety Washington Navel (*Citrus sinensis*) on Lemon rootstock (*Citrus jambar*i). All the 51 trees had their diameter at 30 cm aboveground (DBH) measured and recorded in booking forms. Four trees in the plot were dead and required replacement while a few others showed stress effects of poor growth and were reported to be low yielding. The dead trees were left out in the analysis while the stressed low yielding trees were included in the analysis for biomass.

The slope of the field was generally flat (0.1°) and the orchard was generally well maintained and was therefore weed free (Figure 4). The summary of the results of the calculation of biomass is shown in Table 3. Using equations 1-12, the average carbon stock was found to be 19.4 Mg C/ha. Equation 13 was used to convert the carbon stock into carbon dioxide equivalents.

Figure 4: Picture of a high-input citrus orchard (Plot 1) in Kafue district

Table 3: Carbon stock and sequestration results for citrus trees in Plot 1 determined using four different allometric equations

Equation	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Average
Plot Aboveground Biomass per equation (kg/Plot Area)	6253.25	4370.81	5221.27	6479.43	5581.19
Expansion Factor	5.56	5.56	5.56	5.56	5.56
Aboveground Biomass (kg/ha)	34740.29	24282.30	29007.03	35996.81	31006.61
Belowground Biomass (kg/ha)	8685.07	6070.57	7251.76	8999.20	7751.65
Total Biomass (kg/ha)	43425.37	30352.87	36258.79	44996.01	38758.26
Carbon (kg C/ha)	21712.68	15176.44	18129.40	22498.01	19379.13
Carbon Equivalents (kg CO_2e/ha)	79620.41	55651.99	66480.49	82500.19	71063.27

A regression analysis was done to determine the correlation between DBH and the tree average biomass (kg/tree). The regression coefficient was found to be 0.974 and was highly significant (Table 15).

4.1.2 Biomass (Carbon sequestration) of citrus trees in Plot 2 in Kafue district

This plot had 50 trees and was 1800 m^2 in size and was generally flat like most of agriculture fields. There were four dead citrus trees which were not included in the biomass determination. This farm can be considered a high input system although with a lower level of management compared to Plot 1. More trees had been replaced due to the drying of old ones. The results of the calculations are shown in Table 4 and the carbon stock calculated from equations 1 to 12 is given as 21.2 Mg C/ha.

Table 4: Plot 2 carbon stock and sequestration results

Equation	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Average
Plot Aboveground Biomass per equation (kg/Plot Area)	6943.14	4872.10	5627.07	7011.06	6113.34
Expansion Factor	5.56	5.56	5.56	5.56	5.56
Aboveground Biomass (kg/ha)	38572.99	27067.21	31261.50	38950.33	33963.01
Belowground Biomass (kg/ha)	9643.25	6766.80	7815.37	9737.58	8490.75
Total Biomass (kg/ha)	48216.24	33834.02	39076.87	48687.92	42453.76
Carbon (kg C/ha)	24108.12	16917.01	19538.44	24343.96	21226.88
Carbon Equivalents (kg CO_2e/ha)	88404.48	62034.67	71647.44	89269.29	77838.97

The increase DBH resulted in increase in biomass per tree. Trees with higher DBH diameters produced high biomass. This was confirmed by regression analysis which gave the regression coefficient of 0.984. Regression coefficients of the results from each equation (equations 1, 2, 3 and 4) were calculated (Table 15).

4.1.3 Biomass (Carbon sequestration) results in Plot 3 in Kafue district

This plot was set out to be 30 m by 66 m, giving a plot size of 1980 m^2. It had 55 citrus trees. The slope of the plot was measured to be zero degrees. The plot was free from weeds at the time of the study. Two citrus trees were dead in the plot and therefore, not taken as part of the measured trees. There were several trees with forked branches which necessitated the calculation of equivalent DBHs as shown in equation 6. The huge number of forked branches is an indication that proper thinning of the citrus trees in their young age was not religiously followed. The DBH of each and every tree was measured and recorded in booking forms. Some of the tree heights were measured and generally averaged 6 meters. The results of biomass calculations were as summarized in Table 5. The carbon stock was calculated as 23.3 Mg C/ha which is given as 85.5 Mg CO_2e/ha.

Table 5: Carbon stock and sequestration Results for Plot 3 in Kafue district

Equation	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Average
Plot Aboveground Biomass per equation (kg/Plot Area)	8301.99	6041.29	6743.67	8453.75	7385.17
Expansion Factor	5.05	5.05	5.05	5.05	5.05
Aboveground Biomass (kg/ha)	41929.25	30511.54	34058.92	42695.73	37298.86
Belowground Biomass (kg/ha)	10482.31	7627.89	8514.73	10673.93	9324.71
Total Biomass (kg/ha)	52411.56	38139.43	42573.65	53369.66	46623.57
Carbon (kg C/ha)	26205.78	19069.71	21286.83	26684.83	23311.79
Carbon Equivalents (kg CO_2e/ha)	96096.59	69928.64	78058.80	97853.27	85484.32

Lower coefficient of correlation was calculated for the relationship between DBH and tree biomass. The coefficient of correlation (r^2 = 0.883) was still higher than 0.5 which shows that the increase biomass can be explained in terms of the increase in DBH, (Table 15).

4.1.4 Biomass (Carbon sequestration) of Plot 4 in Kafue district

This plot is part of a commercial or high input orchard. This plot had 48 plants in an orchard with a plant population of 277. The plant spacing was 6 m by 6 m. The plant height was generally above 6.4 m. There was one tree missing. The orchard was weed free and the trees looked health and free of stress and disease. The highest DBH recorded for this plot was 25.1 cm. This necessitated the use of allometric equations which had higher range of allowable diameters (DBHs). The average biomass was calculated and the results were as given in Table 6.

Figure 5: Picture of a commercial (high-input) orchard (Plot 4) in Kafue district

Table 6: Biomass (carbon sequestration) results for Plot 4 in Kafue district

Equation	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Average
Plot Aboveground Biomass per equation (kg/Plot Area)	7574.72	5336.60	6093.89	7603.03	6652.06
Expansion Factor	5.56	5.56	5.56	5.56	5.56
Aboveground Biomass (kg/ha)	42115.42	29671.50	33882.05	42272.86	36985.46
Belowground Biomass (kg/ha)	10528.86	7417.88	8470.51	10568.22	9246.36
Total Biomass (kg/ha)	52644.28	37089.38	42352.56	52841.08	46231.82
Carbon (kg C/ha)	26322.14	18544.69	21176.28	26420.54	23115.91
Carbon Equivalents (kg CO_2e/ha)	96523.28	68003.38	77653.41	96884.12	84766.05

The regression coefficient was very close to one (0.989), and the regression analysis was as shown in Table 15.

4.1.5 Biomass (Carbon sequestration) of Plot 5 in Kafue district

The sample plot size was 36 m by 60 m (2160 m^2) and the resulting expansion factor being 4.63 was used. The calculated carbon stock for this plot is shown in Table 7. Plot 5 was located in the center part of the high input commercial orchard of about 2 ha. The field slope was measured as zero degrees. The orchard was weed free, stress and disease free. Plant spacing like the other plots was 6 m by 6 m. There were 59 trees in the plot, but had a high number six (6) trees were either dead or had dried up and had not been replaced.

Table 7: Carbon stock and sequestration results for plot 5

Equation	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Average
Plot Aboveground Biomass per equation (kg/Plot Area)	8366.57	5981.80	6739.73	8421.00	7377.28
Expansion Factor	4.63	4.63	4.63	4.63	4.63
Aboveground Biomass (kg/ha)	38737.23	27695.74	31204.95	38989.23	34156.79
Belowground Biomass (kg/ha)	9684.31	6923.93	7801.24	9747.31	8539.20
Total Biomass (kg/ha)	48421.53	34619.67	39006.19	48736.54	42695.98
Carbon (kg C/ha)	24210.77	17309.84	19503.09	24368.27	21347.99
Carbon Equivalents (kg CO_2e/ha)	88780.88	63475.17	71517.84	89358.44	78283.08

The regression analysis relating the DBH and tree biomass was performed to confirm the correlation and regression coefficient was found to be 0.854. The summary of the analysis is shown in Table 15.

Summary of carbon sequestration for high input plots

Table 8 shows a summary of carbon sequestration for the high-input orchards. The carbon stock per ha was found to be 21.66 Mg C/ha and the carbon dioxide equivalents was 79.5 Mg CO2e/ha with an annual carbon dioxide equivalents increment of 7.62 Mg CO_2e/ha per year.

Table 8: Summary of carbon stock and sequestration results for the five high input orchards

Orchard	Biomass (Mg/ha)	Carbon Stock (Mg C/ha)	Carbon Eq. (Mg CO_2e/ha)	Annual CO_2e Increment (Mg CO_2e/ha)
Plot 1	38.8	19.4	71.1	7.28
Plot 2	42.5	21.2	77.8	7.54
Plot 3	46.6	23.3	85.5	7.87
Plot 4	46.2	23.1	84.8	8.04
Plot 5	42.7	21.3	78.3	7.32
Average	43.36	21.66	79.5	7.61

4.2 LOW-INPUT CITRUS ORCHARDS

4.2.1 Biomass (Carbon sequestration) of Plot 6 in Lusaka district

The trees in this plot were planted in 1984 and as was the case with the other orchards they comprised of Washington Navel (*Citrus sinensis*) variety grafted on the Lemon (*Citrus jambar*i) rootstock. The seedlings were reported to have been sourced from University of Zambia nursery in Chilanga. Total enumeration was used on this plot which measured 24 m by 65 m (1560 m^2). There were 73 plants in this plot which translated to a slightly higher plant density of 450 plants per hectare. The tree size generally looked smaller than they should, considering their age. At the time of the study, the field was not weed free; the orchard was infested with *Nidorella resedifolia* and grass weeds such as *Eleusine indica*. There seemed not much of pruning and thinning done. Some lemon branches had grown from the rootstock and become trees at full bearing age and in fact, lemons were reported to be a favoured source of revenue from the sales of lemon fruits as compared to orange fruits.

Figure 6: Picture showing small holder orchard (Plot 6) in Lusaka district

The results of the biomass determination are shown in Table 9. The carbon stock was 17.6 Mg C/ha.

Table 9: Carbon stock and sequestration results for Plot 6 in Lusaka district

Equation	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Average
Plot Aboveground Biomass per equation (kg/Plot Area)	4643.17	3199.96	4399.86	5345.76	4397.19
Expansion Factor	6.41	6.41	6.41	6.41	6.41
Aboveground Biomass (kg/ha)	29762.72	20511.73	28203.08	34266.32	28185.96
Belowground Biomass (kg/ha)	7440.68	5127.93	7050.77	8566.58	7046.49
Total Biomass (kg/ha)	37203.40	25639.66	35253.84	42832.90	35232.45
Carbon (kg C/ha)	18601.70	12819.83	17626.92	21416.45	17616.23
Carbon Equivalents (kg CO_2e/ha)	68212.43	47010.32	64637.92	78534.13	64598.70

The regression coefficient was 0.988 and the rest of the parameters were shown in Table 15.

4.2.2 Biomass (Carbon sequestration) of Plot 7 in Kafue district

Plot 7 was a small orchard belonging to a small holder farmer located on fertile flat plain with a chance of flooding in times of heavy rains as reported by the farmers. It was planted in 1992. Standard plant spacing of 5 m by 5 m was used. Two varieties of oranges were noticed and these were Hamlin and Washington Navel which were sourced from Mungu Nursery in Kafue district. The orchard was weed free and clean (Figure 7). There were 25 plants, three of which had deteriorated to the level where they needed replacement. Total enumeration was done in this plot which measured 625 m^2; all the trees had their DBH measured. The slope of the land was zero degrees and expansion factor was 16. The carbon stock (25.5 Mg C/ha) in this plot is higher than that calculated for high input orchards. The rest of the results were shown in Table 10.

Figure 7: Picture showing low-input orchard (Plot 7) in Chikupi area of Kafue district

Table 10: Plot 7 carbon stock and sequestration results

Equation	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Average
Plot Aboveground Biomass per equation (kg/Plot Area)	2860.20	1916.22	2433.96	3002.06	2553.11
Expansion Factor	16.00	16.00	16.00	16.00	16.00
Aboveground Biomass (kg/ha)	45763.20	30659.57	38943.40	48033.01	40849.78
Belowground Biomass (kg/ha)	11440.80	7664.89	9735.85	12008.25	10212.45
Total Biomass (kg/ha)	57204.00	38324.46	48679.25	60041.27	51062.23
Carbon (kg C/ha)	28602.00	19162.23	24339.62	30020.63	25531.11
Carbon Equivalents (kg CO_2e/ha)	104874.95	70262.14	89246.10	110076.66	93614.93

The regression coefficient was 0.995, an indication that the increase in biomass was as a result of the increase in DBH. Table 15 shows the rest of the parameters determined from regression analysis.

4.2.3 Biomass (Carbon sequestration) of Plot 8 in Kafue district

Plot 8 was marked out from an orchard that was planted in 1974 and is among the oldest of the fields studied. It is located in a fertile flat plain, about 6 km from plot 7. It belonged to a small holder farmer. Nitrogenous fertilizer was reported by the owner to have been applied for a period from 1976 to 1980. The varieties planted included the Washington Navel and Valencia. The orchard was 0.25 ha and a 600 m^2 plot was marked out from the middle of the orchard. The plot had 15 trees (Figure 8). The water for irrigation was drawn from shallow wells located within the orchard. The plot was flat, field slope being zero degrees and expansion factor was 16.67. The carbon stock was 29.8 Mg C/ha as shown in Table 11.

Figure 8: Picture showing citrus trees in a Low input orchard (Plot 8) in Kafue district

Table 11: Carbon stock and sequestration results for Plot 8 in Chikupi area of Kafue district

Equation	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Average
Plot Aboveground Biomass per equation (kg/Plot Area)	3208.56	2460.15	2549.72	3221.82	2860.06
Expansion Factor	16.67	16.67	16.67	16.67	16.67
Aboveground Biomass (kg/ha)	53475.96	41002.49	42495.39	53697.03	47667.72
Belowground Biomass (kg/ha)	13368.99	10250.62	10623.85	13424.26	11916.93
Total Biomass (kg/ha)	66844.95	51253.11	53119.23	67121.29	59584.65
Carbon (kg C/ha)	33422.47	25626.56	26559.62	33560.65	29792.32
Carbon Equivalents (kg CO_2e/ha)	122550.19	93964.89	97386.15	123056.82	109239.51

The regression coefficient for DBH and tree biomass was 0.978 at a probability of less than 0.001 (Table 15).

4.2.4 Biomass (Carbon sequestration) of Plot 9 in Palabana area of Chongwe district

Plot 9 planted in 2005 represented the youngest plants of the study, (six years). The orchard was slightly less than 0.25 ha in size, comprising of two parts; one planted with oranges (*Citrus sinensis*) and the other planted with tangerines (*C. reticulata*) and peaches (*Prunus persica*). The focus of this study was on the side planted with oranges which measured 900 m^2 and a total enumeration was done. All the 43 plants in the plot had their DBH measured, (Figure 9). The tree heights were generally around 3 m and the average DBH was 9.49 cm. The Carbon Stock was calculated to be 7.2 Mg C/ha. From this single field, one can safely conclude that biomass accumulation was influenced by age, although it was not the only factor. The rest of the results are shown in Table 12.

Figure 9: Six year old small holder orchard (Plot 9) in Palabana of Chongwe district

Table 12: Carbon stock and sequestration results for Plot 9 in Palabana-Chongwe district

Equation	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Average
Plot Aboveground Biomass per equation (kg/Plot Area)	873.63	888.56	1092.09	1272.67	1031.74
Expansion Factor	11.11	11.11	11.11	11.11	11.11
Aboveground Biomass (kg/ha)	9706.996	9872.904	12134.3	14140.75	11463.74
Belowground Biomass (kg/ha)	2426.749	2468.226	3033.575	3535.189	2865.93
Total Biomass (kg/ha)	12133.74	12341.13	15167.88	17675.94	14329.67
Carbon (kg C/ha)	6066.872	6170.565	7583.938	8837.972	7164.84
Carbon Equivalents (kg CO_2e/ha)	22247.22	22627.46	27810.3	32408.84	26273.46

The regression analysis was shown in Table 15. The regression coefficient was 0.98.

4.2.5 Biomass (Carbon sequestration) of Plot 10 of Chikupi area of Kafue district

Plot 10 Orchard was planted in 1991. The citrus tree varieties were Washington Navel and Hamlin grafted on rough lemon (*Citrus limon*) which were sourced from Mungu Nursery of Kabweza area of Kafue district. The orchard was 1100 square meters and total enumeration was employed and all the 42 trees had their DBH measured. The plot was flat and the expansion factor was determined to be 9.09. The field was weed and disease free and the trees looked health and big. Like Plot 7 and Plot 8, Plot 10 was located in a fertile plain. The carbon stock was determined to be 22.3 Mg C/ha as shown with the rest of the results in Table 13.

Figure 10: Picture of Low input orchard (Plot 10) in Kafue district

Table 13: Carbon stock and sequestration results for Plot 10 in Kafue district

Equation	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Average
Plot Aboveground Biomass per equation (kg/Plot Area)	4420.71	2851.46	3787.85	4650.60	3927.65
Expansion Factor	9.09	9.09	9.09	9.09	9.09
Aboveground Biomass (kg/ha)	40184.22	25919.77	34431.56	42273.96	35702.38
Belowground Biomass (kg/ha)	10046.06	6479.94	8607.89	10568.49	8925.59
Total Biomass (kg/ha)	5030.28	32399.71	43039.46	52842.44	44627.97
Carbon (kg C/ha)	25115.14	16199.86	21519.73	26421.22	22313.99
Carbon Equivalents (kg CO_2e/ha)	92097.21	59404.88	78912.84	96886.62	81825.39

The regression coefficient was 0.993 as shown Table 15.

4.3 Summary of carbon sequestration for the low input plots

The average carbon sequestration for the low input was 23.8 Mg C/ha, 87.3 Mg CO_2e/ha and 9.35 Mg CO_2e/ha for carbon stock, carbon dioxide equivalents and annual CO_2e increment per hectare respectively, as shown in Table 14. When averaging carbon sequestration, only four plots whose trees were older than 19 years were considered leaving out Plot 9 representing young six year old trees

Table 14: Average carbon sequestration results for four low input orchards

Orchard	Biomass (Mg/ha)	Carbon Stock (Mg C/ha)	Carbon Eq. (Mg CO_2e/ha)	Annual CO_2e Increment (Mg CO_2e/ha)
Plot 6	35.2	17.6	64.6	8.67
Plot 7	51.1	25.5	93.6	10.29
Plot 8	59.6	29.8	109.2	9.01
Plot 10	44.6	22.3	81.8	9.43
Average	47.63	23.80	87.30	9.35

4.3.1 Regression Analysis

The regression analysis of the ten orchards to determine the correlation between DBH and tree biomass accumulation (kg/tree) was done and summarized in Table 15.

