OPTIMAL FARM ENTERPRISE MIX AND THRESHOLD DIETARY REQUIEREMENTS FOR SMALLHOLDER FARMERS IN SEMI-ARID CHAMWINO DISTRICT, DODOMA-TANZANIA

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ABSTRACT

Malnutrition is among the serious health problems affecting infants, children and women of reproductive age in Tanzania. Various approaches have been adopted to address this problem. Such approaches include; importation of food, food aid and medical treatment. Despite these efforts, however, millions of Tanzanians particularly women and children continue to suffer from one or more forms of malnutrition. Agriculture has been currently taken as great measure to harness malnutrition among developing countries including Tanzania, whereas recently new attention has been given to the role of agriculture in nutrition and malnutrition. The study was conducted to determine an optimal farm enterprise mix that uses available resources to maximize profit while ensuring adequate supply of food to meet household's macro-nutrient requirements. The study used cross sectional data from 300 farming households from two villages of Chinoje and Mzula in Chamwino District in Dodoma region of central Tanzania. A static linear programming (LP) model was used to determine optimal farm enterprise mix and threshold dietary requirements for smallholder farming households. The findings indicate that the optimal enterprise mix that maximizes profit while meeting adequate macro-nutrient food needs of the households entails a combination of 2.40 acres of millet, 0.75 acres of sunflower, 3.65 acres of groundnuts and at least 16 chickens. This nutrition sensitive optimal resource combination enables the farming household to attain global optimal solution of TZS 1 383 878. It could be concluded that with the current average farm production, most of the farming households were unable to satisfy their household food needs from farm production. In this regard, the study recommends for optimal combination of available resources to meet minimal macro-nutrient requirements while generating an optimal level of farm income.

DECLARATION

I, **George Zabron Kihamba,** do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

This work is dedicated to Almighty God under whose care I was able to finish it successfully. Secondly, to my lovely family, my wife Regina and my children Zabron and Good Lucky.

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LIST OF ABBREVIATION AND ACRONOMY

AERC	African Economic Research Consortium
AIDS	Acquired Immunodeficiency Syndrome
AME	Adult Male Equivalent
ASDP	Agricultural Sector Development Programme
BMI	Body Mass Index
EA	East Africa
FAO	Food and Agriculture Organization of the United Nations
FGP	Fuzzy Goal Programming
FISP	Farm Input Subsidy Program
HIV	Human Immunodeficiency Virus
Kg	Kilogram
LP	Linear Programming
MAFC	Ministry of Agriculture, Food Security and Cooperatives
MC	Marginal Cost
MFC	Marginal Factor Cost
NBS	National Bureau of Statistics

OR	Operational Research
PPP	Purchasing Power Parity
RHS	Right Hand Side
SACCOS	Saving and Credit Cooperatives Society
SAEBS	School of Agriculture Economics and Business Studies
TDHS	Tanzania Demographic Household Survey
TFNC	Tanzania Food and Nutrition Centre
TZS	Tanzanian Shillings
UK	United Kingdom
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
URT	United Republic of Tanzania
US$	United States Dollar
USDA	United States Department of Agriculture
VICOBA	Villages Community Bank
VMP	Value of Marginal Product
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Agriculture is perceived to be a source of gradual structural transformation of African economies and a major means of livelihood of rural communities in these countries (Slavchevska, 2015; Isinika and Msuya, 2016). Therefore, improving agricultural productivity in most of these countries remains a necessary condition for economic growth, poverty reduction as well as improving food and nutrition security (Slavchevska, 2015; Abdulai and Abdulai, 2016).

Tanzania is able to produce enough food to meet its requirements and export excess food to neighbouring countries. In the 2016 cropping season, for example, Tanzania produced 5 000 000 tonnes, 1 959 000 tonnes and 2 576 000 tonnes of maize, beans and rice respectively and exported 200 000 tonnes of maize, 38 222 tonnes of beans and 25 000 tonnes of rice (USDA, 2017; EA MARKET OUTLOOK, 2017). However, some of these exports were made not necessarily out of excess, but rather out of necessity, when households were forced to sell part of their harvest to generate income to meet some other household needs (MAFC, 2013; Kinabo, 2014).

According to Kinabo (2014), household food insecurity in a good year in Tanzania is mainly caused by poor distribution of the available food nationally (from regions with surplus to regions with deficit) as well as access to food at household level. Lack of access is attributed mainly to low purchasing power of food consumers whereas about 90% of the total population lives on less than purchasing power parity (PPP) of TZS 2 800 per day (US$ 1.25) (UNESCO, 2015). Since the poor do not produce adequate food and do not earn enough money to buy extra food, a large proportion of the population does not consume enough calories, proteins and fats to meet its minimum macro-nutrient requirements. This leads to various health problems, which in turn affect the economic growth of a country (URT, 2013).

The government has been importing food and receiving food aid to meet its production shortfalls and unbalanced distribution. Close to 40% of the Tanzanian population lives in areas described by the World Food Program as “chronic food-deficit regions”: where rainfall is scarce and irregular (URT, 2013). The semi-arid regions of central Tanzania are badly hit with food and nutrition insecurity coupled with extreme poverty. Consequently, malnutrition among the most vulnerable groups (i.e. children and women) is likely to occur even during good crop harvest years because of imbalanced food intake (Amede *et al.,* 2004; Mutabazi, 2016). This is supported by the finding of a survey by Tanzania Demographic Household Survey (TDHS) (2015/16) which showed that about 34% of the children were stunted, 14% were underweight, 57% and 33% had deficiencies of iron and vitamin A respectively (NBS, 2016).

Rural households spend up to 66% of their income on food with price volatility being a major concern. Food security is fluctuating between years of surplus in good seasons and years of deficit in poor rainfall seasons and some regions and districts have food surpluses of varying magnitude on an annual basis. However, there are still regions and districts with pockets of persistent food shortage annually and Chamwino District is one of them (URT, 2011). Mutabazi (2016) found that about 33% of the surveyed households in Dodoma were not frequently consuming food rich in vitamin-A and intakes of iron-rich foods were highly limited to only 13% of women living with children of 3 years of age. Inequalities in nutritional status continue to persist, with most malnourished children and women living in rural areas being vulnerable to non-communicable diet related diseases as emergency alarming health problem.

Household production of nutrients across farming systems may be valuable for guiding the improvement of these systems, particularly in situations where securing markets is less important than securing subsistence (Kedding *et al.,* 2011; FAO, 2012). The nutritional quality of food may be improved by various practices, such as application of fertilizers, improvement of soil fertility, selection of varieties with high micronutrient and macronutrient content, the use of indigenous high-nutrient-value crops, and genetic modification of plants to improve nutrient supplies (Amede *et al.,* 2004). However, the application of these methods in addressing malnutrition depends upon the availability of technological and policy interventions that are commonly not within the reach of small-scale farmers in developing countries. It may also be possible to supplement the diet with animal products where livestock is an integral part of the rural farming system. However, animal products are rarely consumed by rural households due to low purchasing power (Yimer, 2000). Dietary supplements are also rarely available to the rural poor. One option for minimizing chronic malnutrition is the reallocation of household's resources in favour of crops and livestock enterprises with high nutritional contents and practicing farming for business purpose to increase household's income as a secondary source of food. This study therefore aimed at establishing an optimum enterprise mix that uses the available resources to maximize profit while ensuring adequate supply of food to meet household's nutritional requirements in terms of macro-nutrients in Chamwino District.

1.2 Problem Statement and Justification

Malnutrition is one of the serious health problems affecting infants, children, and women of reproductive age in Tanzania (URT, 2014). According to the TDHS (2015/16) survey on malnutrition, about one out of three children under five are stunted, one out of ten women are thin (BMI≤18.5) and 28% of all women are overweight or obese (BMI≥25.0). Chronic malnutrition is common among children who are very small at birth (51%), children with thin mother (40%) and children from the poorest households (40%). Six to fifty nine (6-59) months old and 15-49 years old women were tested for anaemia; and the test showed that about 58% and 45% of the children and women in these respective age groups were anaemic. Most of the woman with malnutrition were less educated, living in rural areas and depending on agriculture for their livelihood (URT, 2014; NBS, 2016).

The available literature indicates that malnutrition prevalence in Tanzania is decreasing but at very low rate especially in rural areas. As a matter of fact, the stunting rate in Tanzania has decreased from 50% in 1992 to 34% in 2016 with anaemia decreasing from 48% in 2005 to 45% in 2016. In the same period, stunting rate among children under five years in Dodoma has decreased from 42% in 2005 to 36.5% in 2016 with anaemia decreasing from 44.6% among women aged 15-49 years to 30.6% (WHO, 2006; NBS, 2005; 2016). Various policies and strategies have been implemented to address the malnutrition problem (Kinabo, 2014). Such policies include the Food and Nutrition Policy (1992), the National Health Policy (2007), the Community Development Policy (1996), the Child Development Policy (1998), the National Agricultural and Water Policy (2002) and the National Livestock Policy (2006).

Further, the National food and Nutrition Strategy was designed to translate the relevant policies into strategic objectives. Despite these efforts millions of Tanzanians continue to suffer from one or more forms of malnutrition, including low birth weight, stunting, wasting, anaemia, iodine and vitamin A deficiencies (TFNC, 2012).

Agriculture has currently been taken as one of measures of addressing malnutrition among people in developing countries including Tanzania. In this respect, an appropriate farm enterprise mix is widely seen as a strategy for reducing severity of malnutrition among the rural populations of these countries. Agriculture contributes to food security directly (auto consumption) and indirectly (income generation) and recently the attention has been shifted to the role of agriculture in nutrition and malnutrition (Niragira *et al.*, 2015). However, few studies have attempted to establish the linkage between farming patterns and dietary diversity of households as well as the contribution of dietary diversity in reducing malnutrition in various countries. The studies have revealed that there is a critical and significant relationship between farm enterprise mix in the farm in association with dietary diversity and the reduction of malnutrition among rural households. Furthermore, the studies have revealed that there is a strong association between child and maternal dietary diversity and nutritional status, after controlling for relevant socio economic characteristics of the households including dietary diversity (Herforth, 2010; Jones *et al.,* 2014; Sibhatu *et al.,* 2015; Romeo *et al.,* 2016; Rajendan *et al.,* 2017). As a contribution to the global discourse on the interlinks between household dietary diversity and nutrition and the growing body of literature on the agriculture–nutrition–health linkages nexus, this study seeks to generate necessary information on ways in which these households can reallocate their available resources such as land, labour and capital to maximize profit while ensuring adequate supply of food to meet household's nutritional requirement in terms of macro-nutrient in Chamwino District.

1.3 Objectives of the Study and Research Questions

1.3.1 General objective

The overall objective of this study is to establish an optimum enterprise mix that uses the available resources to maximize profit while ensuring adequate supply of food to meet household's macro-nutrient requirements in Chamwino District.

1.3.2 Specific objectives

i. To determine the returns from farm enterprises using the resources available to smallholder farmers in the study area.
ii. To determine the optimum combination of farm enterprises that utilizes available resources efficiently to maximize profit while meeting household's macro-nutrient food requirements in the study area.

1.3.3 Research questions

i. What are the returns from the existing farm enterprise mix that uses the available resources in the study area?
ii. Is the existing enterprise mix utilizing the available resources efficiently to maximize profit while meeting household nutrient requirements? If not, what is the optimal enterprise mix that maximizes profit while meeting household's nutrient requirements?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Theoretical Framework

This study is guided by the neoclassical theory of the firm where firms seek to either maximize returns or minimize costs subject to resource constraints. The theory is used to provide production decisions related to optimal input mix and/or product mix. According to Halili (1999), individual farmers as a firm always make repeatedly decisions about what commodities to produce, by what method, in which farming season and in what quantities. The decisions are made subject to the prevailing farm physical and financial constraints.

On the basis of the main objective of profit maximization, neoclassical theory of marginal analysis can be used in making production decisions related to optimal input mix and/or output mix in a single or multi-enterprise farm. These decisions are normally made by applying any of the principles of neoclassical marginal analysis (Debertin, 2012). The principles which are derived from production function are explained as follows.

(i) The value of marginal product of an input used in producing a particular product is equal to its marginal factor cost. This principle is concerned with the most profitable level of input use or output in one or more enterprises. The farmer maximizes profit when the marginal value product (VMP) equals the marginal factor cost (MFC).

VMP = MFC………………………………..…………..………………..………………..(1)

(ii) To produce a product at a minimum cost, marginal costs (MC) of the inputs in producing a given product must be equal for all the inputs. This principle is used to determine the least cost input combination for a given level of output or product. Algebraically, the decision rule is:

$MC_{X1} = MC_{X2} = \ldots\ldots = MC_{Xn}$...(2)

Where,

MC is marginal cost and X_i are inputs, for i = 1, 2 and n standing for the first, second and n^{th} input.

(iii) For a given resource allocated to different enterprises, the marginal value products from all outputs produced using the resource should be equal. This principle is used to determine the most profitable enterprise combination. The application of this principle allows product-product decisions to be made in a production environment with several enterprises competing for several resources or inputs (Mishra and Gillespie, 2007). In the case of the smallholder farming system in Chamwino, for example, the principle can be used to determine how many acres of each crop should be grown and how many poultry birds should be raised using land, labour and capital resources which are available to the farmer. Algebraically, the decision rule is as follows.

$VMPX,Y_1 = VMPX,Y_2 = VMPX,Y_3 = \ldots\ldots = VMPX, Y_n$..............................(3)

Where;

$VMPX, Y_n$ denotes the Value of the Marginal Product of X in producing Y_n.

Y denotes the output.

n denotes the number of outputs to be produced (1, 2.........n).

X denotes a resource or input (for example; land, labour and capital)

Many of the economic analyses apply the three principles as a framework where prices are assumed to be determined by the interaction of competitive buyers and sellers in the market. These optimizing principles are interrelated. The application of one principle directly implies the application of the others. This implies that the neoclassical theory of marginal analysis can be used to determine simultaneously the optimum input mix and output mix in a farm of a given household. The major problem with the application of the principles in making production decisions is associated with the realism of the neoclassical assumptions of marginal analysis. These include continuity of the production function, perfect knowledge of the production parameters, divisibility of inputs and outputs and perfect institutions that facilitate the allocation of resources to productive processes (Daellenbach, 2001; Debertin, 2012).

Owing to the problems inherent in the assumptions and the complexity of using marginal analysis principles especially where the number of completing enterprises is large, the use of neoclassical marginal analysis approach in analysing optimization problems is not always favoured. Many researchers, therefore, turn to linear programming techniques in analysing optimization problems in an attempt to come closer to reality and to avoid the computational burden involved in applying the principles of marginal analysis (Alsheikh and Ahmed, 2002). Linear programming (LP) models have linear objective functions which are maximized (or minimized) subject to the identified constraints (Daellenbach, 2001). In general, mathematical form, the linear programming model can be presented in the following pattern (Sofi *et al.*, 2015).