Table 15: Summary of regression analysis results for DBH against biomass accumulation

Plot	R^2	f	Significance f	t-test	p-value	Equation
Plot 1	0.9731	1630	0.000	-22.884	0.000	Y = 14.331X - 159.15
Plot 2	0.984	1697	0.000	-28.893	0.000	Y = 14.88X – 170.32
Plot 3	0.883	385	0.000	-10.07	0.000	Y = 14.74X – 157.65
Plot 4	0.989	4192	0.000	-38.5	0.000	Y = 16.66X – 209.52
Plot 5	0.985	3115	0.000	-30.03	0.000	Y = 14.92X – 171.06
Plot 6	0.927	878	0.000	-17.44	0.000	Y = 10.73X – 95.27
Plot 7	0.996	5095	0.000	-44.89	0.000	Y = 15.14X – 176.81
Plot 8	0.978	576	0.000	-11.91	0.000	Y = 16.14X – 191.01
Plot 9	0.980	1970	0.000	-20.41	0.000	Y = 4.47X – 20.41
Plot 10	0.993	5296	0.000	-43.8	0.000	Y = 13.17X – 142.34

4.3.2 Biomass Analysis

The biomass accumulation per plot were summarized in Table 16 and Figure 11 below which also shows the biomass converted to carbon dioxide equivalents in mega grams carbon dioxide equivalent per hectare.

Table 16: Summary carbon sequestration results from ten orchards

Orchard	Biomass (Mg/ha)	Carbon Stock (Mg C/ha)	Carbon Eq. (Mg CO_2e/ha)	Annual CO_2e Increment (Mg CO_2e/ha)
Plot 1	38.8	19.4	71.1	7.29
Plot 2	42.5	21.2	77.8	7.54
Plot 3	46.6	23.3	85.5	7.87
Plot 4	46.2	23.1	84.8	8.04
Plot 5	42.7	21.3	78.3	7.32
Plot 6	35.2	17.6	64.6	8.67
Plot 7	51.1	25.5	93.6	10.29
Plot 8	59.6	29.8	109.2	9.00
Plot 9	14.3	7.2	26.3	5.34
Plot 10	44.6	22.3	81.8	9.44

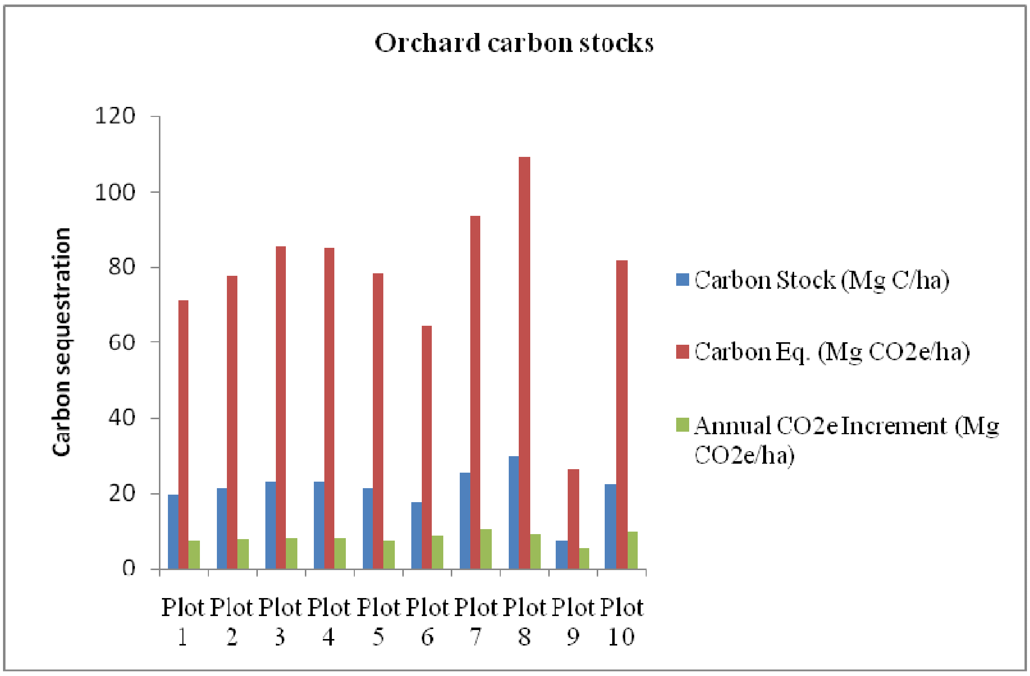

Figure 11: Biomass and carbon sequestration, with annual CO_2e increment in citrus orchards

DETERMINATION OF CARBON EMISSIONS FROM FIVE LOW INPUT ORCHARDS-LCA BASED CARBON FOOTPRINTS OF ORCHARDS

4.4 HIGH INPUT ORCHARDS

4.4.1 Emission for High input Plots

The high input orchards included plots numbered as 1, 2, 3, 4 and 5 and had similar reported inputs, although the calculated emissions for each individual plot were different. The exact planting date for the citrus trees were unknown by the farm manager in-charge of the farm at the time of the study. They were said to have been planted over 30 years before. These Plots were parts of commercial orchards with high levels of inputs having been applied for a continuous period of 15 years leading to the citrus peak bearing age. The agro-chemicals used are given in Table 31. In addition to agro-chemicals, consideration was given to other unit operations involved in the growing of citrus such as land preparation and management, application of fertilizer and pesticides, irrigation and trimmings, recorded as in booking forms. Other operations such as planting seedlings and harvesting were not considered as they were generally done manually and therefore, were carbon neutral or had an insignificant carbon footprint. Transportation of the fruits was taken to be outside the system boundary.

The initial activity in establishing an orchard was to prepare the land for planting tree seedlings. Land was plowed to loosen the soil to facilitate root growth and bed formation to facilitate tending and harvesting operations. Irrigation and drainage systems were also created at this time. There was a concrete water reservoir into which water was pumped for storage before being released into the orchards by gravity using concrete lined canals (now disused) and Poly vinyl chloride (PVC) pipes. Although citrus can live up to 100 years, a conservative 40-year life-span for the orchards was assumed. Four percent of established orchard of old, non-productive, or diseased trees were assumed to be removed per year and the land was reworked in preparation for the planting of new trees on annual basis, (Muraro, 2008a). The existing trees were removed and the land plowed, harrowed and the beds formed in readiness for replanting of new trees.

All carbons emissions were considered negative (carbon sources) and carbon sequestration as positive (carbon sinks).

Table 17 shows the equipment and machinery that were used in land preparation for the establishment of an orchard. Since this farm was established many decades before the study was conducted and that the management of the farm has changed hands, it was difficult to determine the exact equipment and fuel consumption at the time of establishment. An 80 horse power (HP) tractor which was found at the farm was considered in the calculations. At establishment, the farmers plow and harrow land. The duration of the operations and fuel consumptions are shown in Table 18, and Table 19 shows the GHG emissions from the burning of fossil fuel in the running of the tractor for initial land preparations.

Table 17: Initial land preparation equipment and fuel consumption per ha

Equipments	Size of tractor (HP)	Tractor Fuel consumption	Tractor Performance	Frequency of operation per year	Total fuel consumption
		Litre/ha	hr/ha		(litre/ha)
Plow	80	12	4	1	48
Row Disk	80	7	2	2	28
Blade	80	12	4	1	48
Total					124

Table 18: Land maintenance equipment and fuel consumption per ha. Land maintenance was performed after old or unproductive trees were removed in readiness to plant new ones.

Equipments	Size of tractor (HP)	Tractor Fuel consumption	Tractor Performance	Frequency of operation per year	Total fuel consumption
		Litre/ha	hr/ha		(litre/ha)
Row Disk	80	7	2	2	28
Sub-Soillers	80	7	2	1	14
Total					42

Table 19: Direct GHG emissions from burning of fossil fuel in the operation of tractor for initial land preparations

Activity	Fuel used	Emissions factors (g/litre)			Emissions (g/ha)		
	l/ha	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Land Preparation	124	2650	0.149	1.02	326,600	18.48	126.48
Land maintenance	42	2650	0.149	1.02	111,300	6.26	42.84
Sub-Total	166						

Table 20: Volatile organic carbon and carbon monoxide emissions from tractor exhaust during initial land preparation activities

Activity	Tractor Power	Fuel consumption rate	Emissions factors (g/litre)		Emissions (g/ha)	
	(HP)	(liter/ha)	VOC	CO	VOC	CO
Plowing	80	48	7.36	50.62	353.28	2429.76
Row Disking	80	28	3.68	25.31	103.04	708.68
Blade	80	48	7.36	50.62	353.28	2429.76
Sub-Total					809.6	5568.2

Table 21: Volatile organic carbon and carbon monoxide exhaust emissions from tractor during land maintenance activities in preparation for tree replacement

Activity	Tractor Power	Fuel consumption rate	Emissions factors (g/litre)		Emissions (g/ha)	
	(HP)	(liter/ha)	VOC	CO	VOC	CO
Row Disking	80	28	3.68	25.31	103.04	708.68
Sub-soiler	80	14	7.36	50.62	103.04	708.68
Sub-Total					206.08	1,417.36

Table 22: Emission factors due to burning of dry matter of citrus trees removed due to old age and low productivity. Four percent of biomass per ha is replaced annually.

	Emissions factor	Equation 1 (kg/ha)	Equation 2 (kg/ha)	Equation 3 (kg/ha)	Equation 4 (kg/ha)	Average (kg/ha)
Biomass GHG	(g/kg dry matter burned)	1737.01	1214.11	1450.35	1799.84	1550.33
		Emissions (g/ha)				
CO_2	1569	2725376.0	1904946.3	2275601.7	2823949.6	2432468.4
CH_4	4.7	8164.0	5706.3	6816.7	8459.3	7286.6
N_2O	0.26	451.6	315.7	377.1	468.0	403.1
VOC	5.7	9901.0	6920.5	8267.0	10259.1	8836.9
CO	107	185860.6	129910.3	155187.6	192582.9	165885.4

Table 23: Spreading of GHG emissions from initial land preparations at two and half percent per annum and emissions from the burning of biomass and land maintenance were amortized at the rate of four percent per annum.

Diesel	Land preparation	Land Maintenance	Activity Burning	Amortized emissions over 40 years	Unit
Volume	124	42		4.16	l/ha
Energy	4,439.2	1,503.6		148.93	MJ/ha
VOC	809.6	206.08	8836.9	381.96	g/ha
CO	5,568.2	1,417.36	165885.4	6831.32	g/ha
			Greenhouses Gases		
CO_2	326,600	111,300	0	12617	g/ha
CH_4	18.48	6.26	7286.6	292.18	g/ha
N_2O	126.48	42.84	403.1	21.000	g/ha

Table 24: Equipment used in orchards for cultural practices of mowing, spraying and mechanical fertilizer application and their respective fuel consumption in the management of citrus orchards used in the study.

Activity	Size of tractor (HP)	Tractor Fuel consumption	Tractor Performance	Frequency of operation per year	Total fuel consumption
		Litre/ha	hr/ha		(litre/ha)
Rotary Mower	80	7	2	4	56
Sprayer Boom	80	7	2	6	84
Fertilizer Spread	80	7	2	4	56
Total					196

Table 25: Emissions from fuels used in orchard management practices

Fuel	Energy consumption (litre/ha)	Emissions factor (g/litre)			Emissions (g/ha)		
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Diesel	196	2650	0.149	1.02	519,400	29.20	199.92
Sub-Total					519,400	29.20	199.92

Table 26: Volatile organic carbon and carbon monoxide exhaust emissions from tractor used in tending activities of spraying, fertilizer application and mowing of weeds.

Activity	Tractor Power	Fuel consumption rate	Emissions factors (g/litre)		Emissions (g/ha)	
	HP)	(liter/ha)	VOC	CO	VOC	CO
Rotary Mower	80	56	1.84	12.655	103.04	708.68
Sprayer Boom	80	84	1.23	8.437	103.32	708.71
Fertilizer Spread	80	56	1.84	12.655	103.04	708.68
Sub-Total					309.4	2,126.07

Table 27: Energy consumption from pumping water for irrigation was calculated from equation 18. Water was pumped into a reservoir from which it was made to flow by gravity to individual citrus trees.

Pump Type	Nameplate HP	KW	MJ/ha
Mono Pump	30	29.83	477.28
Mono Pump	30	29.83	477.28
Submersible Pump	7.5	7.46	477.44
Total			1432

Table 28: Upstream energy expended in production of electricity and fuels

Power Source	Quantity	Energy consumption (MJ/ha)	Energy Factor	Upstream Energy (MJ/ha)
Electricity	132.6 kWh	477.44	2.565	1,224.6
Diesel	196 Litres	7016.8	0.180	1263.02
Sub-Total				618.62

Table 29: Upstream GHG emissions arising from production of fuels and electricity that were used in the orchard management

Power source	Energy consumption (MJ/ha)	Emissions factor (g/MJ)			Emissions (g/ha)		
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Electricity	477.44	228.464	0.481	0.0029	109077.852	229.649	1.38
Diesel	7,165.73	29.215	0.728	0.000164	209346.802	5216.651	1.17
Sub-Total					318424.654	5446.300	2.56

Energy Factors: (*Source: ANL, 2009*)

Table 30: Emissions of volatile organic carbon and carbon monoxide from production of electricity and diesel

Power source:	Energy consumption (MJ/ha)	Emissions factor (g/MJ)		Emissions (g/ha)	
		VOC	CO	VOC	CO
Electricity	477.44	0.021	0.0541	10.03	25.85
Diesel	7,165.73	0.0131	0.0403	93.87	288.78
Sub-Total				103.89	314.63

Table 31: Agro-chemical inputs (fertilizer and insecticides) orchard management

Input	Chemical	N: P_2O_5: K_2O	Quantity (kg/ha-yr	Active Ingredient (ai) (kg/ha-yr)
Fertilizers	Compound D	10:20: 10	277	-
Fertilizer	Ammonium Nitrate	34: 0: 0	554	-
Fertilizers	Potassium Sulphate	0: 0: 50	277	-
Fertilizer	Calcium Ammonium Nitrate	26.5: 0: 0	277	-
Insecticides	Chloropyrifos			2.42
Insecticides	Endosulfan 50% EC		1.0	0.50
Insecticides	Dimethoate 40% EC		250 ml/ha	2.24
Fungicides	Dithane M45		0.75	0.34
Fungicides	Benlate			1.00
Fungicides	Copper hydroxide			4.20
Herbicides	Glyphosate			2.91
Herbicides	Atrazaine			0.46
Herbicides	Norflurazon			3.12
Herbicides	Diuron 80			4.62

Table 32: Upstream energy inputs for the production, transportation, packaging and application of fertilizers

Fertilizer Source	Use rate	Production	Transportation, packaging, application	Energy Use	Total Energy use (Upstream)
	(kg/ha)		MJ/kg of Nutrient		MJ/ha
Nitrogen (N)	289.5	55.48	8.60	64.08	18,551.16
Phosphate (P_2O_5)	55.4	4.52	9.80	14.32	793.30
Potassium (K_2O)	138.5	4.80	7.30	12.10	1,675.85

Table 33: Emissions from production of fertilizer used in orchard management

Nutrient	Energy (MJ/ha)	Source	Emission Factor (g/MJ) CO_2	CH_4	N_2O	Total Emissions (g/ha) CO_2	CH_4	N_2O
N	Natural Gas	14,999	11.829	0.633	0.000178	177423.2	9494.367	2.670
	Diesel	1,742.8	29.215	0.728	0.000164	50915.9	1268.758	0.286
	Electricity	1,545.9	228.464	0.481	0.00290	353189.4	743.5923	4.483
P_2O_5	Natural Gas	0.00	11.829	0.633	0.000178	0	0	0.000
	Diesel	396.11	29.215	0.728	0.000164	11572.35	288.3681	0.065
	Electricity	397.22	228.464	0.481	0.00290	90750.47	191.0628	1.152
K_2O	Natural Gas	372.57	11.829	0.633	0.000178	4407.131	235.8368	0.066
	Diesel	768.68	29.215	0.728	0.000164	22456.99	559.599	0.126
	Electricity	534.61	228.464	0.481	0.00290	122139.1	257.1474	1.550
Sub-Total						832854.5	13038.73	10.398

Source: (Bhat et al., 1994)

Table 34: Volatile organic carbon (VOC) and carbon monoxide (CO) emissions from fertilizer production

Nutrient	Energy Source (MJ/ha),		Emissions factor (g/MJ) VOC	CO	Emissions (g/ha) VOC	CO
N	Natural Gas	14,999	0.00672	0.0188	100.7933	281.98
	Diesel	1,742.8	0.0131	0.0403	22.83068	70.23
	Electricity	1,545.93	0.021	0.0541	32.46453	83.68
P_2O_5	Natural Gas	0.00	0.00672	0.0188	0	0
	Diesel	396.11	0.0131	0.0403	5.189041	15.96323
	Electricity	397.22	0.021	0.0541	8.34162	21.49
K_2O	Natural Gas	372.57	0.00672	0.0188	2.50367	7.00
	Diesel	768.68	0.0131	0.0403	10.06971	30.98
	Electricity	534.61	0.021	0.0541	11.22681	28.92
Sub-Total					193.4193	540.21

Energy values: *Source: (Bhat et al., 1994*)

Table 35: Energy requirements for the production, formulation, packaging and distribution of pesticides

Pesticide	Production Energy (MJ/kg)	Formulation (MJ/kg)	Packaging and Distribution (MJ/kg)	Total Energy (MJ/kg)	Total Energy (MJ/ha)
Insecticides					
Dimethoate 40% EC	245.06	20	7	272.06	609.41
Chloropyrifos	245.06	20	7	272.06	658.39
Malathion 50% EC	245.06	20	7	272.06	136.03
Fungicides					
Benlate	356.39	30	7	393.39	393.39
Copper hydroxide	356.39	30	7	393.39	1,652.24
Dithane M45	356.39	30	7	393.39	133.75
Herbicides					
Glyphosate	214.93	10	7	231.93	674.92
Atrazaine	214.93	10	7	231.93	106.69
Norflurazon	214.93	10	7	231.93	723.62
Diuron 80	214.93	10	7	231.93	1,071.52

Table 36: Emissions factors and GHG emissions from production of pesticides; emission factors were multiplied by the energy used in the production of pesticides.