Maximize $Z = CX$……………………………………………………………………….(4)

Subject to;

$AX \leq \text{ or } \geq B$ and $X \geq 0$ ………………………………...……………………………… (5)

From the model above, X represents the vector of variables (to be determined) while C is the vector of known matrix of unit returns coming from each production process of X; A is the vector of known matrix of coefficient and *B* is a vector of levels of resource constraints and/or nutrient dietary constraints. The equation $X \geq 0$ is the non-negativity constraint.

2.2 Linear Programming Model

There are seven important assumptions in linear programming modelling. The first three assumptions deal with the appropriateness of the formulation and the last four assumptions deal with mathematical relationships within the model (Philip, 2007).

2.2.1 Assumptions associated with formulation appropriateness

2.2.1.1 Objective function appropriateness

This assumption requires the objective function to be the sole criterion for choosing among the feasible values of the decision variables. In resource allocation problems, satisfying this assumption is often very difficult as, for example, farmers might base their resources allocation plans not only on profit maximization but also on other factors such as ensuring family survival, minimizing the risks associated with crop failure (through diversification), or even maximizing leisure time.

2.2.1.2 Decision variables appropriateness

Decision Variables Appropriateness is among the key assumptions, which require the specification of the decision variables to be appropriate. This assumption requires the decision variables to be fully manipulated table within the feasible region. Moreover, the assumption requires the manipulation of the decision variables to be under the control of the decision maker. Furthermore, the assumption requires all appropriate decision variables to be included in the model.

2.2.1.3 Constraints appropriateness

This entails the assumptions that the constraints fully identify the bounds placed on the decision variables by resource availability, technology, and the external environment. Consequently, any choice of the decision variables which simultaneously satisfies all the constraints is admissible. Moreover, the assumption requires the resources used and/or supplied within any single constraint to be homogeneous items which can be used or supplied by any decision variable appearing in that constraint. Lastly, the assumption bars the inclusion of constraints which improperly eliminate admissible values of the decision variables.

2.2.2 Assumptions on mathematical relationships within the model

2.2.2.1 Proportionality (*i.e.* linearity)

This assumption requires the objective function and the constraints' coefficients to be strictly proportional to the decision variables (for instance, if the first hectare of maize requires 40 man-days of labour, so must the 30th hectare and 60th hectare). Also, implied in this assumption is that the returns to each activity is independent of its level; in other words, the profit per hectare of maize is the same whether the farmer grows a single hectare or ten hectares of maize. It is important to point out that there are several situations where the proportionality assumption is violated. Such circumstances include cases where the product price depends upon the level of production. Consequently, the contribution per unit of an activity varies with the level of the activity. For instance, the assumption would be violated if the return from a given activity varies with the level of that particular activity, for example decreasing profit per unit area with increasing farm size (MacCarl and Spreen, 1997).

2.2.2.2 Divisibility

This assumption means that non-integer values of the decision variables are acceptable. The formulation assumes that all decision variables can take on any non-negative value including fractional ones (*i.e.* the decision variables are continuous). This assumption is violated when non-integer values of certain decision variables make little sense. For instance, a decision variable may correspond to the purchase of a tractor or the construction of a building where it is clear that the variable must take on integer values. In such cases, it is appropriate to use integer programming (Philip, 2007).

2.2.2.3 Certainty

This assumption requires the values for the parameters to be known and constant. This means that the optimum solution so derived is predicted on perfect knowledge of all the parameter values. Since all exogenous factors are assumed to be known and fixed, linear programming models are sometimes known as non-stochastic to distinguish them from models explicitly dealing with stochastic factors. Due to this assumption, studies making use of these models are known as "deterministic" analyses. But in most cases the exogenous parameters of a linear programming model are not known with certainty (MacCarl and Spreen, 1997).

2.2.2.4 Additivity

This assumption requires the terms of the objective function to be additive. Additively deals with the relationships among the decision variables. Simply put, their contributions to an equation must be additive. The total value of the objective function equals the sum of the contributions of each variable to the objective function. Similarly, the total resource use is the sum of the resource utilisation of each variable. This requirement rules out the possibility that interaction or multiplicative terms appear in the objective function or the constraints and one more additional assumption is Non-negativity: Negative values of the decision variables are not allowed. This is mainly because in the process of making production decisions, negative values do not make sense. For instance, a farmer cannot decide to use minus (-) two bags of fertiliser or produce minus (-) forty bags of maize (Philip, 2007).

2.2.3 Validation of linear programming model

Model validation is an important task in any empirical economic analysis. A model can be utilized with confidence only if it is considered as a valid description of the system modelled. According to McCarl and Apland (1986), linear programming (LP) models frequently receive only superficial validation. According to Philip (2007), a model validation is fundamentally subjective. This is mainly because modellers choose the validity tests, the criteria for passing those tests, what model outputs to validate, what setting to test in and what data to use. Thus, the statement "the model was judged valid" can mean almost anything. However, a systematic approach to model validation will provide for a semi-objective evaluation of the strengths and weaknesses of a model. To some extent, two types of validation may be applied to a LP model. These are validation by construct and validation by results (McCarl and Spreen, 1997).

Validation by construct involves assessing the procedures used in model construction. If the model was constructed using sensible techniques which were motivated by real world observations and if by experience, these techniques are used by other modellers, the model is judged valid. On the other hand, validation by results involves comparing model solutions with corresponding real world outcomes. However, validation by construct is the most common type of linear programming model validation (McCarl and Apland, 1986; McCarl and Spreen, 1997). The linear programming model used in the present study was validated by construct and it was judged valid (section 4.11 for procedures used in validating the linear programming model used).

2.3 Empirical Literature

2.3.1 Malnutrition situation in Tanzania

Malnutrition refers to deficiencies, excesses, or imbalances in a person's intake of energy and/or nutrients (TFNC, 2012). The term malnutrition covers two broad groups of conditions. The first one is 'under nutrition which includes stunting (low height for age), wasting (low weight for height), underweight (low weight for age) and micronutrient deficiencies or insufficiencies (lack of important vitamins and minerals). The second one is overweight, obesity and diet-related non-communicable diseases (such as heart diseases, strokes, diabetes and cancer) (WHO, 2016). UNICEF and TFNC conducted a joint detailed study and revealed that malnutrition has an impact across the whole life cycle and begins in the womb with intra-uterine growth retardation, which is caused by diseases (e.g. malaria) and maternal malnutrition which leads to low birth weight (TFNC, 2012). The international recommendation focuses on the window of opportunity (1000 days) means that ensuring good nutrition among girls and women is crucial and malnourished girls are more likely to be malnourished women and more likely to give birth to low birth weight infants, thus transferring malnutrition from one generation to the next. These first 1000 days are most critical for growth, breastfeeding and complementary feeding practices and that inadequate dietary intake increases susceptibility to diseases by denying the child the nutrients it needs for effective immune function. Poor nutritional status among vulnerable groups may be exacerbated by economic vulnerability due to a range of factors, including limited income, poor year-round cash flow and limited and unreliable productive assets. Moreover, seasonal shocks, power inequalities related to intra-household decision-making, cultural norms and poor knowledge related to good nutritional practices also contribute to lack of investment in food, health care, adequate resources utilization, especially among the poorest households (UN Systems Standing Committee on Nutrition, 2014).