Pesticide	Energy (MJ/ha)	Source	Emission Factor (g/MJ) CO_2	CH_4	N_2O	Total Emissions (g/ha) CO_2	CH_4	N_2O
Insecticides								
Dimethoate	Natural Gas	609.41	11.83	0.63	0.00018	7208.711	385.75	0.11
Chloropyrifos	Natural Gas	658.39	11.83	0.63	0.00018	7788.095	416.76	0.12
Malathion	Natural Gas	136.03	11.83	0.63	0.00018	1609.099	86.11	0.02
Fungicides								
Benlate	Natural Gas	393.39	11.83	0.63	0.00018	4653.41	249.016	0.07
Copper hydroxide	Natural Gas	1,652.2	11.83	0.63	0.00018	19544.34	1045.86	0.29
Dithane M45	Natural Gas	133.75	11.83	0.633	0.00018	1582.129	84.66	0.02
Herbicides								
Glyphosate	Natural Gas	674.92	11.83	0.633	0.00018	7983.6287	427.22	0.12
Atrazaine	Natural Gas	106.69	11.83	0.633	0.00018	1262.036	67.53	0.02
Norflurazon	Natural Gas	723.62	11.83	0.633	0.00018	8559.701	458.05	0.13
Diuron 80	Natural Gas	1,071.52	11.83	0.633	0.00018	12675.01	678.27	0.19
Sub-Total						72866.167	3899.26	1.09

Table 37: Volatile organic carbon (VOC) and carbon monoxide (CO) emissions from production of pesticides

Pesticide	Upstream Energy Source (MJ/ha)		Emissions factor (g/MJ)		Emissions (g/ha)	
			VOC	CO	VOC	CO
Insecticides						
Dimethoate	Natural Gas	609.41	0.00672	0.0188	4.095235	11.46
Chloropyrifos	Natural Gas	658.39	0.00672	0.0188	4.424381	12.38
Malathion	Natural Gas	136.03	0.00672	0.0188	0.914122	2.56
Fungicides						
Benlate	Natural Gas	393.39	0.00672	0.0188	2.643581	7.39
Copper hydroxide	Natural Gas	1,652.24	0.00672	0.0188	11.10305	31.06
Dithane M45	Natural Gas	133.75	0.00672	0.0188	0.8988	2.51
Herbicides						
Glyphosate	Natural Gas	674.92	0.00672	0.0188	4.535462	12.69
Atrazaine	Natural Gas	106.69	0.00672	0.0188	0.716957	2.01
norflurazon	Natural Gas	723.62	0.00672	0.0188	4.862726	13.60
Diuron 80	Natural Gas	1,071.52	0.00672	0.0188	7.200614	20.14
Sub-Total					41.39493	115.81

Table 38: Summary of carbon dioxide equivalent emissions for Plot 1; after conversion of LCA data to carbon equivalents using the respective global warming potential

Source of emission	CO_2	CH_4	N_2O	VOC	CO	gCO_2eq/ha
GWP	1	25	298	3.04	1.57	
Land Preparation	10,984	292.08	20.37	377.91	6,803.47	45632.1
Cultural operations	519,400	29.2	199.92	309.4	2,126.07	586655.2
Energy for production of fuels	318,424.6	5446.30	2.56	103.9	314.63	456,464.96
Fertilizers						
Energy for production	832,854.5	13,038.7	10.4	193.42	540.21	1163867.1
N_2O emissions from application	0	0	4550	0	0	1355900.0
N_2O emissions from pruning	0	0	121.81	0	0	36299.4
N_2O Volatile	0	0	455	0	0	135590.0
N_2O leaching	0	0	1051	0	0	313198.0
Pesticides	72,866.17	3899.255	1.1	41.39	115.81	171092.4
Total Emissions of GHGs	1754529.2	567638.4	191082	1595.10	30017.9	4264699.2
Total Carbon dioxide equivalent emissions (g CO_2e/ha)						4,264,699

GWP: (*Source: PAS 2050, 2011*)

Summary of carbon emissions for high input orchards

The average carbon emissions for the five high input orchards was 4.272 Mg CO_2e/ha per year (Table 39). The five orchards received similar amounts of inputs, but the difference in application and residue biomass from pruning resulted in different carbon emissions. The accumulated carbon emissions for the reported 15 years of application is 64.08 Mg CO_2e/ha. The carbon emission figures were presented as negative values in the table.

Table 39: Summary of GHG emissions in for the five high-input orchards

Plot	Field Work Emission	Fuel Production Emissions	Fertilizer Production Emissions	Fertilizer Application Emissions	Pesticide Production Emissions	Total Emissions (Mg CO_2e/ha)
Plot1	-0.632	-0.456	-1.164	-1.841	-0.171	-4.26
Plot 2	-0.635	-0.456	-1.164	-1.845	-0.171	-4.27
Plot 3	-0.638	-0.456	-1.164	-1.85	-0.171	-4.28
Plot 4	-0.639	-0.456	-1.164	-1.849	-0.171	-4.28
Plot 5	-0.636	-0.456	-1.164	-1.845	-0.171	-4.27
Average	-0.636	-0.456	-1.164	-1.846	-0.171	-4.272

CARBON EMISSIONS FROM FIVE LOW INPUT ORCHARDS

4.4.2 Emissions determination for Plot 6 orchard

The life cycle analysis for this low input orchard considered carbon emissions from the inputs of pesticides, electricity and fuel. The pesticides used during the year under consideration included Malathion 50% EC, Dimethoate 40% EC, Dithane M45 and Benlate as shown in Table 40. Water was applied to the orchard by way of pumping from a stream using a 4 HP grid electrical powered pump. Diesel fuel was used in the initial stage of land preparation. The field was established in 1984 on a cleared land. The application of water and pesticides to the orchard was continued for a period of 10 years.

A 60 HP tractor was taken to have been used hooked to plow, disc harrow and row disk. in the initial land preparation. The field was irrigated by pumping water from shallow well using a 5 horse power pump running with a discharge of 4 litres per second operated for predetermined period for 13 days in a year at an irrigation interval of two to three weeks during the dry season. The GHG emissions sources [(i) to (vi)] described in section 3.2.2 were tabulated and the total GHG emissions calculated for this plot were summarized as shown in Table 41. This procedure was repeated for the remaining low in-put orchards.

Table 40: The agro-chemical input (fertilizer and pesticides) to the orchard

Input	Chemical	Quantity (kg/ha-yr)	Active Ingredient (ai) (kg/ha-yr)
Pesticides	Malathion 50% EC	1.0	0.50
	Dimethoate 40% EC	250 ml/ha	2.24
	Benlate	1.0	1.00
Fungicides	Dithane M45	0.75	0.34

Table 41: Summary of GHGs emissions for Plot 6 in Lusaka district

Source of emission GWP	CO_2 1	CH_4 25	N_2O 298	VOC 1.57	CO 3.04	g CO_2eq/ha
Land Preparation	6,784	265.33	17.27	333.05	6,110.84	37663.55
Energy for production of fuels	154,313.2	3379.02	1.011	61.91	189.51	239763.29
N_2O emissions from pruning	0	0	111	0	0	33078.00
N_2O emissions from leaching	0	0	24.9	0	0	7420.20
Pesticides	13618.136	728.74	0.205	7.74	21.64	31975.66
Total Emissions of GHGs	174715.34	109327.3	46007	632.24	19218.85	349900.70
Total Carbon dioxide equivalent emissions (g CO_2e/ha)						349,900.70

4.4.3 Emissions determination for Plot 7 orchard

Plot 7 was small holder relatively low input orchard which was well managed. There was no use of high level mechanization that was reported in the performance of all unit operations on the field. All the activities including irrigation, spraying, fertilizer application and pruning were reported to be done manually. Spraying for control of pests and diseases was done using a Knapsack sprayer, which is considered carbon emissions neutral. The agro-chemical inputs applied included urea and mixed fertilizers (compound D), Malathion 50% EC, Dimethoate 40% EC, Dithane M45 and Benlate as shown in Table 42. The farmer was able to recall the amount of fertilizers applied consistently over the years as was advised by the Ministry of Agriculture and Livestock extension staff, but was unable to remember the exact amounts of pesticides in which case literature and Ministry of Agriculture and Livestock recommendations were used on the mentioned products. For purposes of this study machinery was assumed to be used in the initial land preparation. A 60 HP tractor working with a plow and row disk was used in the calculations. The calculations of the carbon footprints for this orchard are summarized in Table 43.

Table 42: Agro-chemical inputs to the orchard

Input	Chemical	Quantity (kg/ha-yr	Active Ingredient (ai) (kg/ha-yr)
Fertilizer	Compound D	200	-
Fertilizer	Urea	200	-
Pesticides	Malathion 50% EC	1.0	0.5
	Dimethoate 40% EC	250 ml/ha	2.24
Fungicides	Dithane M45	0.75	0.34
Fungicides	Benlate	1.0	1.0

Table 43: Summary of GHG emissions for Plot 7 orchard

Source of emission	CO_2	CH_4	N_2O	VOC	CO	gCO_2eq/ha
GWP	1	25	298	3.04	1.57	
Land Preparation	5,088	384.27	23.2	472.7	8,789.6	49070.94
Energy for production of fuels	100,406.1	2501.99	0.564	45.02	138.503	163615.67
Fertilizers						
Energy for production	313,738.8	4,951.21	4.18	73.2	204.64	439501.75
N_2O emissions from application	0	0	1760	0	0	524480
CO_2 emissions from urea application	314,285.7	0	0	0	0	314285.7
N_2O emissions from pruning	0	0	160.48	0	0	47823.04
N_2O Volatile	0	0	1760	0	0	524480
N_2O leaching	0	0	432.1	0	0	128765.8
Pesticides	13,429.79	728.626	0.230	7.71	21.53	31791.54
Total Emissions of GHGs	746948.45	214152.	1233944	939.8	27828.9	2223814.43
Total Carbon dioxide equivalent emissions (g CO_2e/ha)						2,223,814.43

4.4.4 Emissions determination for Plot 8 orchard

This is among the oldest orchards included in this study, being planted in 1974. It's a small holder orchard. Low inputs were applied for a period of five years from 1976 to 1980 after which the application was stopped after the owner fell ill over an extended period of time. The applied inputs are targeted at improving fruit yield. Ammonium nitrate was used to apply nitrate to the plants. Pesticides (Malathion 50% EC, Dimethoate 40% EC and Dithane M45 were reported to have been used in the control of pests and diseases (Table 44). Irrigation water was drawn from shallow wells located within the orchard. The method of drawing water was the use of pump tied to a string, lowered manually to scoop the water. Initial land preparation was assumed to have been done using a tractor. The farmer owned a tractor and pairs of oxen for Animal Draft Power. Land maintenance, replanting and pruning was said to be done by hand. But its worthy noting that from 1980 to the study date, the orchard was generally left unattended to. The analysis of the carbon emissions due to agro-chemical manufacture, packaging and distribution and use were tabulated. The summary of emissions was recorded in Table 45.

Table 44: Agro-chemical inputs to the orchard

Input	Chemical	Quantity (kg/ha-yr	Active Ingredient (ai) (kg/ha-yr)
Fertilizers	Ammonium Nitrate	800	-
insecticides	Malathion 50% EC	1.0	0.5
insecticides	Dimethoate 40% EC	250 ml/ha	2.24
Fungicides	Dithane M45	0.75	0.34

Table 45: Summary of GHGs emissions for Plot 8

Source of emission GWP	CO_2 1	CH_4 25	N_2O 298	VOC 3.04	CO 1.57	gCO_2eq/ha
Land Preparation	5,088	448.36	26.75	550.45	10,248.3	56287.54
Energy for production of fuels	100,406.1	2501.99	0.564	45.022	138.50	163615.65
Fertilizers						
Energy for production of fertilizers	546,375.2	10811.1	6.99	146.65	409.50	820210.84
N_2O emissions from application	0	0	4274	0	0	1273652
N_2O emissions from pruning	0	0	187.7	0	0	55934.6
N_2O Volatile	0	0	427	0	0	127246
N_2O leaching	0	0	1003.8	0	0	299132.4
Pesticides	10399.94	556.53	0.156	5.91	16.53	24419.21
Total Emissions of GHGs	662,269	14317.98	5927	748.032	10,812.8	2820498.23
Total Carbon dioxide equivalent emissions (g CO_2e/ha)						2,820,498.2

4.4.5 Carbon emissions determination for Plot 9 orchard

Plot 9 was an orchard only six years old. The orchard had reached bearing age and in fact was reported to have at one time produced fruits, although at the time of the study one could easily see that the trees were water stressed and planted in a less productive environment. There was no irrigation of the crop taking place. The crop had not been ever irrigated since the time of planting. An attempt was made to try and lay drip liners, but the project couldn't be completed. Fertilizer was reported to have been applied only once during the establishment year at the rate of 100 g per plant per year as shown in Table 46. The insecticide Malathion 50% EC and the fungicides Dithane M45 and copper oxyhydroxide were commonly used by most citrus farmers. Knapsack is common spraying equipment for small scale farmers and was used. The field as noted above was planed in 2005, but no land use change was done; the field had been planted to other crops before then. The results of the emissions for this orchard were summarized in Table 47.

Table 46: Agro-chemical inputs to Plot 9 orchard

Input	Chemical	Quantity (kg/ha-yr	Active Ingredient (ai) (kg/ha-yr)
Fertilizer	Compound D	45	-
Pesticides	Malathion 50% EC	1.0	0.5
Fungicides	Dithane M45	0.75	0.34

Table 47: Summary of GHGs emissions for Plot 9 Orchard

Source of emission GWP	CO_2 1	CH_4 25	N_2O 298	VOC 3.04	CO 1.57	gCO_2eq/ha
Land Preparation	3,816	107.97	7.43	133.51	2,476.16	16466.53
Energy for production of fuels	69,432.8	1835.25	0.42	32.22	81.7	115738.16
Fertilizers						
Energy for production	28,217.47	286.74	0.36	5.102	12.72	35539.93
N_2O emissions from application	0	0	70.71	0	0	21071.58
N_2O emissions from pruning	0	0	45.04	0	0	13421.92
N_2O Volatile	0	0	7.1	0	0	2115.80
N_2O leaching	0	0	26.06	0	0	7765.88
Pesticides	3,047.71	169.69	0.05	1.75	3.99	7319.74
Total Emissions of GHGs	104513.98	59991.25	46836.66	270.95	7826.69	219439.54
Total Carbon dioxide equivalent emissions (g CO_2e/ha)						219,439.54

4.4.6 Carbon emissions determination for Plot 10 Orchard

Plot 10 appeared to have been receiving sufficient care. The orchard was weed free and apparently disease and pest free. The orchard was planted in 1992. Application of inputs was done and continued for a period of 16 years. The fertilizers used include urea and compound D at the rate of 500 g per tree as given in Table 48. The re-currency of pests and diseases was controlled using the commonly available pesticides Malathion 50% EC, Dimethoate 40% EC and Dithane M45 (Table 44). Irrigation water was supplied by a 1 HP submersible pump from a shallow well. The initial land preparation is assumed to have been done using a 60 HP tractor hooked to implements such as plow and disc harrow. The calculation procedures outlined for Plot 1 was used to calculate emissions for this plot and the rest of the calculated carbon emissions were summarized and recorded in Table 49.

Table 48: Agro-chemical inputs to Plot 10

Input	Chemical	Quantity (kg/ha-yr	Active Ingredient (ai) (kg/ha-yr)
Fertilizer	Compound D	200	-
Fertilizer	Urea	200	-
Pesticides	Malathion 50% EC	1.0	0.5
	Dimethoate 40% EC	250 ml/ha	2.24
Fungicides	Dithane M45	0.75	0.34

Table 49: Summary of GHG emissions for Plot 10 Orchard

Source of emission	CO_2	CH_4	N_2O	VOC	CO	gCO_2e/ha
GWP	1	25	298	3.04	1.57	
Land Preparation	5,088	335.89	20.52	414.04	7,687.76	43621.04
Energy for fuel production	205,682.32	2723.64	1.9	54.7	163.43	274922.23
Fertilizers						
Energy for production	320,373.7	4949.8	4.01	73.59	205.32	446053.39
N_2O emissions from application	0	0	1760	0	0	524480.00
CO_2 emissions from urea application	314,285.7	0	0	0	0	314285.70
N_2O emissions from pruning	0	0	140.2	0	0	41779.60
N_2O Volatile	0	0	176	0	0	52448.00
N_2O leaching	0	0	427.5	0	0	127395.00
Pesticides	10399.94	556.53	0.156	5.91	16.53	24419.21
Total Emissions of GHGs	855829.66	214146	754025	860.7368	24542.04	1849404.2
Total Carbon dioxide equivalent emissions (g CO_2e/ha)						1,849,404

Average GHG emissions from the four low input plots

The average carbon emissions for the four (4) low input orchards was 1.81 Mg CO_2e/ha per year (Table 50). Plot 9 was left out from the average on account of young age (six years) when compared to those in other plots which were all 19 years and above.

Biomass accumulation was directly related to the age of the plants and this necessitated averaging within the age group. Figure 12 shows the average carbon sequestration and average GHG emissions per level of management-High and low input. Notably the bar graph shows more average carbon sequestration for the low input than the high input management level. The average GHG emissions are lower for the low input orchards than the high inputs. The carbon emission figures were presented as negative values in the tables and figures below.

Table 50: Summary of carbon emissions for the four (4) low input orchards

Plot	Field Work Emission	Fuel Production Emissions	Fertilizer Production Emissions	Fertilizer Application Emissions	Pesticide Production Emissions	Total Emissions (Mg CO_2e/ha)
Plot 6	-0.04	-0.24	-0.0	-0.04	-0.03	-0.35
Plot 7	-0.05	-0.16	-0.44	-1.54	-0.03	-2.22
Plot 8	-0.06	-0.16	-0.82	-1.76	-0.02	-2.82
Plot 10	-0.04	-0.27	-0.45	-1.06	-0.02	-1.85
Average	-0.0475	-0.2075	-0.4275	-1.1	-0.025	-1.81

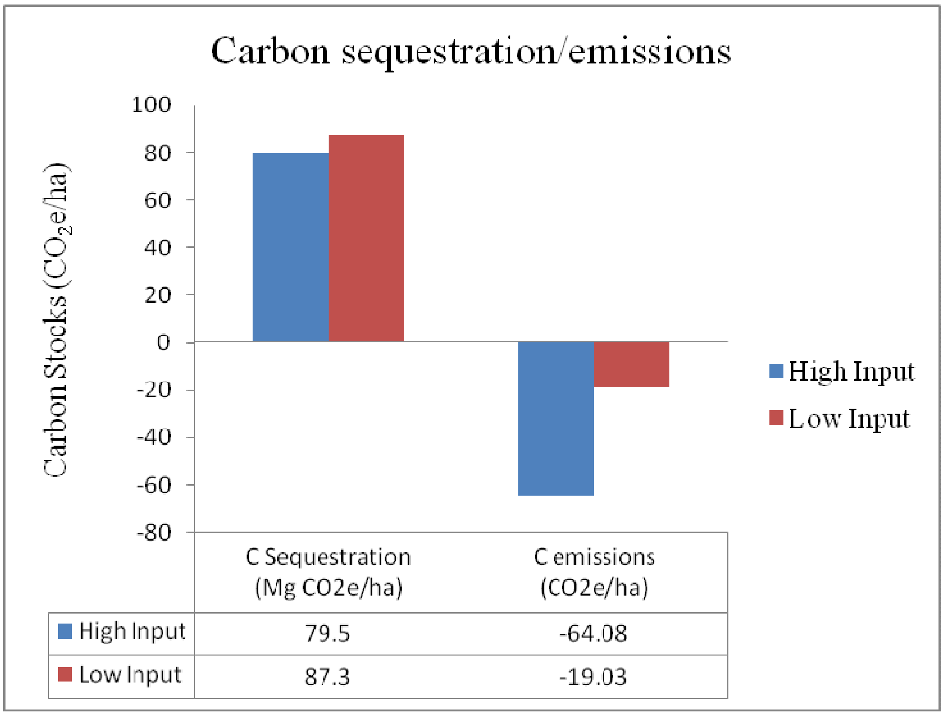

Figure 12: Average carbon sequestration and emissions by management level

The accumulated emissions over the reported period of external input application for the low input are shown in Table 51. Small holder farmers did not report continuous use of inputs through out the life of the orchards. For some periods the orchards were left with minimum attention during which carbon emissions due to external inputs was negligible.

Table 51: Weighted average accumulated emissions from the low input orchards

Plot	Total Emissions (Mg CO_2e/ha)	Reported period of application (years)	Accumulated emissions (Mg CO_2e/ha)
Plot 6	-0.35	10.00	-3.50
Plot 7	-2.22	13.00	-28.91
Plot 8	-2.82	5.00	-14.10
Plot 9	-0.22	2.00	-0.44
Plot 10	-1.85	16.00	-29.59
Average	-1.81		-19.03

4.8 SUMMARY OF GHG EMISSIONS

All the carbon emissions per hectare orchard were treated as negative emissions and the biomass accumulation as carbon sequestration (positive), for purposes of comparison. The summary of GHG emissions from all the orchards was shown in Table 52 and Figure 13. The highest emissions are from the commercial orchards (Plot 1, Plot 2, Plot 3, Plot 4 and Plot 5). The commercial orchards showed the highest use of inputs and highest use of machinery. The lowest emissions were recorded from the low input plot (Plot 9) which also had the youngest trees, only six years. The results of the life cycle assessment based carbon footprints of orchards can now be compared to citrus tree carbon sequestration to determine the net carbon sequestration potential of citrus orchards. The results of the commercial orchards were averaged for both carbon sequestration and GHG emissions to come up with the six orchards used in the net carbon sequestration potential analysis. The GHG emissions for high input orchards were very much similar, as similar amounts of inputs were applied to all the five orchards studied, but show a difference in the amount of biomass accumulated per orchard.

Table 52: Summary of carbon emissions for the ten orchards

Plot	Field Work Emission	Fuel Production Emissions	Fertilizer Production Emissions	Fertilizer Application Emissions	Pesticide Production Emissions	Total Emissions (Mg CO_2e/ha)
Plot 1	-0.632	-0.456	-1.164	-1.841	-0.171	-4.26
Plot 2	-0.635	-0.456	-1.164	-1.845	-0.171	-4.27
Plot 3	-0.638	-0.456	-1.164	-1.85	-0.171	-4.28
Plot 4	-0.639	-0.456	-1.164	-1.849	-0.171	-4.28
Plot 5	-0.636	-0.456	-1.164	-1.845	-0.171	-4.27
Plot 6	-0.04	-0.24	-0.0	-0.04	-0.03	-0.35
Plot 7	-0.05	-0.16	-0.44	-1.54	-0.03	-2.22
Plot 8	-0.06	-0.16	-0.82	-1.76	-0.02	-2.82
Plot 9	-0.02	-0.12	-0.04	-0.04	-0.01	-0.22
Plot10	-0.04	-0.27	-0.45	-1.06	-0.02	-1.85

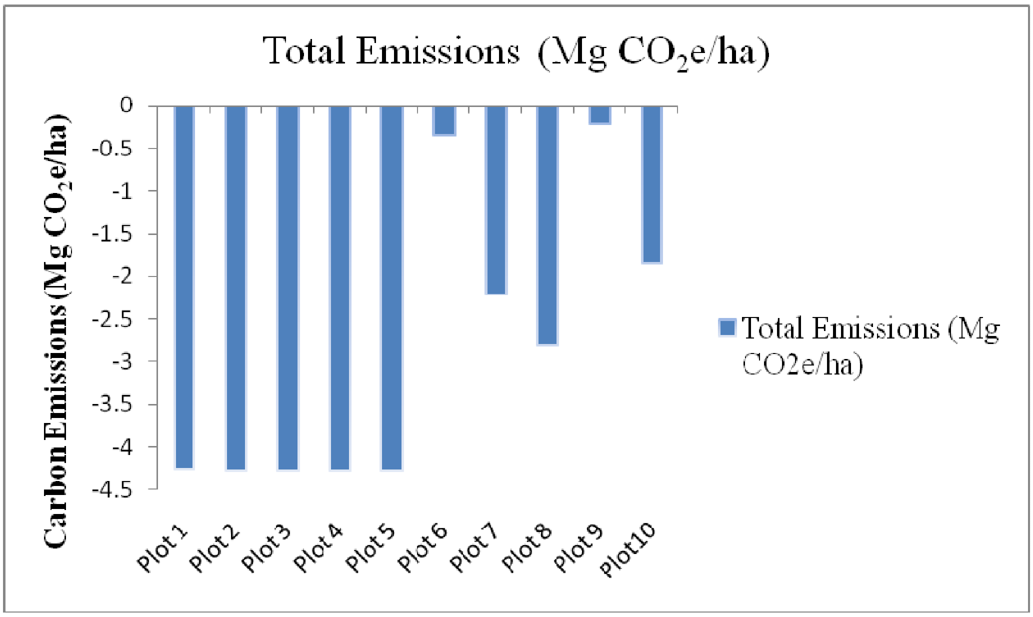

Figure 13: Total GHG emissions for the ten orchards in various districts of Lusaka province

Table 53: Summary of carbon sequestration, GHG emissions and net carbon sequestration for the ten orchards

Plot	Carbon Sequestration (Mg CO_2e/ha)	Total Carbon Emissions (Mg CO_2e/ha)	Net Carbon Sequestration (MgCO_2e/ha)
Plot 1	71.1	-63.9	7.20
Plot 2	77.8	-64.05	13.75
Plot 3	85.5	-64.2	21.30
Plot 4	84.8	-64.2	20.60
Plot 5	78.3	-64.05	14.25
Plot 6	64.6	-3.50	61.10
Plot 7	93.6	-28.86	64.74
Plot 8	109.2	-14.1	95.10
Plot 9	26.3	-0.44	25.86
Plot10	81.8	-29.6	52.20

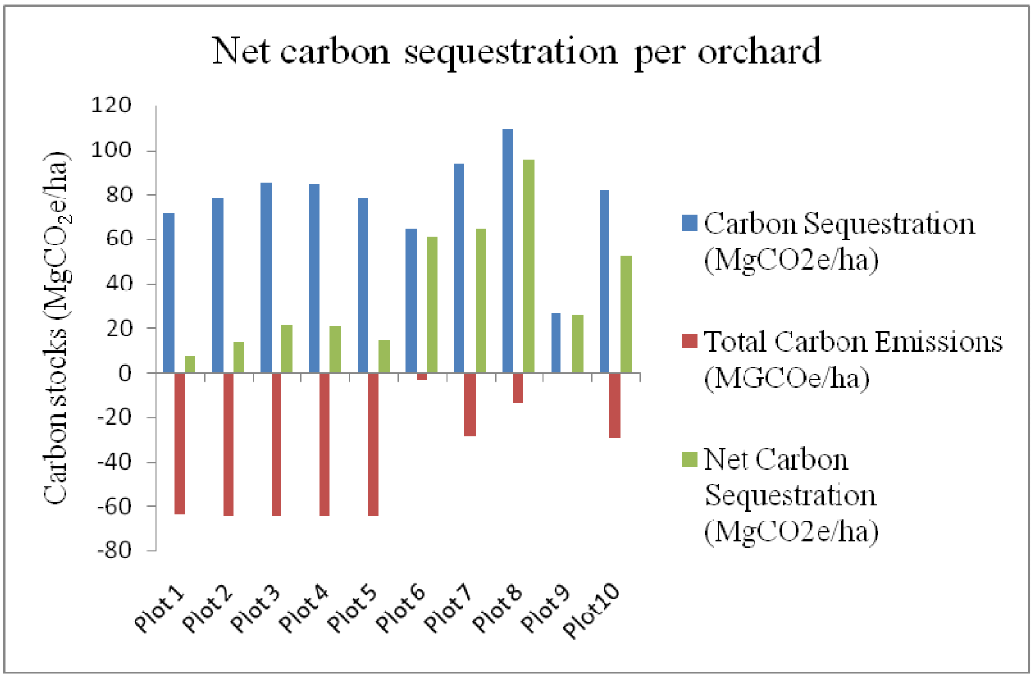

Figure 14: Carbon sequestration, GHG emissions and net carbon sequestration. Carbon emissions were indicated as negative (middle bar) and the carbon sequestration was denoted by positive values. The net carbon sequestration was the difference between carbon sequestration and carbon emissions (right bar) were positive for all the ten (10) orchards.

The average carbon sequestration, GHG emissions and net carbon sequestration were as shown in Table 54, Table 55 and Table 56.

Table 54: Average carbon sequestration results for different levels of management

Management Level	Biomass (Mg/ha)	Carbon Stock (Mg C/ha)	Carbon Eq. (Mg CO_2e/ha)	Annual CO_2e Increment (Mg CO_2e/ha)
High Input	43.36	21.66	79.5	7.62
Low input	47.63	23.80	87.30	9.35

Table 55: Average GHG emissions for different levels of management

Management Level	Field Work Emission	Fuel Production Emissions	Fertilizer Production Emissions	Fertilizer Application Emissions	Pesticide Production Emissions	Total Emissions (Mg CO_2e/ha)
High input	-0.636	-0.456	-1.164	-1.846	-0.171	-4.272
Low input	-0.0475	-0.2075	-0.4275	-1.1	-0.025	-1.81

Table 56: Net carbon sequestration potential of orchard per management level

Management Level	Biomass-Average (Mg CO_2e/ha)	LCA (MgCO_2e/ha)	Period of Input application (Years)	GHG Emissions Accumulation (Mg CO_2e/ha)	Net Carbon Sequestration (Mg CO_2e/ha)
High Input	79.49	-4.28	15.00	-64.08	15.42
Low Input	87.3	-1.81	-	-19.03	68.27

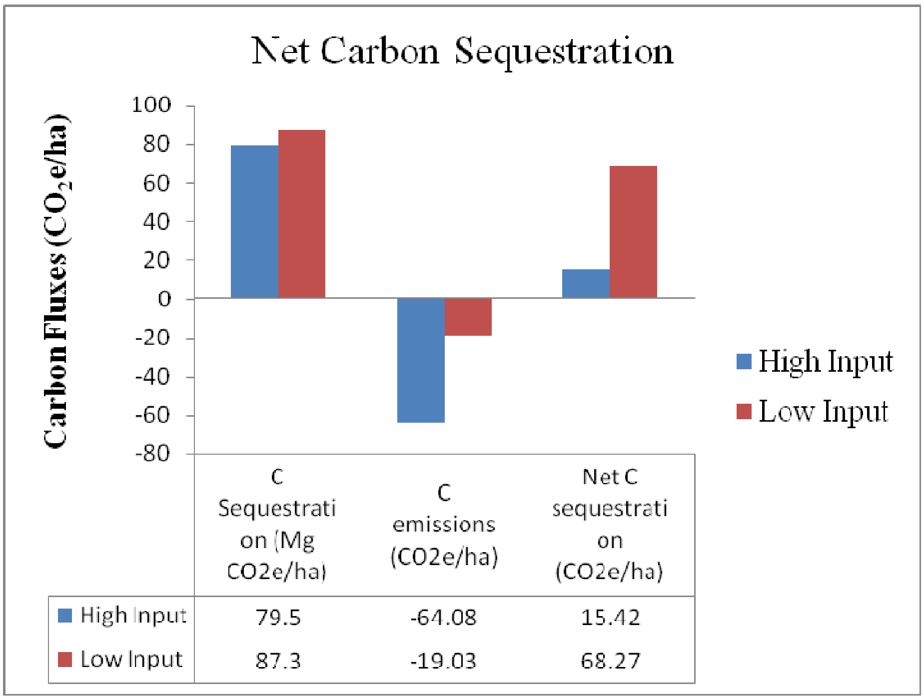

Figure 15: Net carbon sequestration by management level. The average carbon sequestration for high input (left bar) orchards is lower than that for low inputs. Net carbon sequestration for both management levels was postive and there was higher average net carbon sequestration for low input orchards than for the high input orchards.

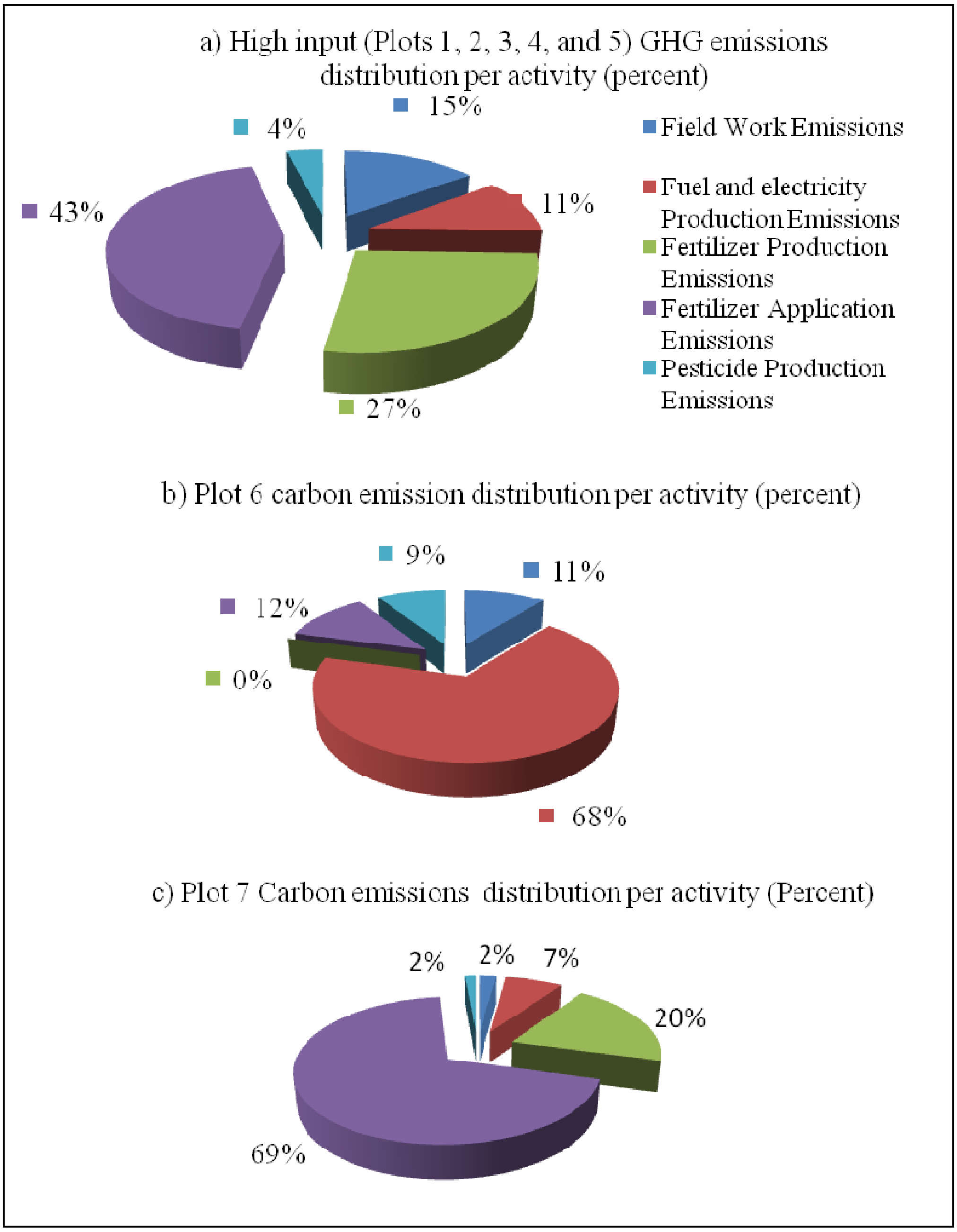

Figure 16: The average distribution of carbon emissions by contribution per activity under high (a) and low (b and c) in-puts systems showing the differences of contribution of fertilizer production and application to total GHG emissions between high and low input orchard management.

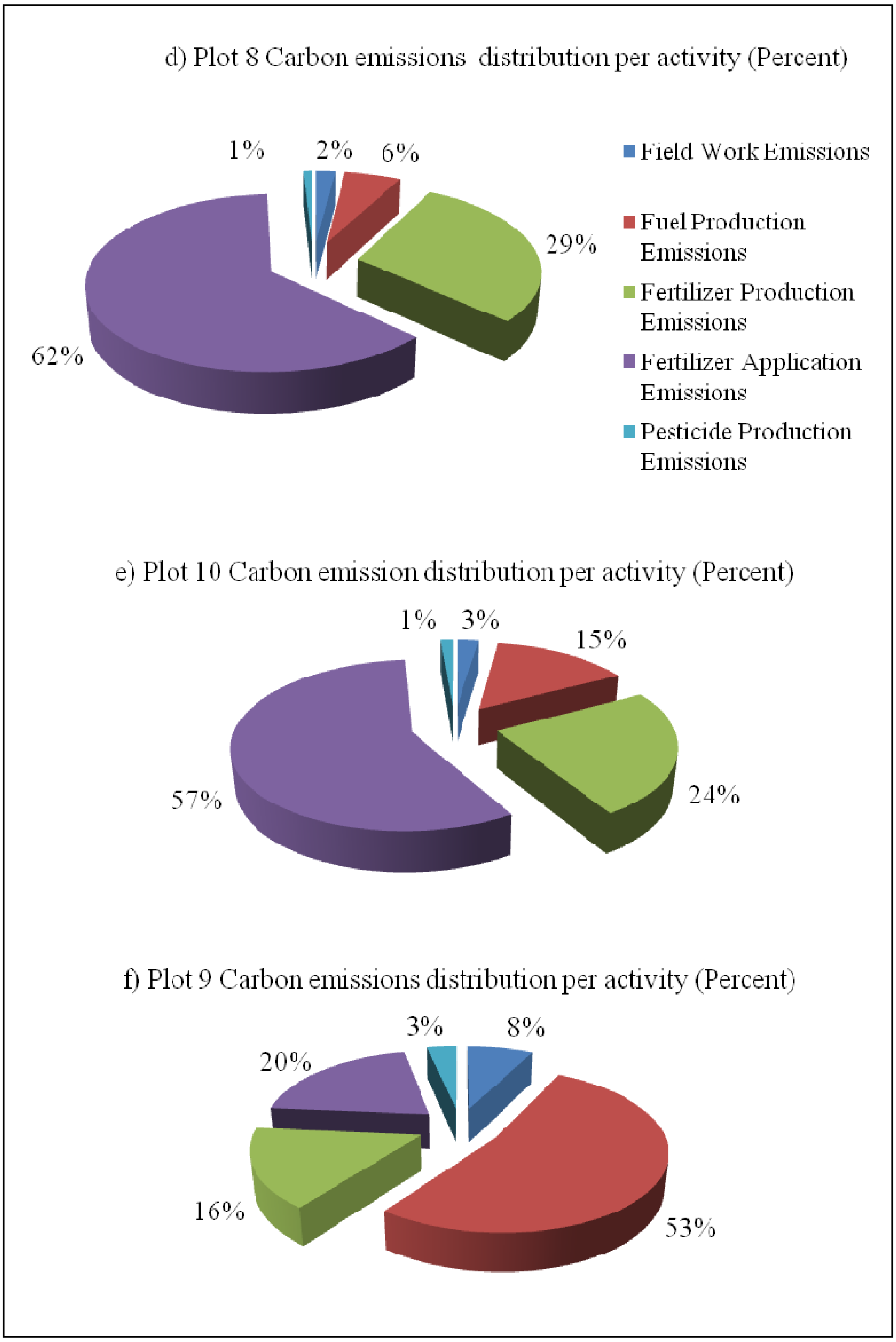

Figure 17: Emissions distribution by activity-low input (d to f) orchards. For low input orchards where fertilizer application is low, the contribution of GHG emissions from fertilizer production and application is also low.