Existing literature suggests that agricultural diversification and particularly crop diversification is fundamental for development in agrarian based economies (Jones *et al.*, 2014). Agricultural diversification has been promoted in developing countries for its ability to enhance household incomes and ensure food and nutrition security (Mazunda *et al.*, undated). Following the successes of the Asian Green Revolution, crop diversification is strongly regarded as a vital element in raising incomes, improving food security outcomes, and reducing poverty (Ibrahim *et al.*, 2009). At the household level, farm enterprise diversification is a potential vital pathway for household food security and nutrition through the incomes realized from the sales of agricultural produce (Haddad, 2000). According to Joshi *et al.* (2003) a farm enterprise diversification portfolio that includes cultivation of high yielding and high value crops has the strongest impact on incomes at the household level resulting in improving nutritional intake for the household. The effects of crop diversification on poverty reduction have also been documented by Mukherjee and Benson (2003) who find that households that cultivate a diverse range of crops (i.e. other than the traditional maize and tobacco) are less likely to be poor. Agricultural incomes have also been found to make a positive contribution to child nutrition particularly where households have access to improved health and education systems (Bhagowalia *et al.*, 2012).

2.3.2 Use of linear programming in determining resource allocation

Linear programming is a mathematical technique under the category of optimization models. Other mathematical programming models are fuzzy goal programming (FGP)

(Sharma *et al.*, 2007), Multiple Objective Linear Programming (Annets and Audsley, 2002) and non-linear linear programming (Mahsafar *et al.*, 2017) just to mention few. Methods of engineering like mathematical modelling and optimization methods have been applied to some extent in the food, fishing, and agricultural industries. These methods have, however, been applied in other purposes than for production scheduling so as to improve product processing and to optimize the sorting of raw material (Nath and Talukdar, 2014). The methods have been utilized by many firms in making decisions about the establishment of new industries, different methods of production, distribution, marketing and policy decision making.

During the last few decades, several operations research techniques have been used in agricultural planning. Sharma *et al.* (2007) used fuzzy goal programming (FGP) approach for optimal allocation of land under cultivation and proposes an annual agricultural plan for different crops in India. In their model formulation, goals such as crop production, net profit, water and labour requirements and machine utilization were modelled as fuzzy. In their study, they found that FGP approach was a better technique over a single objective criterion when multiple conflicting objectives are involved. The model which was developed provides the best possible solution subject to the model constraints.

Annets and Audsley (2002) used multiple objective linear programming model developed to consider a wide range of farming situations, which allow optimisation of profit or environmental outcome(s) or both in the UK and the European arable and mixed livestock farming. Their objective was to identify the best cropping and machinery options which were both profitable and which would result in improvements to the environment, depending upon the farm situation, the market prices, potential crop yields, soil and weather characteristics. In their study, they found that in the UK scenario, large reductions in environmental impact can be achieved for the reduction of farm profits which were insignificant relative to the annual variation in yields and prices.

Mahsafar *et al*. (2017) used non-linear programming model for optimal allocation of agriculture water for irrigation of multiple crops. The objective function of the non-linear programming model was to maximize total net benefit return from all crops in the Qazvin plain, Iran. The model was solved using Lingo solver package for conditions existing in the region. The results showed that; optimizing the cropping patterns along with proper allocation of irrigation water has potential to increase the net return to irrigation water. Also, an optimal cropping pattern considering maximum net economic profit was found from a scenario 40% water deficit. Although models such as goal, multiple objective and non-linear programming are rarely used because they employ multiple goals or objectives which are always conflicting in nature, it is not possible to maximize or minimize all goals or objectives simultaneously (Sofi *et al*., 2015). Certain goals or objectives may be achieved to the expense of others. Some compromises among the goals are required to obtain a "satisfactory solution" in the decision-making process. The most widely used technique in agriculture planning is linear programming (LP) which has been used for the maximization of production of crops, livestock, or a combination of the two and for minimizing the cost to a farmer. Due to these reasons, the model has largely been attempted in many studies in different countries (Wankhade and Lunge, 2012). Linear Programming (LP) is perhaps the most important and most used optimization model. Many real-world problems can be formulated as linear programming problems (Sofi *et al.*, 2015).

Operations research (OR) models began to be applied in agriculture in the early 1950s. It was Waugh (1951) who first proposed the use of linear programming to establish least-cost combinations of feeding stuffs and livestock rations. The linear program minimizes the cost of the blend, while some specified levels of nutritional requirements represent the model's constraints. The founder of linear programming, George B. Danzig, published his first related work in 1947, that is, just four years before Waugh's publication. Heady (1954) proposed the use of linear programming for determining optimum crop rotations on a farm. Mirkarimi (2013) developed linear programming farm model that maximizes output from major food crops across dietary group (Fat, Protein and Vitamin) to enhance balanced dietary requirement and farm optimization. The study revealed that linear programming was one of the most widely used in farm optimization. Felix and Judith (2010) used an LP model for farm resource allocation. The authors compared between the results obtained from the use of the LP model and the traditional method of planning and observed that the results obtained from using the LP model are more superior than those obtained from using traditional methods. Ion and Turek (2012) suggested LP method to determine the optimal structure of crops. Different methods which take into account the income and expenditure of crops per hectare were used for optimizing profit. The authors observed that after applying the econometric model the profit rose to 143% and the costs were reduced to 81%.

In a study by Wankhade and Lunge (2012), a linear programming technique was applied to determine the optimum land allocation to 10 major crops of the saline track of rain red zone in India using agricultural data and observed that the LP model was appropriate for finding the optimal land allocation to the major crops. The study by Ibrahim and Bello (2009) utilized linear programming model to determine the optimal farm plan that can enhance the food security status of farming households in North Central Nigeria. Crops involved were cassava, maize, cowpea, benniseed, groundnut and yam. Niragira *et al.* (2015) applied mathematical linear programming in estimating the optimal crop mix and resources needed to provide the family with food containing sufficient energy, fat and protein using household-level data collected in 2010 in Ngozi province in northern Burundi. They concluded that despite land scarcity, it was still possible for households to find optimal crop combinations that can meet their minimal food security requirements while generating a certain level of income.

Weintraub and Romero (2006) analysed the use of operations research models to assess the past performance in the field of agricultural and forestry and to highlight current problems and future directions of research and applications. In the agricultural part, they concentrated on planning problems at the farm and regional-sector level, environmental implications, risk and uncertainty issues, multiple criteria and the formulation of livestock rations and feed stuffs. Today linear programming is the standard tool that has saved thousands or millions of money (dollars) of many production companies and agricultural sector (Sofi *et al.,* 2015).

In this study, a static linear programming model has been used to determine the optimal enterprise mix that maximizes returns while providing the household with food containing sufficient energy, fat and protein in Chamwino District of Dodoma region.

2.3.3 Enterprise mix and its role in addressing malnutrition

Diversification into high nutritive food production has the potential of improving nutritional outcomes for farming households (Kankwamba *et al.,* 2013). Studies that have analysed the food and nutrition security outcomes of crop diversification found varying effects on nutrition. Koppmair *et al.* (2016) used regression model in Malawi to Measure the association between farm production diversity and dietary diversity in rural smallholder households. The authors found farm production diversity, which is positively associated with dietary diversity with access to markets for buying food and selling farm produce and the use of chemical fertilizers, to be more important for dietary diversity than diverse farm production. A study by Jones *et al*. (2014) using multiple linear regression models found diversity on farm production in Malawi to be consistently positively associated with dietary diversity of farming households. Based on nationally representative data, they also found that households whose diets relied less on subsistence production had more diverse diets which controlled household wealth. Immink and Alarcon (1991) found crop diversification as being associated with higher incomes but there were no significant nutritional changes at the individual or household level. For the purposes of improving food diversity and nutritional outcomes, the authors suggest that agricultural production interventions be implemented alongside social investment programs in health and education.