Chapter 5

DISCUSSION

Carbon sequestration

The citrus tree biomass accumulation from the planting date to the date of the study was determined by the use of allometric equations developed for citrus, dry tropical forest and other agro-forestry and shade trees which relate the biophysical parameter such as plant diameter to biomass. A total of fourteen orchards were visited out of which ten were used in the analysis for this study. The average carbon sequestration for four low input orchards was high at 87.3 Mg CO_2e/ha as compared to 79.5 Mg CO_2e/ha for high input or commercial orchards. The carbon sequestration of citrus did not appear to increase with the increase in external inputs (regression coefficient was 0.44), but appeared to increase with the age of citrus trees (regression coefficient was 0.55) and other factors such as soil fertility which were not considered in this study.

A wide range of diameters at breast height (DBH, in this case at 30 cm above ground) were measured in each plot or orchard. The smallest DBH recorded was 5.8 cm from Plot 9 (Mean DBH was 9.94 cm) which had six year old plants and the highest recorded was 27.1 cm from Plot 8 (Mean DBH was 23.65 cm) which was the oldest orchard at 37 years. The highest population density of 450 citrus plants per hectare was observed in Plots 1 and 6 which were among the plots from the small holder or low input growers and the lowest density was 277 plants per hectare among the commercial growers. The plots with the highest population density recorded the lowest biomass accumulation of 14.3 and 35.2 Mg/ha for plots Plot 9 and plot 6 respectively. This result is in agreement with Juwarkar *et al*., (2011) who also found that in the natural forest, trees with higher population density had smaller DBH but accumulated lower biomass compared to those with larger DBH.

The calculated biomass per tree ranged from 23.99 kg/tree from Plot 9 to 190.67 kg/tree from Plot 8 and this is equivalent to carbon sequestration of 26.3 and 109.2 Mg CO_2e/ha for plots Plot 9 and Plot 8 respectively. The average biomass per tree for high input plots was found to be 156.5 kg/tree. The average carbon sequestration for the five commercial plots was 79.57 Mg CO_2e/ha and the average carbon sequestration for low input was 87.3 Mg CO_2e/ha. The value of carbon sequestration for the low input management systems was higher than that for the high input management, a finding was not expected, but could be explained from spatial location differences in terms of soil fertility and also the age of the trees as noted above. The citrus trees are said to increase trunk diameter at the rate of 0.78 cm annually, (UNFCCC/NUCC, 2011), during their active growing period before reaching the optimum tree size. From this annual increment in diameter, the annual biomass change converted to carbon dioxide equivalents, has been calculated (using equation 4) to range from 5.3 to 10.3 Mg CO_2e/ha.

The calculated biomass per tree was comparable with what Morgan *et al*. (2006) found in a study to determine biomass and Nitrogen distribution of sweet oranges using a Destructive Method to determine dry weight tree biomass of citrus, (*Citrus sinensis* L. Osbeck). In their study the dry weight per tree was found to be about 100 kg/tree and the fresh weight ranged from 120 to 194 kg/tree, (Morgan *et al*., 2006) and other studies have also shown similar results of dry weight biomass of about 100 kg/tree.

The carbon stock recorded in this study was lower than what other studies have recorded in natural forests. This is mainly on account of different species of trees; citrus spp are generally small to medium trees reaching only up to a maximum height of 13 m while forest trees can reach the height of 22 m, (Manner *et al*., 2006 and Juwarkar *et al*., 2011).

The allometric equation which was developed by Scroth (Scroth *et al*., 2002) had limited use becuase the upper limit DBH of 17 cm was far exceeded by most citrus trees in the study. This probably explains why the average biomass per tree found in this study was slightly higher than what Morgan *et al*. (2006) found in their study, whose age range for the citrus was 3 to 15 years.

The biomass accummulation was seen to be affected by application of external inputs as well as natural factors such as climate and georaphical location. Several complex and interacting factors affect citrus growth. These include air and soil temperature, soil moisture conditions, soil pH and sunshine. The average rainfall and soil moisture condition is very important in semi-arid environments. Since all the orchards studied are located in the same agro-ecological region, the effect of air temperature, sunshine and wind speed on the differences in biomass accummulation may be generally the same for all the orchards. The effect of local soil moisture conditions and pH and plant nutrient status for each particular orchard may have a profound effect on biomass accummulation. Like noted in sections 4.2.2, 4.2.3 and section 4.2.5 above, citrus trees in Plot 7, Plot 8 and Plot 10 which are located in the fertile flood plain, despite being low input (small holder) orchards recorded marked biomass accummulation even higher than commercial orchards (Plot 1) planted in other regions. The large increase in biomass accummulation by trees in plots 7, 8 and 10 may have been due to the availability of sufficient soil moisture during the most part of the dry season, which was also supplemented by irrigation with water drawn from shallow wells. Although citrus are shallow rooted trees, it is possible that they were able to access flood plain moisture from the soil during the most part of the dry season. Plot 9 which was located on a higher land, despite being an old orchard, the biomass accummulation was low; partly because no fertilizers were reported to have been used and also due to insufficient soil moisture during the dry season. The reported irrigation during the dry season may have not been sufficient. The biomass accummulation was observed to be increasing linearly with the increase in DBH. The regression analysis showed the regression coefficient ranged from 0.883 to 0.996 which is a strong correlation.

Life cycle assessment

Life Cycle Assessment was a process used to evaluate the total environmental impact of agro-chemical inputs from manufacture to application and use on the orchards in order to determine the GHG emissions attributed to citrus orchard biomass production. The second part of this study determined the total GHG emissions using the life cycle approach of carbon foot-printing of inputs and outputs at the farm/orchard level. The GHG emissions of citrus orchard production were calculated in conformity with PAS 2050: 2011 recommendations. All carbon (or GHG) emissions were considered negative emissions and carbon sequestration as positive values. The output was expressed as tree biomass accumulated in a hectare of citrus trees. Two different production systems were considered; the high input which were commercial orchard production and the low input practiced by small holder citrus producers. For the high input the average GHG emissions was 4.272 Mg CO_2e/ha while that for low input was 1.81 Mg CO_2e/ha. The GHG emissions from the individual orchards from the low input management systems ranged from 0.22 to 2.82 Mg CO_2e/ha. The major source of GHG emissions from the commercial orchards was from the production and application of chemical fertilizers which supply the essential plant elements of N, P_2O_5 and K_2O. The other major contribution to carbon emissions was the field work operations and electricity consumed in the running of irrigation water pumps. Small holder orchards had the GHG emissions also mainly coming from fertilizer production and application and emissions due to crop residues where applicable and from electricity use.

In the high input orchard 43 percent of GHG emissions were due to fertilizer application-the release of nitrous oxide from fertilizer applied as nitrogen and also from urea application. The other greenhouse gas emissions were due to upstream emissions from the production and delivery of fertilizers (27%). The other major contributing factor to the GHG emissions were emissions attributed to field work; fifteen percent (15%) for high input orchards and three percent (3%) for low inputs, and that associated with fuel and electricity production and use. Field work emissions were as a result of burning fossil fuels in farm machinery. Where there was no application of fertilizers, the bulky of emissions shifted to the production and use of fuel and electricity (68%) followed by emissions due to crop residue and field work at 12 and 11 percent (%) respectively. The emissions from the application of nitrogen fertilizer also include emissions estimated from the decomposing organic matter (from pruning material left as crop residue on fields). The GHG emissions from the small holder orchards were much smaller as compared to the emissions from the commercial orchards.

Both the commercial and small holder farmers may have opportunities to reduce their farm GHG emissions by reducing emissions from fertilizer application and from field work operations by implementing measures such as reducing fertilizer inputs and use of smaller tractors with lower fuel consumption and use of renewable energy. The reported amount of nitrogen fertilizer use was high and a reduction in the amount of nitrogen fertilizer applied would result in significant reduction in emissions.

The results of this study were similar to studies conducted in other countries. A study conducted in Egypt reported a baseline scenario (without composting) carbon emissions of 3.2 Mg CO_2e/ha for citrus production, (Luske, 2010). This value falls within the range determined for this study and compares well with other studies done for similar perennial crops like Apples (Page, 2011). Page, (2011) in a study conducted in New Zealand found carbon emissions of 2.8 and 3.8 Mg CO_2e/ha from energy use only in a Kiwifruit and Apple organic orchard production systems respectively. Another study done in the USA on citrus found similar amount of emissions from inputs, 8.4 Mg CO_2e/ha, although slightly high on account of heavy use of inputs and highly mechanized orchards which included even conveyor belts to transport harvested fruits, (EPA, 2010).

The variation in the reported GHG emissions per hectare of citrus could first and foremost partly be explained in terms of the differences in the levels of external inputs and management. Differences in methodologies and assumptions made can also lead to differences in results. The other explanation would be due to the use of emissions factors that were not developed for the local environment. The emission factors and the GREET Model: 2011 used in this study were developed for use in the United States and Europe. Apparently there were no country-specific emission factors for inputs and processes in Zambia. This lead to the use of emission factors and models which were derived mostly for European systems and American systems such as for the production, packaging and transportation of fertilisers and pesticides which may not accurately reflect the situation in Zambia. In conformity with the British Standards' PAS 2050, (2011), the carbon foot-printing applied in this study did not consider the orange fruits as carbon sequestration product and carbon sequestration and emissions from the soil was excluded due to uncertainty of the impact of agricultural technologies used in land management, (PSA: 2050, 2011). Most of the orchards where the study was done were established before 31st December 1989 and therefore, emissions from land use change were not considered and there were no reports of expanding the orchards into natural forests.

The data collected from the farmers/managers had some gaps that were filled by use of secondary data from literature. For some orchards which were established many years ago and without proper records, it was not possible to establish the exact amount of external inputs that were used. The small holder farmers were unable to remember the exact amount of pesticides. This necessitated the use of the standard values from literature.

Net carbon sequestration

Net carbon sequestration can be determined by caculating the difference between biomass accumulation and the total accumulated GHG emissions over the life span of the orchard. Alternatively, annual biomass increment (carbon sequestration) can be compared with the annual GHG emissions, (Page, 2011). Farmers reported that they had been applying the inputs annually to the orchards for different periods ranging from two years for plot 9 to 15 years for high input plots and 16 years for Plot 10. The resulting accumulative GHG emissions ranged from 3.5 Mg CO_2 e/ha for Plot 9 representing low input plots to 64.2 Mg CO_2 e/ha and high inputs. The resulting net carbon sequestration ranged from 15.35 Mg CO_2e/ha for high input orchards to 68.27 Mg CO_2e/ha for low input orchards. Alternatively, from the average annual GHG emissions of 4.3 Mg CO_2e/ha and annual carbon sequestration of 7.62 Mg CO_2e/ha, the net carbon sequestration was calculated as 3.32 Mg CO_2e/ha for high input orchards. The low input orchards had a higher average annual carbon sequestration of 9.35 Mg CO_2e/ha and a lower avarage annual GHG emissions of 1.81 Mg CO_2e/ha, the net carbon emission for the low input orchards was determined to be 7.54 Mg CO_2e/ha. The net carbon sequestration potential for high input orchard mangement systems could become negative after a contionous annual application of inputs of similar amounts as the ones used in this analysis beyond the fruit bearing age.

Both of the methods for determining the net carbon sequestration have their own weaknesses. The total accumulated GHG emissions were calculated by assuming that the external inputs used in a typical year as reported by the farmers/managers, the exact same amounts were repeated every other typical year for the period of application reported. On the other hand, the annual biomass increment (annual carbon sequestration) was calculated using equation which is an exponential function which gives higher values for higher DBH.

Chapter 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

Citrus trees sequester carbon and the net carbon sequestration potential by citrus (*Citrus sinensis* (L.) Oesbeck) is higher for low external input management systems than higher external input management systems (commercial production). Although the carbon stock in citrus trees is lower than that found in the natural forest, clearly citrus trees do sequester carbon in biomass, and can remain so for well over 50 years. The carbon sequestration potential of citrus partly depended on age. Older plants sequestered more carbon than younger plants. The productivity could be enhanced by proper management; well managed orchards sequestered more carbon than those that did not receive good care.

The application of agro-chemical inputs and use of mechanized technologies on orchards results in carbon emissions. This study has established that GHG emissions do not exceed carbon sequestration for both high and low input citrus orchard management systems. Low input citrus orchards are carbon sinks. High input orchards remain carbon sinks until the carbon emissions exceed carbon sequestration due to continuous application of agro-chemical inputs beyond the optimum fruit bearing age. This means, therefore, that growing of citrus especially with low input management systems offers an opportunity to mitigate climate change by reducing CO_2 from the atmosphere through carbon sequestration in citrus biomass. The results showed that continuous application of inputs-fertilizer, pesticides and water (except where water is applied manually), beyond the bearing period of citrus resulted in net carbon emissions becoming negative, otherwise judicious application of inputs to citrus plantations does not give net negative greenhouse gas emissions.

6.2 Recommendations

The UNFCCC's Kyoto protocol CDM meant to help developing countries to come up with sustainable life improvement projects that which remove or sequester carbon in exchange for developed countries to have the right to emit similar amount of carbon, needs to be relooked at or reviewed. On the face value, such schemes do give the same benefits to the developed and developing countries. The value of a ton of carbon sequestered in forests in terms of improving the lives of poor people living in developing countries, may not be the same as a tone of carbon emitted through industrial activities and effect it has on the lives of citizens of developed countries. This could be taken into account when negotiating and developing policies on the implementation of CDM programmes.

In this study four (4) different equations were used and the biomass determined from the average, and thus, there was generally little variation. In future it would be worthwhile to conduct studies but using Destructive Methods and comparing the reliability.

Such data can be used to formulate more allometric equations that incorporate local environment variability. Accurately determining GHG emissions and carbon sequestration is vital to forest and agro-forestry management. But this is difficult to achieve without locally developed carbon emission factors and allometric equations for calculating aboveground biomass. It is recommended that comprehensive studies could be carried out to develop country specific and local allometric equations and GHG emission factors, which could be applied in the assessment of live biomass held by both the natural and agro-forests.

Chapter 7

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APPENDICES

APPENDIX A

Appendix A1: Citrus tree biomass calculation and results for Plot 1

		Name of Farm:		**A1**					
		Province:		Lusaka					
		Plot Size: A1		1,800 sqm					
		Citrus Varieties:		Washington Navel, Valencia					
Tree No.	**Tree Age**	**DBH**	D (m)	BA (cm2)	Biomass Eq1 kg/Tr	Biomass Eq2 kg/Tr	Biomass Eq3 kg/Tr	Biomass Eq4 kg/Tr	Average
1	35	14	0.14	153.94	48.49	31.12	51.74	61.97	48.33
2	35	20.6	0.206	333.29	151.82	103.94	122.10	151.82	132.42
3	35	15.7	0.157	193.59	66.64	43.58	66.76	80.84	64.45
4	35	16.8	0.168	221.67	80.46	54.07	77.60	94.59	76.68
5	35	20.1	0.201	317.31	143.40	96.24	115.61	143.40	124.67
6	35	20.1	0.201	317.31	143.40	96.24	115.61	143.40	124.67
7	35	22.9	0.229	411.87	194.07	143.45	154.49	194.07	171.52
8	35	20.1	0.201	317.31	143.40	96.24	115.61	143.40	124.67
9	35	19.6	0.196	301.72	135.26	88.87	109.32	135.26	117.18
10	35	21.1	0.211	349.67	160.50	111.97	128.79	160.50	140.44
11	35	15.6	0.156	191.13	65.46	42.71	65.81	79.65	63.41
12	35	20.1	0.201	317.31	143.40	96.24	115.61	143.40	124.67
13	35	21	0.21	346.36	158.74	110.34	127.44	158.74	138.82
14	35	22.4	0.224	394.08	184.38	134.31	147.10	184.38	162.54
15	35	12	0.12	113.10	31.49	22.64	36.73	43.34	33.55
16	35	11	0.11	95.03	24.52	21.04	30.27	35.41	27.81
17	35	15.9	0.159	198.56	69.02	45.35	68.66	83.25	66.57
18	35	22.4	0.224	394.08	184.38	134.31	147.10	184.38	162.54
19	35	24.1	0.241	456.17	218.49	166.57	173.07	218.49	194.15
20	35	16.1	0.161	203.58	85.70	47.18	70.59	85.70	72.29
21	35	20.1	0.201	317.31	143.40	96.24	115.61	143.40	124.67
22	35	23.3	0.233	426.38	202.03	150.97	160.56	202.03	178.90
23	35	19.5	0.195	298.65	133.67	87.44	108.08	133.67	115.71
24	35	18.9	0.189	280.55	124.32	79.13	100.83	124.32	107.15
25	35	22.6	0.226	401.15	188.23	137.93	150.03	188.23	166.10
26	35	18	0.18	254.47	97.64	67.61	90.46	111.01	91.68
27	35	17	0.17	226.98	83.17	56.18	79.67	97.23	79.06
28	35	15.4	0.154	186.27	63.16	41.04	63.95	77.30	61.36
29	35	20.5	0.205	330.06	150.11	102.38	120.79	150.11	130.85
30	35	19.6	0.196	301.72	135.26	88.87	109.32	135.26	117.18
31	35	22.1	0.221	383.60	176.02	128.97	142.75	178.71	156.61
32	35	14.8	0.148	172.03	56.57	36.40	58.55	70.49	55.50
33	35	21.2	0.212	352.99	155.89	113.61	130.15	162.27	140.48
34	35	19.5	0.195	298.65	133.67	87.44	108.08	133.67	115.71
35	35	16	0.16	201.06	70.24	46.25	69.62	84.47	67.65
36	35	23	0.23	415.48	198.00	145.31	156.00	196.05	173.84
37	35	21.7	0.217	369.84	171.29	122.02	137.07	171.29	150.42
38	35	20.3	0.203	323.65	146.74	99.28	118.19	146.74	127.74
39	35	26.7	0.267	559.90	277.11	222.03	217.34	277.11	248.40
40	35	21.9	0.219	376.68	174.98	125.47	139.90	174.98	153.83
41	35	15	0.15	176.71	58.71	37.88	60.32	72.72	57.41
42	35	20.1	0.201	317.31	143.40	96.24	115.61	143.40	124.67
43	35	19.1	0.191	286.52	127.39	81.84	103.21	127.39	109.96
44	35	15.6	0.156	191.13	65.46	42.71	65.81	79.65	63.41
45	35	17.1	0.171	229.66	84.54	57.26	80.71	98.56	80.27
46	35	16.8	0.168	221.67	80.46	54.07	77.60	94.59	76.68
47	35	25.8	0.258	522.79	255.92	202.04	201.39	255.92	228.82
48	35	18.8	0.188	277.59	122.80	77.79	99.64	122.80	105.76
Plot Biomass					**6253.25**	**4370.81**	**5221.27**	**6479.43**	**5581.19**
Expansion Factor					5.56	5.56	5.56	5.56	5.56
Aboveground Biomass/ha					34740.29	24282.30	29007.03	35996.81	31006.61
Belowground Biomass/ha					8685.07	6070.57	7251.76	8999.20	7751.65
Total Biomass/ha					43425.37	30352.87	36258.79	44996.01	38758.26
Carbon/ha (Total Biomas/2ha)					21712.68	15176.44	18129.40	22498.01	19379.13
arbon Equivalents (kg CO2eq.)					79620.41	55651.99	66480.49	82500.19	71063.27
5% of Biomass Prunned					1737.01	1214.11	1450.35	1799.84	1550.33
Maintenance/Replacement @4%					1737.01	1214.11	1450.35	1799.84	1550.33

Appendix A2: Citrus tree biomass calculation and results for Plot 2

		Name of Farm:		**A2**					
		Province		Lusaka					
		Plot Size:	A2	1,800	sqm				
		Citrus Varieties:		Washington Navel, Valencia					
Tree No.	**Tree Age**	**DBH**	D (m)	BA (cm2)	Biomass Eq1 kg/Tr	Biomass Eq2 kg/Tr	Biomass Eq3 kg/Tr	Biomass Eq4 kg/Tr	Average kg/Tree
1	35	13	0.13	132.73	39.45	26.02	43.88	52.18	40.38
2	35	19.1	0.19	286.52	127.39	81.84	103.21	127.39	109.96
3	35	21.1	0.21	349.67	160.50	111.97	128.79	160.50	140.44
4	35	25.5	0.26	510.71	249.07	195.56	196.22	249.07	222.48
5	35	18	0.18	254.47	111.01	67.61	90.46	111.01	95.03
6	35	20.1	0.20	317.31	143.40	96.24	115.61	143.40	124.67
7	35	22.1	0.22	383.60	178.71	128.97	142.75	178.71	157.28
8	35	14	0.14	153.94	48.49	31.12	51.74	61.97	48.33
9	35	22.8	0.23	408.28	192.11	141.60	153.00	192.11	169.71
10	35	21.8	0.22	373.25	173.13	123.74	138.48	173.13	152.12
11	35	23.4	0.23	430.05	204.05	152.88	162.09	204.05	180.77
12	35	23.8	0.24	444.88	212.23	160.64	168.32	212.23	188.35
13	35	21	0.21	346.36	158.74	110.34	127.44	158.74	138.82
14	35	23	0.23	415.48	196.05	145.31	156.00	196.05	173.35
15	35	20.3	0.20	323.65	146.74	99.28	118.19	146.74	127.74
16	35	19.3	0.19	292.55	130.51	84.61	105.63	130.51	112.82
17	35	18.6	0.19	271.72	119.79	75.16	97.30	119.79	103.01
18	35	14.4	0.14	162.86	52.43	33.63	55.09	66.15	51.82
19	35	22.1	0.22	383.60	178.71	128.97	142.75	178.71	157.28
20	35	20.2	0.20	320.47	145.07	97.75	116.90	145.07	126.20
21	35	19.7	0.20	304.81	136.87	90.32	110.56	136.87	118.66
22	35	20.4	0.20	326.85	148.42	100.82	119.48	148.42	129.29
23	35	18.3	0.18	263.02	115.35	71.32	93.85	115.35	98.97
24	35	21	0.21	346.36	158.74	110.34	127.44	158.74	138.82
25	35	17.6	0.18	243.28	105.38	62.86	86.05	105.38	89.92
26	35	24.9	0.25	486.95	235.68	182.88	186.10	235.68	210.09
27	35	14.6	0.15	167.42	54.48	34.98	56.80	68.30	53.64
28	35	16.7	0.17	219.04	79.13	53.04	76.58	93.29	75.51
29	35	20.5	0.21	330.06	150.11	102.38	120.79	150.11	130.85
30	35	24.1	0.24	456.17	218.49	166.57	173.07	218.49	194.15
31	35	20.3	0.20	323.65	146.74	99.28	118.19	146.74	127.74
32	35	22.8	0.23	408.28	192.11	141.60	153.00	192.11	169.71
33	35	21	0.21	346.36	158.74	110.34	127.44	158.74	138.82
34	35	20.1	0.20	317.31	143.40	96.24	115.61	143.40	124.67
35	35	25	0.25	490.87	237.89	184.97	187.77	237.89	212.13
36	35	18.1	0.18	257.30	112.45	68.83	91.58	112.45	96.33
37	35	21.6	0.22	366.44	169.47	120.31	135.67	169.47	148.73
38	35	21	0.21	346.36	158.74	110.34	127.44	158.74	138.82
39	35	20.5	0.21	330.06	150.11	102.38	120.79	150.11	130.85
40	35	22.3	0.22	390.57	182.48	132.52	145.64	182.48	160.78
41	35	24.2	0.24	459.96	220.60	168.57	174.67	220.60	196.11
42	35	19.2	0.19	289.53	128.95	83.22	104.42	128.95	111.38
43	35	21.3	0.21	356.33	164.05	115.27	131.52	164.05	143.72
44	35	17.6	0.18	243.28	105.38	62.86	86.05	105.38	89.92
45	35	19.3	0.19	292.55	130.51	84.61	105.63	130.51	112.82
46	35	21.7	0.22	369.84	171.29	122.02	137.07	171.29	150.42
	Plot Biomass				**6943.14**	**4872.10**	**5627.07**	**7011.06**	**6113.34**
	Expansion Factor				5.56	5.56	5.56	5.56	5.56
	Aboveground Biomass/ha				38572.99	27067.21	31261.50	38950.33	33963.01
	Belowground Biomass/ha				9643.25	6766.80	7815.37	9737.58	8490.75
	Total Biomass/ha				48216.24	33834.02	39076.87	48687.92	42453.76
	Carbon/ha (Total Biomas/2ha)				24108.12	16917.01	19538.44	24343.96	21226.88
	Carbon Equivalents (kg CO2eq.)				88404.48	62034.67	71647.44	89269.29	77838.97
	5% of Biomass Prunned				1928.65	1353.36	1563.07	1947.52	1698.15
	Tree Maintenance/Replacement @4%				1928.65	1353.36	1563.07	1947.52	1698.15

Appendix A3: Citrus tree biomass calculation and results for Plot 3

			Name of Farm:		**A3**				
			Province:		Lusaka				
			Plot Size:	A3	1,980	sqm			
			Citrus Varieties:		Washington Navel, Valencia				
Tree No.	**Tree Age**	**DBH**	D (m)	BA (cm2)	Biomass Eq1 kg/Tr	Biomass Eq2 kg/Tr	Biomass Eq3 kg/Tr	Biomass Eq4 kg/Tr	Average kg/Tree
1	35	23.5	0.24	433.74	206.08	154.81	163.64	206.08	182.65
2	35	19.6	0.20	301.72	135.26	88.87	109.32	135.26	117.18
3	35	30.1	0.30	711.58	365.95	304.25	283.70	365.95	329.96
4	35	22.0	0.22	380.13	176.84	127.21	141.32	176.84	155.55
5	35	16.7	0.17	219.04	79.13	53.04	76.58	93.29	75.51
6	35	30.6	0.31	736.97	381.14	317.99	294.97	381.14	343.81
7	35	14.0	0.14	153.94	48.49	31.12	51.74	61.97	48.33
8	35	16.2	0.16	206.12	72.70	48.12	71.57	86.94	69.83
9	35	19.6	0.20	301.72	135.26	88.87	109.32	135.26	117.18
10	35	16.8	0.17	221.67	80.46	54.07	77.60	94.59	76.68
11	35	19.2	0.19	289.53	128.95	83.22	104.42	128.95	111.38
12	35	15.6	0.16	191.13	65.46	42.71	65.81	79.65	63.41
13	35	21.8	0.22	373.25	173.13	123.74	138.48	173.13	152.12
14	35	18.3	0.18	263.02	115.35	71.32	93.85	115.35	98.97
15	35	18.1	0.18	257.30	112.45	68.83	91.58	112.45	96.33
16	35	22.1	0.22	383.60	178.71	128.97	142.75	178.71	157.28
17	35	17.4	0.17	237.79	102.62	60.57	83.90	102.62	87.43
18	35	23.8	0.24	444.88	212.23	160.64	168.32	212.23	188.35
19	35	18.3	0.18	263.02	115.35	71.32	93.85	115.35	98.97
20	35	21.1	0.21	349.67	160.50	111.97	128.79	160.50	140.44
21	35	23.6	0.24	437.44	208.12	156.74	165.19	208.12	184.54
22	35	23.0	0.23	415.48	196.05	145.31	156.00	196.05	173.35
23	35	23.4	0.23	429.93	203.98	152.82	162.04	203.98	180.70
24	35	31.7	0.32	787.11	411.38	345.05	317.36	411.38	371.29
25	35	22.8	0.23	408.28	192.11	141.60	153.00	192.11	169.71
26	35	16.5	0.17	213.82	90.72	51.03	74.55	90.72	76.76
27	35	17.9	0.18	251.65	109.59	66.40	89.35	109.59	93.73
28	35	16.2	0.16	206.12	86.94	48.12	71.57	86.94	73.39
29	35	17.1	0.17	229.66	98.56	57.26	80.71	98.56	83.77
30	35	14.0	0.14	153.94	48.49	31.12	51.74	61.97	48.33
31	35	13.6	0.14	145.27	44.74	28.88	48.51	57.94	45.02
32	35	19.8	0.20	309.11	139.11	92.35	112.30	139.11	120.72
33	35	17.0	0.17	226.98	83.17	56.18	79.67	97.23	79.06
34	35	14.6	0.15	167.42	54.48	34.98	56.80	68.30	53.64
35	35	19.7	0.20	304.81	136.87	90.32	110.56	136.87	118.66
36	35	29.1	0.29	663.40	337.37	278.12	262.43	337.37	303.82
37	35	20.3	0.20	323.65	146.74	99.28	118.19	146.74	127.74
38	35	19.4	0.19	295.59	132.08	86.02	106.85	132.08	114.26
39	35	23.8	0.24	444.88	212.23	160.64	168.32	212.23	188.35
40	35	29.9	0.30	701.72	360.08	298.91	279.33	360.08	324.60
41	35	22.9	0.23	411.87	194.07	143.45	154.49	194.07	171.52
42	35	26.7	0.27	558.91	276.54	221.49	216.91	276.54	247.87
43	35	30.2	0.30	715.00	367.99	306.10	285.21	367.99	331.83
44	35	20.2	0.20	320.47	145.07	97.75	116.90	145.07	126.20
45	35	20.0	0.20	314.16	141.75	94.74	114.34	141.75	123.15
46	35	20.6	0.21	333.29	151.82	103.94	122.10	151.82	132.42
47	35	20.7	0.21	336.54	153.53	105.52	123.42	153.53	134.00
48	35	20.0	0.20	314.16	141.75	94.74	114.34	141.75	123.15
49	35	15.6	0.16	191.13	65.46	42.71	65.81	79.65	63.41
50	35	13.1	0.13	134.78	40.30	26.45	44.64	53.12	41.13
51	35	21.6	0.22	366.44	169.47	120.31	135.67	169.47	148.73
52	35	18.3	0.18	263.02	115.35	71.32	93.85	115.35	98.97
	Plot Biomass				**8301.99**	**6041.29**	**6743.67**	**8453.75**	**7385.17**
	Expansion Factor				5.05	5.05	5.05	5.05	5.05
	Aboveground Biomass/ha				41929.25	30511.54	34058.92	42695.73	37298.86
	Belowground Biomass/ha				10482.31	7627.89	8514.73	10673.93	9324.71
	Total Biomass/ha				52411.56	38139.43	42573.65	53369.66	46623.57
	Carbon/ha (Total Biomas/2ha)				26205.78	19069.71	21286.83	26684.83	23311.79
	Carbon Equivalents (kg CO2eq.)				96096.59	69928.64	78058.80	97853.27	85484.32
	5% of Biomass Prunned				2096.46	1525.58	1702.95	2134.79	1864.94
	Tree Maintenance/Replacement @4%				2096.46	1525.58	1702.95	2134.79	1864.94

Appendix A4: Citrus tree biomass calculation and results for Plot 4

		Name of Farm:		B1					
		Province:		Lusaka					
		Plot Size:	B1	1800	sqm				
		Citrus Varieties:		Washington Navel, Valencia					
Tree No.	Tree Age	DBH	D (m)	BA (cm2)	Biomass Eq1 kg/Tr	Biomass Eq2 kg/Tr	Biomass Eq3 kg/Tr	Biomass Eq4 kg/Tr	Averange kg/Tree
1	35	20.7	0.207	336.54	153.53	105.52	123.42	153.53	134.00
2	35	20.7	0.207	336.54	153.53	105.52	123.42	153.53	134.00
3	35	21.3	0.213	356.33	164.05	115.27	131.52	164.05	143.72
4	35	22	0.22	380.13	176.84	127.21	141.32	176.84	155.55
5	35	19.4	0.194	295.59	132.08	86.02	106.85	132.08	114.26
6	35	24.7	0.247	479.16	231.32	178.74	182.80	231.32	206.04
7	35	15.8	0.158	196.07	67.82	44.45	67.70	82.04	65.51
8	35	26.7	0.267	559.90	277.11	222.03	217.34	277.11	248.40
9	35	21.9	0.219	376.68	174.98	125.47	139.90	174.98	153.83
10	35	20.9	0.209	343.07	157.00	108.72	126.09	157.00	137.20
11	35	19.7	0.197	304.81	136.87	90.32	110.56	136.87	118.66
12	35	21.2	0.212	352.99	162.27	113.61	130.15	162.27	142.08
13	35	21.8	0.218	373.25	173.13	123.74	138.48	173.13	152.12
14	35	20.9	0.209	343.07	157.00	108.72	126.09	157.00	137.20
15	35	19.8	0.198	307.91	138.49	91.78	111.81	138.49	120.14
16	35	22.6	0.226	401.15	188.23	137.93	150.03	188.23	166.10
17	35	21.8	0.218	373.25	173.13	123.74	138.48	173.13	152.12
18	35	21.8	0.218	373.25	173.13	123.74	138.48	173.13	152.12
19	35	20.2	0.202	320.47	145.07	97.75	116.90	145.07	126.20
20	35	20.3	0.203	323.65	146.74	99.28	118.19	146.74	127.74
21	35	21.9	0.219	376.68	174.98	125.47	139.90	174.98	153.83
22	35	22.8	0.228	408.28	192.11	141.60	153.00	192.11	169.71
23	35	19.2	0.192	289.53	128.95	83.22	104.42	128.95	111.38
24	35	22.1	0.221	383.60	178.71	128.97	142.75	178.71	157.28
25	35	21.1	0.211	349.67	160.50	111.97	128.79	160.50	140.44
26	35	21.1	0.211	349.67	160.50	111.97	128.79	160.50	140.44
27	35	20.5	0.205	330.06	150.11	102.38	120.79	150.11	130.85
28	35	21.7	0.217	369.84	171.29	122.02	137.07	171.29	150.42
29	35	20.5	0.205	330.06	150.11	102.38	120.79	150.11	130.85
30	35	22.3	0.223	390.57	182.48	132.52	145.64	182.48	160.78
31	35	20.5	0.205	330.06	150.11	102.38	120.79	150.11	130.85
32	35	20.7	0.207	336.54	153.53	105.52	123.42	153.53	134.00
33	35	19.3	0.193	292.55	130.51	84.61	105.63	130.51	112.82
34	35	25.1	0.251	494.81	240.10	187.07	189.44	240.10	214.18
35	35	21	0.21	346.36	158.74	110.34	127.44	158.74	138.82
36	35	19.1	0.191	286.52	127.39	81.84	103.21	127.39	109.96
37	35	20.9	0.209	343.07	157.00	108.72	126.09	157.00	137.20
38	35	22.2	0.222	387.08	180.59	130.74	144.19	180.59	159.03
39	35	18.5	0.185	268.80	118.30	73.87	96.14	118.30	101.65
40	35	20.4	0.204	326.85	148.42	100.82	119.48	148.42	129.29
41	35	20.4	0.204	326.85	148.42	100.82	119.48	148.42	129.29
42	35	20.2	0.202	320.47	145.07	97.75	116.90	145.07	126.20
43	35	16.9	0.169	224.32	81.81	55.12	78.63	95.91	77.87
44	35	22.8	0.228	408.28	192.11	141.60	153.00	192.11	169.71
45	35	20.2	0.202	320.47	145.07	97.75	116.90	145.07	126.20
46	35	21.6	0.216	366.44	169.47	120.31	135.67	169.47	148.73
47	35	23	0.23	415.48	196.05	145.31	156.00	196.05	173.35
	Plot Biomass				**7574.72**	**5336.60**	**6093.89**	**7603.03**	**6652.06**
	Expansion Factor				5.56	5.56	5.56	5.56	5.56
	Aboveground Biomass/ha				42115.42	29671.50	33882.05	42272.86	36985.46
	Belowground Biomass/ha				10528.86	7417.88	8470.51	10568.22	9246.36
	Total Biomass/ha				52644.28	37089.38	42352.56	52841.08	46231.82
	Carbon/ha (Total Biomas/2ha)				26322.14	18544.69	21176.28	26420.54	23115.91
	Carbon Equivalents (kg CO2eq.)				96523.28	68003.38	77653.41	96884.12	84766.05
	5% of Biomass Prunned				2105.77	1483.58	1694.10	2113.64	1849.27
	Tree Maintenance/Replacement @4%				2105.77	1483.58	1694.10	2113.64	1849.27