Other empirical studies in different African countries have revealed a positive association between crop diversification and dietary diversity. Herforth (2010) examined the relationship between farm diversity and dietary diversity and found that the number of crops grown is positively associated with household dietary diversity in both Kenya and Tanzania. In Mali, Torheim *et al.* (2004) found that the number of crops cultivated by a household was positively associated with adult nutrient adequacy. A study by Remans *et al.* (2011) found the diversity of plant species on farms positively associated with the diversity of nutrients provided by farms based on the nutritional composition of their plant species in rural areas of Malawi, Mali and Uganda. Holden and Lunduka (2010) found that the sampled households were allocated small areas of land for maize cultivation using a panel data set for 2006, 2007 and 2009 agricultural seasons. The land allocated to maize had decreased from 0.73 hectares in 2006 to 0.64 hectares in 2009. The study by Holden and Lunduka (2010) did not directly show the causal relationship between the receipt of an input subsidy and the decrease in maize area, however, their analysis provided descriptive evidence that when Farm Input Subsidy Program (FISP) was scaled up, maize intensification could have facilitated crop diversification by releasing maize area and improved dietary diversity from the farm.

2.4 Conceptual Framework

Figure 1 shows the typical structure of the flow of resources between households and farms as separate entities, the households are the sources of own labour and capital which can be employed into the production of nutrition-based crops and livestock, households can also generate off-farm income in terms of wages by selling own labour (Chiang, 2016). The farming households will realize food stocks at the homesteads and part of the produce will find its way to the output markets. The off-farm activities (including non-agricultural activities and agricultural activities on other farms) will influence the farm production and the farm household livelihood (Pfeiffer *et al.*, 2009; Babatunde and Qaim, 2010; Van Wijk *et al.*, 2014). Income realized by selling part of the produce and off-farm income can be expended in purchasing inputs such as improved seeds and fertilizers, and command nutritious food baskets from the markets for own consumption. Through diversified food stocks and food market baskets, the households are expected to have nutritious diversified diets for consumption and utilization (Mutabazi, 2016). The off-farm income can provide the farming house ccess to food and increase their ability to invest in productivity-enhancing inputs for the farm (Reardon *et al.*, 1998). The effective food consumption and utilization will deliver nu making ho ectly i duce the alnutrit

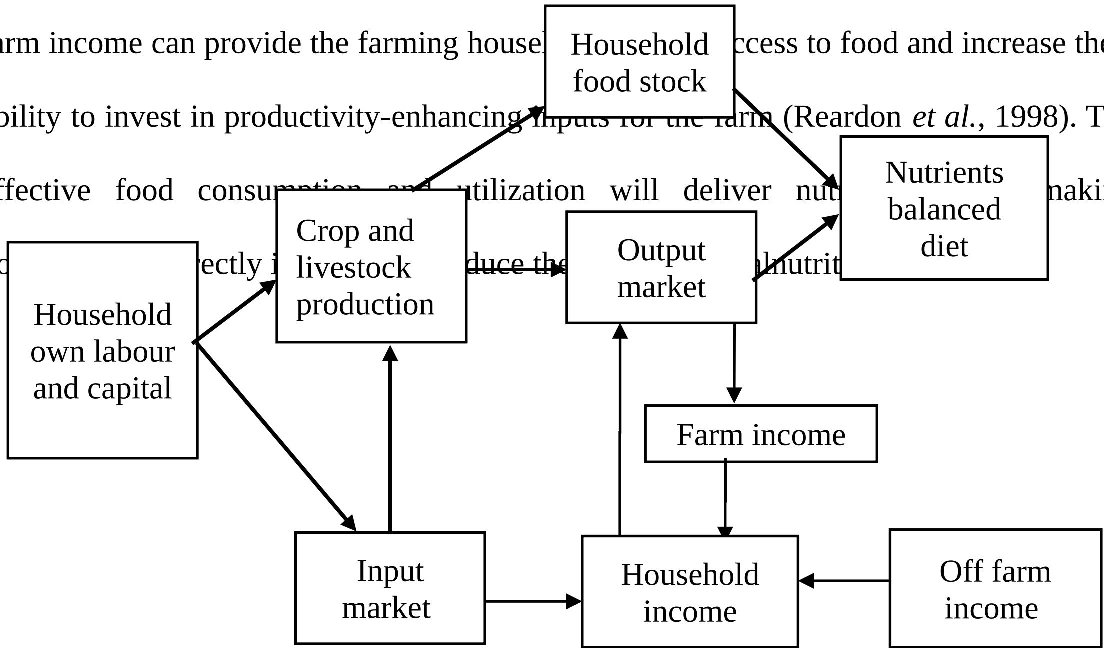

Figure 1: Conceptual representation of flows of resources and nutrients in the households

Source: Researcher’s construct

CHAPTER THREE

3.0 METHODOLOGY

3.1 Specification and Estimation of the Analytical Model

The matrix of the model presented in section 2.1 of Chapter Two, was applied in this study to determine the optimum enterprise mix that uses the available resources to maximize profit while ensuring adequate supply of food to meet household’s nutritional requirements. This section describes the analytical model in detail.

3.1.1 Objective function

The objective function Z, was to maximize total farm gross margin from food security from crop and poultry enterprises. The mathematical equation for the objective function is

$$Maximizes\ Z = C_1X_1 + C_2X_2 + \dots\dots\dots + C_nX_n \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (6)$$

Where,

$C_1, C_2, \dots\dots\dots, C_n$ are gross margins from the farm enterprises (activities) described in section 3.1.3.

The gross margins were generated using farm budgeting. Apart from profit maximization, smallholder farmers have other objectives. One of these objectives is to ensure attainment minimum macro-nutritional requirements (Mlambiti, 1985). This objective is included in the model as constraints as described in section 3.1.2. However, the model does not consider income that households generate from other sources such as off-farm income, non-form income and remittances due to their nature of being unreliable and unsustainable sources of household income.

3.1.2 Activities of the models

An activity in an LP model may be defined as any processes which utilize resources (inputs) available to the farm to produce output. Activities considered in the model were land based enterprises including both crop and livestock production activities. Crop and livestock enterprises identified as major enterprises, which were capable of providing more than 80% of the household food supply and income (Kahimba *et al.,* 2015). The crop enterprises are maize (X_1) (*Zea mays*), sorghum (X_2) (*Sorghum bicolor*), millet (X_3) (*Pennisetum glaucum*), Sunflower (X_4) (*Helianthus annuus*), groundnut (X_5) (*Arachishypogaea*), sesame (X_6) (*sesamum indicum*), Pigeon peas (X_7) (*Cajanus cajan*) and sweet potatoes (X_8) (*Ipomoea batatas*). Only one livestock enterprise, poultry (*Pullus*) denoted as X_9 was included in the model.

3.1.3 Constraints

Three types of constructs namely resource, subsistence and non-negativity constraints were included in the model. The resource constraints are based on the fact that the smallholder farmers as other economic agents are aiming to maximizing profit. The subsistence constraints are based on the fact that smallholder farmers have other objectives apart from maximizing profit such as producing food to meet subsistence requirements of their households (Mlambiti, 1985) while non negativity constraints are included in the model to avoid negative values of the activities.

3.1.3.1 Resource constraints

The main resource constraints included in the models are these of land, labour and capital as described below:

(i) Land constraint

This includes all land that was available for crop production and poultry keeping among the sampled households. The available land comprises the land that was owned by the household and that rented in by the sampled households. In this study, land requirement estimation was based on each acre that was reported to be potentially growing crop farm enterprises. The land for poultry was estimated according to the study on scavenging poultry keeping in sub Saharan countries that showed that most of the households keep small number of poultry by scavenging method, activities which were regarded for children and women; the average land area was reported to be $50m^2$ per bird (FAO, 2004; Goromela, 2009).

Thus, the study estimates the area under poultry enterprise by taking the product between the number of birds in the households and the area for single birds to get the total area under poultry keeping for each household; the area was converted further to acre unit to be compatible with the model. Mathematically, the land constraints can be expressed as

$a_{11}X_1 + a_{12}X_2 + \ldots\ldots + a_{1n}X_n \leq b_1$ ……………………………….………..………..(7)

(ii) Labour constraint

Labour requirement per acre (a_{2i}) was estimated in terms of man days per acre, the total labour in this study included of household labour and rented in labour by households. The total labour which was expended was divided by the total acre that was produced from the respective farm enterprises. The labour available was taken as the sum of the total labour used for planting, weeding and harvesting in the respective enterprise and in the case of poultry keeping, the labour used was estimated as hour in the day which a member of the household devoted to poultry keeping, like opening their door in the morning, supplying the remains of foods and other consumable matters, opening of the door for lying egg and closing the door in the evening. Mathematically, the labour constraints can be expressed as:

$a_{21}X_1 + a_{22}X_2 + \ldots\ldots + a_{2n}X_n \leq b_2$ ……………………………………..…………..(8)

(iii) Working capital constraints

Working capital requirement (a_{3i}) was estimated in terms of TZS per acre and includes money for land acquisition, purchase of seeds, agrochemicals and fertilizers and payments for some service charges for transportation of the outputs from the field to the household in the respective farm enterprise. It also includes ploughing costs since in the study area farmers usually hire tractors, ox plough, or other workers from outside the household to plough their farms of total enterprise in the study area. The study assumed no family labour was used in the ploughing of their farms. The study excludes further planting cost, weeding costs and harvesting cost because these activities are generally carried out by household labour. They were excluded to avoid double counting because were already considered as labour cost as explained above. Mathematically, working capital constraints can be expressed as

$$a_{31}X_1 + a_{32}X_2 + \ldots\ldots + a_{3n}X_n \leq b_3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

3.1.3.2 Minimum subsistence food requirements

Three subsistence constraints were incorporated in the model. These are energy, protein and fat constraints. Mathematically, these constraints can be expressed as follows

Energy constraint: $a_{41}X_1 + a_{42}X_2 + \ldots\ldots + a_{4n}X_n \leq b_4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$

Protein constraint: $a_{51}X_1 + a_{52}X_2 + \ldots\ldots + a_{5n}X_n \leq b_5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$

Fat constraint: $a_{61}X_1 + a_{62}X_2 + \ldots. + a_{6n}X_n \leq b_6 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$

The estimates made to assess the threshold nutritional requirement among the household in the study area. The nutrients produced from the farm were compared with the threshold nutritional requirements which are recommended by different studies and nutritional organizations. The quantity harvested from different enterprises were changed to nutrient value expressed in nutrient terms, these changes were aided by the Tanzania Food Composition Table established in 2008 (Lukmanji *et al.*, 2008). Changing the nutrient requirement from the physical quantity to nutritional value, which is expressed in macro nutritional term, was needed to compare with the actual value which is recommended for a person to remain healthier and estimate the land size that household should produce to meet households macro nutrient requirements (energy, fat and protein) (Mijili *et al.,* 2017). The estimated nutrient requirement value is always estimated using Adult Male Equivalent, since, nutrient requirements vary from person to person, in accordance with his or her level of activity, climate, age, sex and the like. In Tanzania, the reference for energy intake is estimated at 2200 kilocalories per adult equivalent per day (NBS, 2014). Similar, results are reported in a study by Majili *et al.* (2017) who reveal that the average energy intake is 2295 Kilocalories per adult male equivalent.

Adult Male Equivalents (AME) have been proposed as a tool of reducing the gap between the estimates derived from the household and from individual levels data, and for comparing dietary energy consumption among households of various sizes and compositions (Claro *et al.*, 2010; Dop *et al.,* 2012; Weisell and Dop, 2012). In dietary studies, AMEs are based on the relative energy requirements of different age and sex groups of the population, and are expressed as the proportion of the requirements of an adult male (Moltedo *et al.,* 2018). The AMEs for protein and fat intake were estimated and set at 65.5g and 79g respectively (NBS, 2014; Majili *et al*., 2017; Moltedo *et al.*, 2018).

3.1.3.3 Non-negativity constraint

Nine non-negativity constraints were included in combined market oriented and subsistence-oriented models to avoid negative values of the activities. Mathematically, non-negativity constraints can be expressed as

$$X_1, X_2, X_3, \ldots X_n \geq 0 \quad \ldots(13)$$

3.2 Data

This study used cross sectional data collected in 2016 by for the Scale-Up Nutrition project from 300 households in Chinoje and Muungano Mzula villages in Chamwino District, Dodoma-Tanzania (Figure 2). According to the 2012 National population census and with the projection of 1.6 percent population increase per annum, Chamwino District Council had about 289 959 people in 2016, among these 153 161 were females and 136 798 were males. The sample size of 300 farming households was considered to be a sufficient representation of the households practicing farming in the two villages. The villages were purposively selected basing on their performance in crop production and household food security in this semi-arid area. According to Scale-N fact sheet (2016), enterprises undertaken by most of the households in Chinoje and Muungano Mzula include maize grown in a different cropping system with pigeon peas and pure strands of sorghum, millet, groundnuts, sunflower, simsim, pigeon peas and sweet potatoes. On average, 80% of the villagers keep local chicken, which contribute significant in terms of income and source of protein.