Appendix A5: Citrus tree biomass calculation and results for Plot 5

		Name of Farm:		**B2**					
		Province:		Lusaka					
		Plot Size:	B2	2,160	sqm				
		Citrus Varieties:		Washington Navel, Valencia					
					Biomass	Biomass	Biomass	Biomass	Average
Tree No.	**Tree Age**	**DBH**	D (m)	BA (cm2)	Eq1 kg/Tr	Eq2 kg/Tr	Eq3 kg/Tr	Eq4 kg/Tr	kg/Tree
1	35	18.9	0.19	280.55	124.32	79.13	100.83	124.32	107.1486
2	35	22.2	0.22	387.08	180.59	130.74	144.19	180.59	159.0258
3	35	21.7	0.22	369.84	171.29	122.02	137.07	171.29	150.4183
4	35	0	0.00	0.00	0.00	0.00	0.00	0.00	0
5	35	20.8	0.21	339.79	155.26	107.11	124.75	155.26	135.596
6	35	21.2	0.21	352.99	162.27	113.61	130.15	162.27	142.077
7	35	24	0.24	452.39	216.39	164.58	171.48	216.39	192.2106
8	35	22.3	0.22	390.57	182.48	132.52	145.64	182.48	160.7792
9	35	24.5	0.25	471.44	226.99	174.64	179.52	226.99	202.037
10	35	22.5	0.23	397.61	186.30	136.11	148.56	186.30	164.318
11	35	18.2	0.18	260.16	113.90	70.07	92.71	113.90	97.6439
12	35	21.5	0.22	363.05	167.65	118.62	134.28	167.65	147.0498
13	35	23.3	0.23	426.38	202.03	150.97	160.56	202.03	178.8975
14	35	20.5	0.21	330.06	150.11	102.38	120.79	150.11	130.8474
15	35	20.7	0.21	336.54	153.53	105.52	123.42	153.53	134.0025
16	35	19.4	0.19	295.59	132.08	86.02	106.85	132.08	114.2598
17	35	20.5	0.21	330.06	150.11	102.38	120.79	150.11	130.8474
18	35	21.3	0.21	356.33	164.05	115.27	131.52	164.05	143.7239
19	35	0	0.00	0.00	0.00	0.00	0.00	0.00	0
20	35	19.3	0.19	292.55	130.51	84.61	105.63	130.51	112.8161
21	35	15.6	0.16	191.13	65.46	42.71	65.81	79.65	63.41119
22	35	0	0.00	0.00	0.00	0.00	0.00	0.00	0
23	35	22.1	0.22	383.60	178.71	128.97	142.75	178.71	157.283
24	35	19.6	0.20	301.72	135.26	88.87	109.32	135.26	117.1793
25	35	24.4	0.24	467.59	224.85	172.61	177.90	224.85	200.0507
26	35	22.3	0.22	390.57	182.48	132.52	145.64	182.48	160.7792
27	35	23.4	0.23	430.05	204.05	152.88	162.09	204.05	180.7676
28	35	24.5	0.25	471.44	226.99	174.64	179.52	226.99	202.037
29	35	24.9	0.25	486.95	235.68	182.88	186.10	235.68	210.0879
30	35	0	0.00	0.00	0.00	0.00	0.00	0.00	0
31	35	16	0.16	201.06	70.24	46.25	69.62	84.47	67.64586
32	35	20.3	0.20	323.65	146.74	99.28	118.19	146.74	127.7352
33	35	0	0.00	0.00	0.00	0.00	0.00	0.00	0
34	35	21.1	0.21	349.67	160.50	111.97	128.79	160.50	140.4408
35	35	13.7	0.14	147.41	45.66	29.41	49.31	58.93	45.82701
36	35	18.3	0.18	263.02	115.35	71.32	93.85	115.35	98.96947
37	35	20.8	0.21	339.79	155.26	107.11	124.75	155.26	135.596
38	35	21.3	0.21	356.33	164.05	115.27	131.52	164.05	143.7239
39	35	18.9	0.19	280.55	124.32	79.13	100.83	124.32	107.1486
40	35	23.1	0.23	419.10	198.03	147.19	157.51	198.03	175.189
41	35	20.6	0.21	333.29	151.82	103.94	122.10	151.82	132.4196
42	35	21.8	0.22	373.25	173.13	123.74	138.48	173.13	152.1185
43	35	23.9	0.24	448.63	214.30	162.60	169.89	214.30	190.277
44	35	0	0.00	0.00	0.00	0.00	0.00	0.00	0
45	35	23.2	0.23	422.73	200.02	149.08	159.03	200.02	177.0379
46	35	21.6	0.22	366.44	169.47	120.31	135.67	169.47	148.7287
47	35	23.8	0.24	444.88	212.23	160.64	168.32	212.23	188.354
48	35	0	0.00	0.00	0.00	0.00	0.00	0.00	0
49	35	0	0.00	0.00	0.00	0.00	0.00	0.00	0
50	35	13	0.13	132.73	39.45	26.02	43.88	52.18	40.38238
51	35	24	0.24	452.39	216.39	164.58	171.48	216.39	192.2106
52	35	22.6	0.23	401.15	188.23	137.93	150.03	188.23	166.1033
53	35	22	0.22	380.13	176.84	127.21	141.32	176.84	155.5509
54	35	21.3	0.21	356.33	164.05	115.27	131.52	164.05	143.7239
55	35	21.6	0.22	366.44	169.47	120.31	135.67	169.47	148.7287
56	35	20.4	0.20	326.85	148.42	100.82	119.48	148.42	129.286
57	35	23.1	0.23	419.10	198.03	147.19	157.51	198.03	175.189
58	35	21	0.21	346.36	158.74	110.34	127.44	158.74	138.8152
59	35	22.3	0.22	390.57	182.48	132.52	145.64	182.48	160.7792
	Plot Biomass				**8366.57**	**5981.80**	**6739.73**	**8421.00**	**7377.28**
	Expansion Factor				4.63	4.63	4.63	4.63	4.63
	Aboveground Biomass/ha				38737.23	27695.74	31204.95	38989.23	34156.79
	Belowground Biomass/ha				9684.31	6923.93	7801.24	9747.31	8539.20
	Total Biomass/ha				48421.53	34619.67	39006.19	48736.54	42695.98
	Carbon/ha (Total Biomas/2ha)				24210.77	17309.84	19503.09	24368.27	21347.99
	Carbon Equivalents (kg CO2eq.)				88780.88	63475.17	71517.84	89358.44	78283.08
	5% of Biomass Prunned				1936.86	1384.79	1560.25	1949.46	1707.84
	Tree Maintenance/Replacement @4%				1936.86	1384.79	1560.25	1949.46	1707.84

Appendix A6: Citrus tree biomass calculation and results for Plot 6

	Name of Farm:		K.1						
	Province:	Lusaka							
	Plot Size:	K.1	1560	sqm					
	Citrus Varieties:		Washington Navel, Valencia, Lemons						
Tree No.	Tree Age	DBH	D (m)	BA (cm2)	Biomass Eq1 kg/Tr	Biomass Eq2 kg/Tr	Biomass Eq3 kg/Tr	Biomass Eq4 kg/Tr	Averange kg/Tree
1	27	12.7	0.13	127.32	37.22	24.94	41.90	49.72	38.45
2	27	9.5	0.10	71.62	15.98	25.51	22.10	25.51	22.27
3	27	10.8	0.11	91.99	23.38	20.94	29.20	34.10	26.90
4	27	14.0	0.14	154.06	48.54	31.15	51.79	62.03	48.38
5	27	18.5	0.18	268.80	118.30	73.87	96.14	118.30	101.65
6	27	16.6	0.17	215.18	77.19	51.55	75.08	91.39	73.80
7	27	16.9	0.17	223.53	81.41	54.81	78.33	95.52	77.51
8	27	15.1	0.15	179.20	59.86	38.68	61.26	73.91	58.43
9	27	14.0	0.14	154.06	48.54	31.15	51.79	62.03	48.38
10	27	16.0	0.16	201.65	70.52	46.47	69.85	84.76	67.90
11	27	15.0	0.15	176.43	58.58	37.79	60.21	72.59	57.29
12	27	20.3	0.20	322.57	146.17	98.76	117.74	146.17	127.21
13	27	16.1	0.16	203.85	71.59	47.28	70.70	85.83	68.85
14	27	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	27	15.0	0.15	175.79	58.29	37.58	59.97	72.28	57.03
16	27	12.7	0.13	127.32	37.22	24.94	41.90	49.72	38.45
17	27	17.3	0.17	236.36	101.91	59.99	83.34	101.91	86.78
18	27	13.7	0.14	147.14	45.54	29.34	49.21	58.80	45.72
19	27	11.4	0.11	101.27	26.88	21.40	32.48	38.12	29.72
20	27	11.9	0.12	111.91	31.02	22.49	36.30	42.81	33.15
21	27	11.8	0.12	108.94	29.85	22.13	35.23	41.49	32.18
22	27	11.5	0.11	103.13	27.60	21.55	33.15	38.94	30.31
23	27	11.7	0.12	107.16	29.16	21.93	34.59	40.71	31.60
24	27	13.7	0.14	147.96	45.89	29.55	49.51	59.19	46.04
25	27	13.1	0.13	133.77	39.88	26.24	44.26	52.65	40.76
26	27	11.8	0.12	108.81	29.80	22.11	35.18	41.44	32.13
27	27	11.1	0.11	96.28	24.99	21.09	30.71	35.95	28.19
28	27	12.4	0.12	121.04	34.66	23.83	39.61	46.88	36.24
29	27	12.9	0.13	131.16	38.79	25.70	43.30	51.46	39.81
30	27	13.9	0.14	151.78	47.55	30.54	50.94	60.96	47.50
31	27	12.0	0.12	112.50	31.25	22.56	36.52	43.07	33.35
32	27	12.7	0.13	126.87	37.03	24.86	41.73	49.51	38.28
33	27	14.3	0.14	161.14	51.67	33.13	54.44	65.35	51.15
34	27	17.0	0.17	226.92	83.14	56.16	79.65	97.20	79.03
35	27	14.3	0.14	161.14	51.67	33.13	54.44	65.35	51.15
36	27	14.6	0.15	168.39	54.91	35.27	57.17	68.76	54.03
37	27	14.2	0.14	157.58	50.09	32.12	53.11	63.67	49.75
38	27	23.5	0.23	432.61	205.46	154.22	163.17	205.46	182.08
39	27	21.0	0.21	344.95	157.99	109.64	126.86	157.99	138.12
40	27	18.5	0.18	267.70	117.74	73.38	95.71	117.74	101.14
41	27	17.0	0.17	227.77	83.57	56.50	79.98	97.62	79.42
42	27	17.7	0.18	246.69	107.09	64.29	87.39	107.09	91.46
43	27	14.2	0.14	157.58	50.09	32.12	53.11	63.67	49.75
44	27	15.2	0.15	181.69	61.02	39.51	62.21	75.11	59.46
45	27	18.7	0.19	274.20	121.06	76.27	98.29	121.06	104.17
46	27	13.4	0.13	140.37	42.65	27.70	46.70	55.68	43.18
47	27	12.7	0.13	127.32	37.22	24.94	41.90	49.72	38.45
48	27	11.3	0.11	100.29	26.51	21.33	32.14	37.70	29.42
49	27	16.6	0.17	215.18	77.19	51.55	75.08	91.39	73.80
50	27	13.7	0.14	147.14	45.54	29.34	49.21	58.80	45.72
51	27	13.5	0.13	142.38	43.51	28.18	47.44	56.61	43.93
52	27	8.6	0.09	58.01	11.28	19.98	17.49	19.98	17.18
53	27	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	27	11.2	0.11	99.39	26.17	21.27	31.82	37.30	29.14
55	27	15.5	0.16	188.92	64.41	41.95	64.97	78.58	62.48
56	27	12.7	0.13	127.32	37.22	24.94	41.90	49.72	38.45
57	27	13.1	0.13	133.77	39.88	26.24	44.26	52.65	40.76
58	27	11.0	0.11	95.30	24.62	21.05	30.36	35.53	27.89
59	27	10.8	0.11	91.99	23.38	20.94	29.20	34.10	26.90
60	27	16.8	0.17	222.17	80.72	54.27	77.80	94.84	76.91
61	27	15.4	0.15	185.42	62.76	40.75	63.63	76.90	61.01
62	27	15.1	0.15	179.55	60.02	38.80	61.39	74.08	58.57
63	27	16.1	0.16	202.75	71.06	46.87	70.27	85.29	68.37
64	27	18.8	0.19	277.31	122.65	77.66	99.53	122.65	105.63
65	27	17.7	0.18	247.35	107.42	64.57	87.65	107.42	91.77
66	27	18.7	0.19	274.96	121.45	76.61	98.60	121.45	104.53
67	27	20.1	0.20	315.84	142.64	95.54	115.02	142.64	123.96
68	27	23.8	0.24	445.67	212.67	161.05	168.65	212.67	188.76
69	27	18.7	0.19	274.98	121.46	76.62	98.60	121.46	104.53
70	27	25.5	0.25	508.90	248.05	194.60	195.45	248.05	221.54
71	27	6.1	0.06	29.35	1.99	9.06	8.20	9.06	7.08
72	27	7.8	0.08	47.77	7.86	15.95	14.09	15.95	13.46
73	27	8.9	0.09	62.39	12.77	21.74	18.96	21.74	18.80
	Plot Biomass				**4643.17**	**3199.96**	**4399.86**	**5345.76**	**4397.19**
	Expansion Factor				6.41	6.41	6.41	6.41	6.41
	Aboveground Biomass/ha				29762.72	20511.73	28203.08	34266.32	28185.96
	Belowground Biomass/ha				7440.68	5127.93	7050.77	8566.58	7046.49
	Total Biomass/ha				37203.40	25639.66	35253.84	42832.90	35232.45
	Carbon/ha (Total Biomas/2ha)				18601.70	12819.83	17626.92	21416.45	17616.23
	Carbon Equivalents (kg CO2eq.)				68212.43	47010.32	64637.92	78534.13	64598.70
	5% of Biomass Prunned				1488.14	1025.59	1410.15	1713.32	1409.30
	Tree Maintenance/Replacement @4%				1488.14	1025.59	1410.15	1713.32	1409.30

Appendix A7: Citrus tree biomass calculation and results for Plot 7

	Name of Farm:		**M1**						
	Province:	Lusaka							
	Plot Size:	M1	625	sqm					
	Citrus Varieties:		Washington Navel, Valencia, Hamlin, Tangerine, smooth Lemons						
					Biomass	Biomass	Biomass	Biomass	Average
Tree No.	Tree Age	DBH	D (m)	BA (cm2)	Eq1 kg/Tr	Eq2 kg/Tr	Eq3 kg/Tr	Eq4 kg/Tr	kg/Tree
1	19	17.5	0.18	240.72	104.09	61.79	85.05	104.09	88.75
2	19	18.8	0.19	277.01	122.50	77.53	99.41	122.50	105.49
3	19	22.6	0.23	401.15	188.23	137.93	150.03	188.23	166.10
4	19	16.6	0.17	215.18	77.19	51.55	75.08	91.39	73.80
5	19	17.8	0.18	249.55	108.53	65.51	88.52	108.53	92.77
6	19	18.1	0.18	258.55	113.08	69.37	92.08	113.08	96.90
7	19	18.5	0.18	267.70	117.74	73.38	95.71	117.74	101.14
8	19	15.9	0.16	198.94	69.21	45.49	68.81	83.44	66.74
9	19	15.6	0.16	191.07	65.43	42.69	65.79	79.62	63.38
10	19	16.6	0.17	215.18	77.19	51.55	75.08	91.39	73.80
11	19	16.2	0.16	206.98	73.13	48.44	71.91	87.36	70.21
12	19	16.6	0.17	215.18	77.19	51.55	75.08	91.39	73.80
13	19	17.2	0.17	232.05	85.78	58.22	81.65	99.75	81.35
14	19	20.7	0.21	336.21	153.36	105.36	123.29	153.36	133.85
15	19	19.1	0.19	286.48	127.37	81.82	103.20	127.37	109.94
16	19	17.8	0.18	249.55	108.53	65.51	88.52	108.53	92.77
17	19	15.9	0.16	198.94	69.21	45.49	68.81	83.44	66.74
18	19	16.2	0.16	206.98	73.13	48.44	71.91	87.36	70.21
19	19	21.6	0.22	367.97	170.29	121.08	136.30	170.29	149.49
20	19	22.0	0.22	378.87	176.15	126.57	140.80	176.15	154.92
21	19	24.5	0.25	471.81	227.21	174.84	179.68	227.21	202.23
22	19	20.4	0.20	325.95	147.94	100.39	119.12	147.94	128.85
23	19	16.6	0.17	215.18	77.19	51.55	75.08	91.39	73.80
24	19	18.1	0.18	258.55	113.08	69.37	92.08	113.08	96.90
25	19	19.7	0.20	305.90	137.44	90.83	111.00	137.44	119.18
	Plot Biomass				**2860.20**	**1916.22**	**2433.96**	**3002.06**	**2553.11**
	Expansion Factor		**10,000/Plot Area**		16.00	16.00	16.00	16.00	16.00
	Aboveground Biomass/ha				45763.20	30659.57	38943.40	48033.01	40849.78
	Belowground Biomass/ha				11440.80	7664.89	9735.85	12008.25	10212.45
	Total Biomass/ha				57204.00	38324.46	48679.25	60041.27	51062.23
	Carbon/ha (Total Biomas/2ha)				28602.00	19162.23	24339.62	30020.63	25531.11
	Carbon Equivalents (kg CO2eq.)				104874.95	70262.14	89246.10	110076.66	93614.93
	5% of Biomass Prunned				2288.16	1532.98	1947.17	2401.65	2042.49
	Tree Maintenance/Replacement @4%				2288.16	1532.98	1947.17	2401.65	2042.49

Appendix A8: Citrus tree biomass calculation and results for Plot 8

		Name of Farm:		M2					
		Province:	Lusaka						
		Plot Size:	M2	600	sqm				
		Citrus Varieties:		Washington Navel, Valencia, Tangerine,					
					Biomass	Biomass	Biomass	Biomass	Average
Tree No.	Tree Age	DBH	D (m)	BA (cm2)	Eq1 kg/Tr	Eq2 kg/Tr	Eq3 kg/Tr	Eq4 kg/Tr	kg/Tree
1	37	22.6	0.23	401.15	188.23	137.93	150.03	188.23	166.10
2	37	13.7	0.14	147.14	45.54	29.34	49.21	58.80	45.72
3	37	22.6	0.23	401.15	188.23	137.93	150.03	188.23	166.10
4	37	25.6	0.26	514.72	251.34	197.71	197.93	251.34	224.58
5	37	23.6	0.24	435.77	207.19	155.87	164.49	207.19	183.69
6	37	22.3	0.22	389.93	182.13	132.19	145.37	182.13	160.46
7	37	23.6	0.24	435.77	207.19	155.87	164.49	207.19	183.69
8	37	25.5	0.25	509.30	248.27	194.81	195.62	248.27	221.74
9	37	25.8	0.26	522.11	255.53	201.67	201.09	255.53	228.46
10	37	22.3	0.22	389.93	182.13	132.19	145.37	182.13	160.46
11	37	27.1	0.27	574.95	285.77	230.16	223.84	285.77	256.38
12	37	25.5	0.25	509.30	248.27	194.81	195.62	248.27	221.74
13	37	26.7	0.27	561.50	278.03	222.89	218.03	278.03	249.24
14	37	21.6	0.22	367.97	170.29	121.08	136.30	170.29	149.49
15	37	26.4	0.26	548.21	270.41	215.72	212.30	270.41	242.21
	Plot Biomass				**3208.56**	**2460.15**	**2549.72**	**3221.82**	**2860.06**
	Expansion Factor				16.67	16.67	16.67	16.67	16.67
	Biomass/ha				53475.96	41002.49	42495.39	53697.03	47667.72
	Belowground Biomass/ha				13368.99	10250.62	10623.85	13424.26	11916.93
	Total Biomass/ha				66844.95	51253.11	53119.23	67121.29	59584.65
	Carbon/ha (Total Biomas/2ha)				33422.47	25626.56	26559.62	33560.65	29792.32
	Carbon Equivalents (kg CO2eq.)				122550.19	93964.89	97386.15	123056.82	109239.51
	5% of Biomass Prunned				2673.80	2050.12	2124.77	2684.85	2383.39
	Tree Maintenance/Replacement @4%				2673.80	2050.12	2124.77	2684.85	2383.39