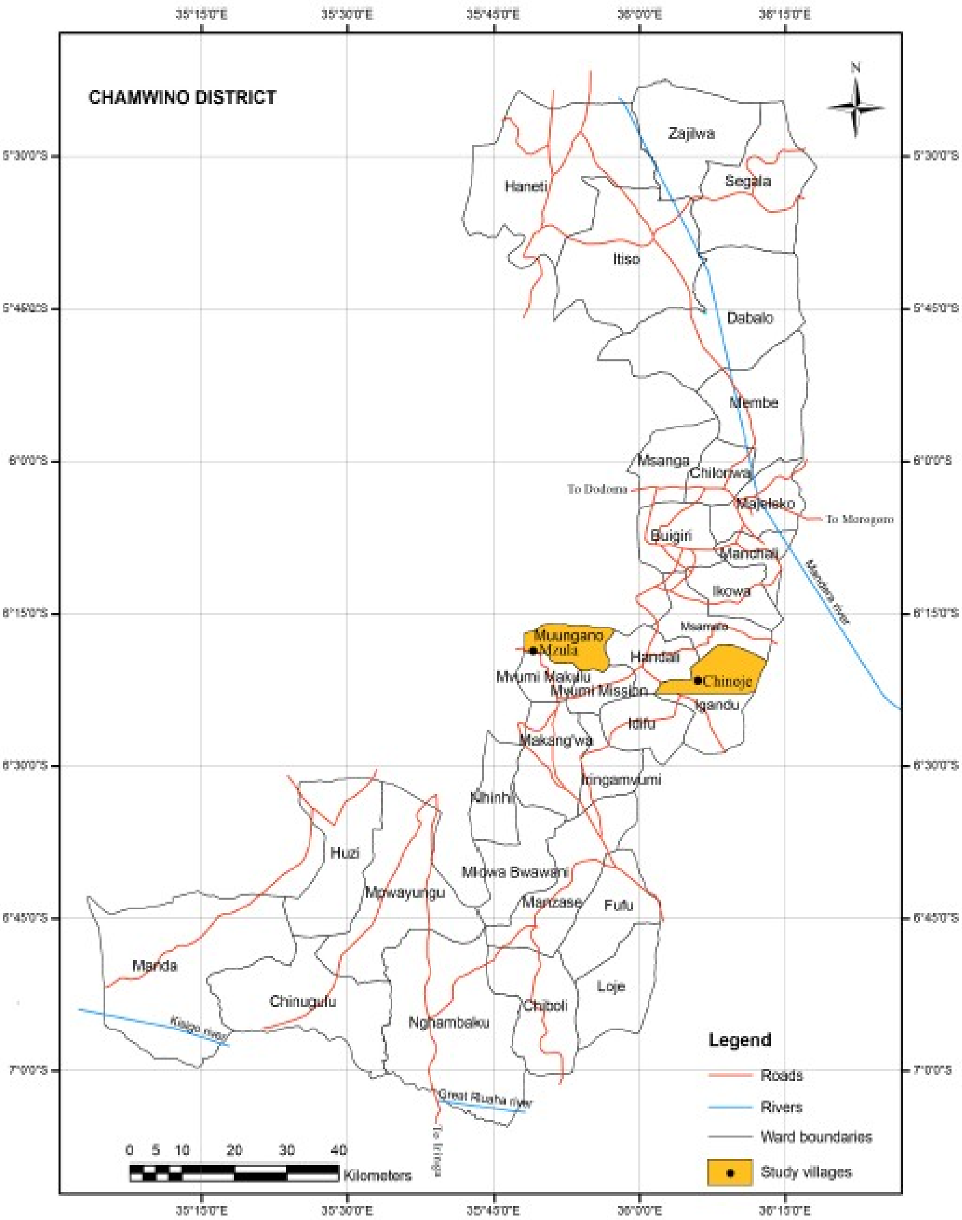

Figure 2: Map showing the study area

3.3 Data Analysis

The data from the scale-up Nutrition project were analysed using different quantitative and qualitative statistical procedures and methods. Descriptive statistical measures such as means and percentages were used to summarize the raw data about Chamwino District. The raw data included the resources and subsistence limitation which were available for producing farm enterprises.

The constraints were estimated to fulfil the general objective of the farmer as explained in section 3.1.2. Both the objectives and limitation of the farmer were considered to assist in producing farm enterprises that were sufficient to fulfil household food need while maximizing profit, which were fed in the Optimization software to generate feasible solutions.

Furthermore, the interpretation of data was assisted by mathematical programming using linear programming method through mathematical computer software known as LINGO computer-based software in obtaining the optimum profit and optimum combination of farm enterprises. In simplified manner the basic information which was necessary in constructing a linear programming model and constraints data were fed into the software to perform the actual optimization. Hence, the analysis was mainly quantitative. However, qualitative data were partly analysed to supplement the quantitative analysis.

3.4 Sensitivity Analysis

Realistic LPs require large amounts of data. Accurate data are expensive to collect; thus, LPs is generally forced to use data in which we have less than complete confidence. A time-honoured adage in data processing circles is “garbage in, garbage out”. The user of a model should be concerned with how the recommendations of the model are altered by changes in the input data. Sensitivity analysis is the term which is applied in the process of attaining confidence in data set. Fortunately, an LP solution report provides supplemental information that is useful in the sensitivity analysis. This information falls under two headings namely reduced costs and dual prices (Lindo system inc, 2003).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Characteristics of Sample Households

4.1.1 Household size

Table 1 shows the average household size in the study area as being 4.2 persons per household. This figure is below the national average household size of 4.8 persons (NBS, 2013). A bigger household size is associated with higher labour endowment, which would enable households to undertake various agricultural activities.

4.1.2 Access to credit

About 37% of the household heads reported to have accessed credit facilities as shown in Table 1. In the study area, there were non-formal credit facilities for the reported agricultural enterprise production. This demonstrates that credit facilities that exist provide credit for other activities. The major problems which were reported regarding credit facilities include the fact that loan processing take a long time, repayment periods are short and credit information is usually in accessible to smallholder farmers. Credit sources in the study area were SACCOS, VICOBA and Brac Microfinance.

4.1.3 Number of poultry birds per household

About 80% of the households were rearing small numbers of local poultry averaging about 10 birds per household by scavenging method as shown in Table 1. The local poultry rearing activities were regarded as the domain for children and women (FAO, 2004). Poultry are important in providing animal protein and additional income for the households (Kahimba *et al*., 2015).

Table 1: Descriptive statistics for the respondent characteristics

Variable	Mean	Standard Deviation	Minimum	Maximum
Family size	4.22	1.79	1	11
Access to credit	0.37	0.48	0	1
Number of poultry birds	10.35	9.64	0	67
Land size (Acre)	3.54	2.68	0.25	15

Source: scale-up Nutrition project, field data

4.1.4 Land availability and use

Table 1 shows that an average of 3.54 acres of land were available per a household for crop and livestock production. This is above the average utilized area which is 2.0 acres of land for cropping activities per agricultural household in Tanzania (NBS, 2013). The land for agricultural enterprise under this study included both those owned by households and those rented in by the households. On the other hand, the average land areas used under different enterprises undertaken by households in 2015/2016 cropping season are shown in Table 2.

Table 2: Farm size (Acre) of different farm enterprise in 2015/16 cropping season

Land used to produce enterprises	Mean	Standard Deviation	Minimum	Maximum
Land under maize cultivation	0.28	0.82	0	7
Land under sorghum cultivation	0.72	1.31	0	10
Land under millet cultivation	1.45	1.58	0	15
Land under sunflower cultivation	0.28	0.85	0	9
Land under groundnuts cultivation	0.61	1.25	0	8
Land under sesame cultivation	0.16	0.79	0	9
Land under pigeon cultivation	0.02	0.17	0	2
Land under sweet potatoes cultivation	0.03	0.17	0	2
Land under poultry keeping	0.13	0.14	0	2

Source: scale-up Nutrition project, field data

The average land size which was used for enterprise production includes all land that was allocated for the production of crops and poultry keeping enterprises from the sample households. These crop enterprises were maize, sorghum, millet, sunflower, groundnuts, sesame, pigeon peas and sweet potatoes. On average 0.28 acres of total area under cultivation was for maize crop; sorghum was cultivated on average of 0.72 acres while in larger samples millet was cultivated on the average land of 1.45 acres. Because of adaptation to climate, and the fact that Chamwino District is a drought prone district receiving very small amount of rainfall of an average of 500 mm annually, farmers were forced to plant drought resistance crops. Sunflower, groundnuts and sesame are a greater source of fat and protein; however, they were considered as cash crops and with larger part of the produce being sold to generate household income for purchasing non-farm commodities including food which is not produced by the household. On average, sunflower, groundnuts and sesame were produced at 0.28, 0.60 and 0.15 acres respectively. Pigeon and sweet potatoes are the main source of protein and energy but they are produced on small areas of an average of 0.02 to 0.03 acres.

4.2 Estimation of Market-Oriented Constraints

4.2.1 Land requirement and availability for farming enterprise

The land estimation was based on the land that was owned by the household and that which rented outside the sampled households. In the study, land estimation was based on each acre which reported as growing farm enterprises. The results show that 1 061.2 acres, which was equivalent to 3.54 acres of land utilized per household, were under enterprise production in two villages. The study area comprised of two villages; the first village was Chinoje Village. This village covers about 3 856 ha among these 1 460 ha are suitable for agriculture. The village was estimated to have a population of 3 228 people living in 765 households making an average household size of 4 people. The second village was Muungano Mzula which covers about 3 559 ha among these 2 390 ha is suitable for agriculture. The village is estimated to have the population of 2 385 people living in 605 households –with an average household size of 4 people as well. From the two villages, the total land suitable for agriculture was 3850 ha, which is equivalent to 9 625 acres making an average land size suitable for agriculture for each household to be 7.0 acres.