Appendix A9: Citrus tree biomass calculation and results for Plot 9

			Name of Farm:		**P1**				
			Province:		Lusaka				
			Plot Size: P1		900	sqm			
			Citrus Varieties:		Washington Navel				
					Biomass	Biomass	Biomass	Biomass	Average
Tree No.	**Tree Age**	DBH(cm)	D (m)	BA (cm2)	Eq1 kg/Tr	Eq2 kg/Tr	Eq3 kg/Tr	Eq4 kg/Tr	kg/Tree
1	6	10.8	0.11	91.61	23.23	20.93	29.06	33.94	26.79
2	6	12.9	0.13	130.70	38.60	25.60	43.14	51.25	39.65
3	6	9.9	0.10	76.98	17.88	27.73	23.95	27.73	24.33
4	6	9.6	0.10	72.38	16.25	25.82	22.37	25.82	22.57
5	6	8.4	0.08	55.42	10.40	18.94	16.62	18.94	16.23
6	6	8.9	0.09	62.49	12.80	21.77	18.99	21.77	18.84
7	6	10.0	0.11	78.54	18.44	21.26	24.49	28.39	23.15
8	6	10.7	0.11	89.93	22.61	20.91	28.47	33.22	26.30
9	6	10.9	0.11	94.06	24.15	21.00	29.93	34.99	27.52
10	6	8.2	0.08	52.81	9.53	17.91	15.75	17.91	15.28
11	6	9.1	0.09	65.04	13.68	22.81	19.86	22.81	19.79
12	6	9.8	0.10	75.43	17.33	21.53	23.42	27.09	22.34
13	6	9.6	0.10	72.38	16.25	21.88	22.37	25.82	21.58
14	6	8.9	0.09	62.21	12.71	21.66	18.90	21.66	18.73
15	6	9.3	0.09	67.93	14.68	23.99	20.84	23.99	20.88
16	6	11.5	0.11	103.12	27.60	21.55	33.15	38.93	30.31
17	6	12.2	0.12	116.90	33.00	23.18	38.10	45.03	34.83
18	6	11.6	0.12	105.00	28.32	21.72	33.82	39.76	30.90
19	6	8.5	0.09	56.75	10.85	19.47	17.06	19.47	16.71
20	6	12.2	0.12	117.18	33.11	23.22	38.21	45.16	34.92
21	6	12.5	0.13	122.72	35.34	24.11	40.22	47.64	36.83
22	6	11.3	0.11	99.66	26.27	21.29	31.91	37.42	29.22
23	6	13.5	0.14	143.14	43.83	28.36	47.72	56.95	44.22
24	6	11.3	0.11	100.29	26.51	21.33	32.14	37.70	29.42
25	6	11.4	0.11	102.07	27.19	21.46	32.77	38.47	29.98
26	6	11.8	0.12	108.98	29.87	22.13	35.25	41.51	32.19
27	6	9.5	0.10	70.88	15.72	25.20	21.85	25.20	21.99
28	6	12.6	0.13	124.45	36.04	24.42	40.85	48.42	37.43
29	6	8.2	0.08	52.81	9.53	17.91	15.75	17.91	15.28
30	6	10.6	0.11	88.75	22.17	20.90	28.05	32.71	25.96
31	6	10.0	0.10	79.18	18.68	21.22	24.71	28.66	23.32
32	6	8.9	0.09	62.21	12.71	21.66	18.90	21.66	18.73
33	6	12.0	0.12	113.10	31.49	22.64	36.73	43.34	33.55
34	6	9.2	0.09	66.01	14.02	23.21	20.19	23.21	20.16
35	6	10.3	0.10	83.23	20.14	21.00	26.12	30.36	24.41
36	6	6.2	0.06	30.19	8.46	9.36	8.46	9.36	8.91
37	6	7.0	0.07	38.48	11.08	12.41	11.08	12.41	11.75
38	6	5.9	0.06	27.34	7.58	8.35	7.58	8.35	7.96
39	6	11.0	0.11	95.57	24.72	21.06	30.46	35.65	27.97
40	6	8.7	0.09	59.45	11.76	20.55	17.97	20.55	17.71
41	6	11.0	0.11	95.03	24.52	21.04	30.27	35.41	27.81
42	6	5.8	0.06	26.42	7.30	8.02	7.30	8.02	7.66
43	6	5.8	0.06	26.42	7.30	8.02	7.30	8.02	7.66
	Plot Aboveground Biomass				**873.63**	**888.56**	**1092.09**	**1272.67**	**1031.74**
	Expansion Factor				11.11	11.11	11.11	11.11	11.11
	Aboveground Biomass/ha				9707.00	9872.90	12134.30	14140.75	11463.74
	Belowground Biomass/ha				2426.75	2468.23	3033.58	3535.19	2865.93
	Total Biomass/ha				12133.74	12341.13	15167.88	17675.94	14329.67
	Carbon/ha (Total Biomas/2ha)				6066.87	6170.57	7583.94	8837.97	7164.84
	Carbon Equivalents (kg CO2eq.)				22247.22	22627.46	27810.30	32408.84	26273.46
	5% of Biomass Prunned				485.35	493.65	606.72	707.04	573.19
	Tree Maintenance/Replacement @4%				485.35	493.65	606.72	707.04	573.19

Appendix A10: Citrus tree biomass calculation and results for Plot 10

	Name of Farm:		S1						
	Province: Lusaka								
	Plot Size:	S1	1100	sqm					
	Citrus Varieties:		Washington Navel, Valencia, Hamlin and Tangerines						
					Biomass	Biomass	Biomass	Biomass	Average
Tree No.	Tree Age	DBH	D (m)	BA (cm2)	Eq1 kg/Tr	Eq2 kg/Tr	Eq3 kg/Tr	Eq4 kg/Tr	kg/Tree
1	20	19.10	0.19	286.48	127.37	81.82	103.20	127.37	109.94
2	20	18.78	0.19	277.01	122.50	77.53	99.41	122.50	105.49
3	20	15.28	0.15	183.35	61.79	40.06	62.84	75.90	60.15
4	20	19.42	0.19	296.11	132.35	86.26	107.06	132.35	114.50
5	20	17.19	0.17	232.05	99.75	58.22	81.65	99.75	84.84
6	20	17.83	0.18	249.55	108.53	65.51	88.52	108.53	92.77
7	20	15.60	0.16	191.07	65.43	42.69	65.79	79.62	63.38
8	20	19.42	0.19	296.11	132.35	86.26	107.06	132.35	114.50
9	20	18.46	0.18	267.70	117.74	73.38	95.71	117.74	101.14
10	20	20.05	0.20	315.84	142.64	95.54	115.02	142.64	123.96
11	20	16.87	0.17	223.53	81.41	54.81	78.33	95.52	77.51
12	20	18.14	0.18	258.55	113.08	69.37	92.08	113.08	96.90
13	20	14.64	0.15	168.39	54.91	35.27	57.17	68.76	54.03
14	20	19.10	0.19	286.48	115.47	81.82	103.20	127.37	106.97
15	20	18.46	0.18	267.70	104.88	73.38	95.71	117.74	97.93
16	20	18.78	0.19	277.01	110.09	77.53	99.41	122.50	102.38
17	20	19.42	0.19	296.11	121.04	86.26	107.06	132.35	111.68
18	20	18.78	0.19	277.01	110.09	77.53	99.41	122.50	102.38
19	20	15.60	0.16	191.07	65.43	42.69	65.79	79.62	63.38
20	20	17.19	0.17	232.05	85.78	58.22	81.65	99.75	81.35
21	20	17.51	0.18	240.72	104.09	61.79	85.05	104.09	88.75
22	20	15.28	0.15	183.35	61.79	40.06	62.84	75.90	60.15
23	20	19.10	0.19	286.48	127.37	81.82	103.20	127.37	109.94
24	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	20	18.78	0.19	277.01	122.50	77.53	99.41	122.50	105.49
26	20	16.87	0.17	223.53	81.41	54.81	78.33	95.52	77.51
27	20	17.83	0.18	249.55	108.53	65.51	88.52	108.53	92.77
28	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	20	18.46	0.18	267.70	117.74	73.38	95.71	117.74	101.14
30	20	16.87	0.17	223.53	81.41	54.81	78.33	95.52	77.51
31	20	19.10	0.19	286.48	127.37	81.82	103.20	127.37	109.94
32	20	17.98	0.18	254.03	110.79	67.42	90.29	110.79	94.82
33	20	17.83	0.18	249.55	108.53	65.51	88.52	108.53	92.77
34	20	20.05	0.20	315.84	142.64	95.54	115.02	142.64	123.96
35	20	19.10	0.19	286.48	127.37	81.82	103.20	127.37	109.94
36	20	18.46	0.18	267.70	117.74	73.38	95.71	117.74	101.14
37	20	18.21	0.18	260.36	114.00	70.16	92.80	114.00	97.74
38	20	18.78	0.19	277.01	122.50	77.53	99.41	122.50	105.49
39	20	18.14	0.18	258.55	113.08	69.37	92.08	113.08	96.90
40	20	15.60	0.16	191.07	65.43	42.69	65.79	79.62	63.38
41	20	17.19	0.17	232.05	85.78	58.22	81.65	99.75	81.35
42	20	18.78	0.19	277.01	122.50	77.53	99.41	122.50	105.49
43	20	17.51	0.18	240.72	104.09	61.79	85.05	104.09	88.75
44	20	16.87	0.17	223.53	81.41	54.81	78.33	95.52	77.51
	Plot Biomass				**4420.71**	**2851.46**	**3787.85**	**4650.60**	**3927.65**
	Expansion Factor				9.09	9.09	9.09	9.09	9.09
	Aboveground Biomass/ha				40184.22	25919.77	34431.56	42273.96	35702.38
	Belowground Biomass/ha				10046.06	6479.94	8607.89	10568.49	8925.59
	Total Biomass/ha				50230.28	32399.71	43039.46	52842.44	44627.97
	Carbon/ha (Total Biomas/2ha)				25115.14	16199.86	21519.73	26421.22	22313.99
	Carbon Equivalents (kg CO2eq.)				92097.21	59404.88	78912.84	96886.62	81825.39
	5% of Biomass Prunned				2009.21	1295.99	1721.58	2113.70	1785.12
	Tree Maintenance/Replacement @4%				2009.21	1295.99	1721.58	2113.70	1785.12

APPENDIX B

Appendix B1: GREET model 2011 upstream energy and carbon emissions results

Vehicle Technologies, Light-Duty Trucks 2: Well-to-Pump Energy Consumption and Emissions

(Btu or grams per mmBtu of Fuel Available at Fuel Station Pumps)

Year: 1990	CA RFG	Compressed Natural Gas, NA NG	LNGV: Dedicated, NA NG	LPGV: Dedicated	Naphtha, nNA NG	FCV: MeOH, nNA NG	Dedi. MeOH Vehicle: M90, nNA NG	CIDI Vehicle: DME, nNA NG	CIDI Vehicle: FT100, nNA NG	Electricity (transportation)
Total Energy	255,495	187,400	254,612	164,273	806,956	714,878	617,799	635,641	803,341	1,848,283
WTP Efficiency	79.6%	84.2%	79.7%	85.9%	55.3%	58.3%	61.8%	61.1%	55.5%	35.1%
Fossil Fuels	216,099	176,375	253,097	162,071	806,148	713,708	616,202	634,492	802,523	1,607,762
Coal	35,276	53,921	7,408	10,786	3,951	5,726	7,816	5,620	4,001	1,176,333
Natural Gas	112,193	112,816	232,238	107,108	777,741	667,429	561,682	594,255	776,922	311,039
Petroleum	68,630	9,638	13,451	44,177	24,456	40,553	46,704	34,617	21,599	120,390
CO2 (w/ C in VOC & CO	16,088	12,480	15,163	12,314	34,022	30,378	27,747	27,821	30,822	241,029
CH4	135.565	667.821	604.837	303.186	769.014	723.154	612.713	691.071	768.501	507.615
N2O	2.371	0.188	0.324	0.185	0.178	0.493	0.441	0.189	0.173	3.060
GHGs	20,184	29,232	30,381	19,949	53,300	48,603	43,196	45,154	50,086	254,631
VOC: Total	28.699	7.088	7.654	10.757	32.767	27.330	27.334	14.026	13.857	22.115
CO: Total	24.138	19.786	24.824	21.877	43.144	55.543	49.302	52.276	42.555	57.106
NOx: Total	63.665	51.226	76.992	61.466	108.878	154.549	138.140	124.891	103.067	502.754
PM10: Total	14.440	10.631	2.822	5.048	15.814	17.013	15.354	15.367	15.661	333.296
PM2.5: Total	5.811	3.295	1.707	2.530	14.916	15.749	13.536	14.091	14.775	88.879
SOx: Total	47.271	46.565	18.833	33.163	37.380	44.289	43.199	46.432	36.373	1184.290
VOC: Urban	16.536	0.207	0.134	2.239	13.428	9.150	10.346	1.165	0.891	1.538
CO: Urban	5.801	0.657	0.653	2.604	0.656	1.297	1.881	1.029	0.574	9.036
NOx: Urban	13.887	3.453	4.326	7.095	3.319	6.487	7.364	5.011	2.626	85.630
PM10: Urban	3.138	0.125	0.099	1.201	0.118	0.220	0.604	0.178	0.099	3.315
PM2.5: Urban	1.538	0.077	0.084	0.611	0.085	0.164	0.346	0.128	0.069	1.878
SOx: Urban	15.332	6.248	0.783	6.463	1.494	2.288	4.031	2.261	1.403	205.037

Appendix B2: GREET model 2011 upstream energy and carbon emissions results

Vehicle Technologies, Light-Duty Trucks 2: Well-to-Pump Energy Consumption and Emissions

(Btu or grams per mmBtu of Fuel Available at Fuel Station Pumps)

Year: 2004	Baseline CG and RFG	CA RFG	Compressed Natural Gas, NA NG	LNGV: Dedicated, NA NG	LPGV: Dedicated	Naphtha, nNA NG	FCV: MeOH, nNA NG	Dedi. MeOH Vehicle: M90, nNA NG	CIDI Vehicle: DME, nNA NG	CIDI Vehicle: FT100, nNA NG	Electricity (transportation)
Total Energy	210,584	224,315	181,472	232,111	160,285	766,579	654,640	573,423	602,835	762,961	1,656,935
WTP Efficiency	82.6%	81.7%	84.6%	81.2%	86.2%	56.6%	60.4%	63.6%	62.4%	56.7%	37.6%
Fossil Fuels	194,459	188,719	170,965	230,810	158,396	765,822	653,584	569,644	601,770	762,195	1,436,648
Coal	18,526	21,077	49,798	6,165	8,966	3,584	5,010	7,474	5,045	3,629	1,044,032
Natural Gas	102,363	100,769	113,305	211,575	112,166	738,070	608,458	515,940	562,429	737,255	313,993
Petroleum	73,570	66,873	7,862	13,071	37,264	24,168	40,116	46,230	34,296	21,310	78,623
CO2 (w/ C in VOC & CO	15,655	13,663	11,918	13,781	11,530	31,619	26,777	24,830	25,843	28,419	222,202
CH4	128.120	126.994	663.153	590.935	337.766	751.832	697.569	593.476	677.247	751.325	493.220
N2O	0.877	1.878	0.186	0.292	0.180	0.175	0.477	0.548	0.187	0.170	2.982
GHGs	19,119	17,397	28,552	28,641	20,028	50,467	44,359	39,831	42,829	47,253	235,421
VOC: Total	27.464	27.755	6.842	6.972	10.717	31.936	25.769	26.078	13.259	13.191	20.451
CO: Total	17.022	16.181	15.645	19.035	16.756	34.053	42.394	37.755	38.355	33.487	53.824
NOx: Total	55.154	47.127	40.809	57.822	47.877	88.708	121.622	109.468	102.188	85.343	368.290
PM10: Total	8.420	8.977	9.770	2.378	4.201	16.806	17.946	16.202	16.941	16.641	308.338
PM2.5: Total	4.347	4.269	3.000	1.472	2.389	16.077	16.955	14.650	15.914	15.913	82.393
SOx: Total	32.962	30.871	35.951	16.729	28.324	36.055	42.161	40.476	44.773	35.047	828.306
VOC: Urban	15.581	16.471	0.202	0.092	1.970	13.373	9.016	10.216	1.103	0.858	1.469
CO: Urban	3.758	4.951	0.634	0.548	1.804	0.417	0.823	1.359	0.623	0.343	9.700
NOx: Urban	9.546	11.876	2.677	3.064	4.994	2.379	4.374	5.320	3.752	1.986	61.889
PM10: Urban	1.858	2.518	0.117	0.086	0.803	0.156	0.262	0.554	0.242	0.137	3.148
PM2.5: Urban	1.066	1.411	0.074	0.077	0.473	0.133	0.225	0.379	0.207	0.116	1.807
SOx: Urban	8.980	11.702	4.372	0.523	4.120	1.295	1.946	3.232	1.967	1.207	142.258

APPENDIX C

Appendix C1: Booking form for aboveground biomass determination

UNIVERSITY OF ZAMBIA
School of Agricultural Sciences, Plant Science Department

Form AGB 1

TITLE: Estimation of Net Carbon Sequestration Potential of Citrus under Different Management Systems Using the Life Cycle Approach

Name of Farm:				Date:	
Contact Person:					
Camp:		Block:		District	
Site Center:		Long.		Lat.	
Species:			Rootstock:		
Slope of Field:					

1. ABOVE GROUND BIOMASS

Plot No.:				Plot Area:		Slope of Plot:					
Tree	Age (yrs)	Long.	Lat.	DBH@ 30cm	TD @ 5cm	Ht	Hc	L	W	HGH	Tree Status
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
21											

All dimensions in cm

Appendix C2: Booking form for external input determination

UNIVERSITY OF ZAMBIA
School of Agricultural Sciences, Plant Science Department

Form AGB 2

TITLE: Estimation of Net Carbon Sequestration Potential of Citrus under Different Management Systems Using the Life Cycle Approach

Name of Farm:				**Date:**	
Contact Person:					
Camp:		**Block:**		**District**	
Site Center:		**Long.:**		**Lat.:**	
Species:			**Rootstocks:**		

2. FARM EXTERNAL INPUT DETERMINATION

Activity[1]	**Area (m^2)**	**Date**	**Frequency (No.)**	**Machinery /Chemical (Name/type)**	**Operation HOURS**	**Consumption rate of fuel (L/hr)**	**Actual fuel used (L)**	**Qty of chemical used (kg)**
Land Clearing								
Land Preparation								
Cultural Activities								
Tree replacement								
Pruning								
Fertilizers								
N								
P_2O_5								
K_2O								
Micro-nutrients								
Growth hormones								
Irrigation Water Source								
Pesticides								
Herbicides								
Insecticides								
Fungicides								