The land for poultry was estimated according to a study which was conducted on sub Saharan countries that showed that, most of the households kept small numbers of poultry by scavenging method and is the activities which are regarded as the domain for children and women. The average flock size kept per acre was 80 birds, which is equivalent to land size of $50m^2$ per bird (FAO, 2004). The studies by FAO (2004) and Goromela (2009) revealed the mean flock size in Tanzania for scavenging poultry per households to be 16 birds which is equivalent to an average size of land of 0.2 acres per a household. The poultry is raised by 80% of all the households in the study area (Kahimba *et al*., 2015). Land per bird was calculated and estimated to be 0.0125 acres per bird; however, this study reveals further that the mean average for the flock size per household could increase reaching 16-60 birds in rural communities.

4.2.1.1 Cost of hiring land

The average cost of hiring land for enterprise production in the 2015/16 farming season was TZS 20 000 per acre for crop enterprises. No land was hired for poultry enterprise. The average price of hiring land was almost the same because, these crops were produced on the same type of land using the same planting calendar (cropping pattern). The other reason for the similarity of land price was that most of the crop enterprises were annual crops which last for only one production season. After that, the land is returned to the owner and then a farmer could enter into a new contract.

4.2.2 Labour availability and requirements

4.2.2.1 Labour requirement and availability for crop enterprises

Labour availability and requirement were estimated in terms of man day per acre in order to determine the average labour which was used to produce the enterprises, the total labour in this study included of household labour and rented in labour by households. The total labour used was divided by the total acre used to produce the respective farm enterprises. Labour availability and requirement in man-days/acre for the production of crop enterprises were calculated by adding up the average quantities of labour (man-days/acre) which were used by smallholder farmers in different farming operations which were taking place in the production period. On the other hand, the number of man day which was sold outside to other farms as the household's efforts of generating additional incomes from that farm produces were not considered in this study. However, these are important in generating other sources of income for the household. Table 3 shows the average quantities of labour (man-days) available and required per acre of crop enterprises.

Table 3: Labour requirement per acre for the c*rop enterprises*

Enterprise Name	Labour requirement for each farm operation (Man day/Acre)								
	Ploughing	**Land preparat**	**Planting**	**Weeding**	**Fertilizer applic**	**Agrochemc applic**	**Harvesting**	**Transportation**	**Total Labour**
Maize	0.00	3.42	4.16	9.02	0.00	0.00	3.90	0.00	20.50
Sorghum	0.00	3.32	1.96	12.50	0.00	0.00	7.09	0.00	24.87
Millet	0.00	4.15	3.45	17.38	0.00	0.00	9.90	0.00	34.88
Sunflower	0.00	3.07	4.16	8.30	0.00	0.00	6.74	0.00	22.27
Groundnuts	0.00	3.89	7.59	8.35	0.00	0.00	12.35	0.00	32.18
Sesame	0.00	3.71	3.40	8.14	0.00	0.00	6.14	0.00	21.39
Pigeon peas	0.00	3.15	3.91	8.50	0.00	0.00	7.00	0.00	22.56
Sweet potatoes	0.00	7.78	9.49	10.42	0.00	0.00	9.82	0.00	37.51
Total	**0.00**	**32.49**	**38.12**	**82.61**	**0.00**	**0.00**	**62.94**	**0.00**	**216.16**

Source: scale-up Nutrition project, field data

Land ploughing in Chamwino District is usually done in December through February. Smallholder farmers in the District mostly use tractors and ox power for ploughing. It is not common for farmers to use human labour. That is why in Table 3 labour (man-days/acre) which is required for ploughing was given the value of zero. Moreover, it can be observed in Table 3 that the labour requirement for fertilizer application, agrochemical application and transportation was given the value of zero. This is because the use of agrochemical and fertilizers among smallholder farmers is not common in Chamwino District. Also, they (farmers) pay for transport of the produce from the farm to their homesteads; thus, it is not common for farmers to use family labour in transportation.

4.2.2.2 Labour availability and requirement for poultry enterprise

In the case of poultry keeping, labour was estimated at an hour per day that a member of a household devoted for poultry keeping. The estimation based on activities such as opening their door in the morning, supplying the left overs of food stuffs and other consumable matters, opening of the door for lying egg and closing of the door in the evenings. This was equivalent to an average of 0.125 man-days for each household in the study area. The study by Goromela (2009) in Mpwapwa and Kongwa Districts in Dodoma region reveals that 245 days circle for is year is the season for poultry keeping, and this is equivalent to an average labour size of 30.63 man-days per season for each household. Similar requirement was reported in the poultry keeping households in Chamwino District.

4.2.2.3 Labour costs

Table 4 shows the average costs per man-day of labour which is used for crop production. The average cost of labour per man day included both household labour and those rented in by the households, it was found to be almost the same in all farm operations and what distinguished them was the number of man-days which are required to accomplish a specific farm operation. The detailed calculation of the average costs per man-day for land preparation, planting, weeding and harvesting are found in Appendices 1, 2, 3 and 4. The labour cost for poultry keeping was not estimated because of the use of a formula which was adopted from FAO (2004) to determine the income of the households' poultry keeping by scavenging method using the field data as shown in Appendix 13.

Table 4: Average costs per man-day of labour used in crop *production*

Farm operations	Average labour cost (TZS/Man-day)
Land preparation	5 000
Planting	5 000
Weeding	5 000
Harvesting	5 000

Source: Appendix 1, 2, 3 and 4

4.2.3 Working capital availability and use

In Chamwino District it was not common for small householder farmers to take loans for agricultural production activities. The use of their savings of income from agricultural production activities was found to be common. All 300 interviewed farmers (100%) reported to have used their own savings for both crop production and poultry keeping. Fear of crop failure as a result of such factors as unreliable rainfall, pests and diseases and fire accidents to mention a few, scared farmers from taking loans. Therefore, capital was very limited among smallholder farmers in Chamwino District because they were only using their own savings for agricultural production activities.

4.2.3.1 Working capital requirement for crop production enterprises

Working capital availability included payment for transportation of crops from the fields. Ploughing cost was also included in the working capital since farmers are using tractors and ox power for ploughing instead of human labour. The costs of hiring labour and land were not included in the working capital. This is because in the objective function of the linear programming model, the costs of hiring labour and land were subtracted separately to see if the attainment of the optimal solution would require land and/or labour hiring, and by what amount. Working capital which is required per acre in each crop (crop enterprises) was calculated by adding up the average costs incurred per acre of a crop minus the costs for hiring labour and land. Working capital which is required per acre of a crop in each enterprise was also considered as the working capital used per acre of a crop in a cropping season in the production year 2015/16 as shown in Table 5.

Table 5: Working capital requirement for crop production enterprises per acre

Enterprise Name	**Ploughing Cost**	**Purchase of seed**	**Purchase-Fertiliz**	**Purchase Agrochemi**	**Transport ation Cost**	**Total Capital**
Maize	25 090.91	16 631.07	0	0	6 676.95	48 398.93
Sorghum	26 610.84	1 059.91	0	0	6 557.34	34 228.09
Millet	26 858.30	2 121.95	0	0	6 037.17	35 017.42
Sunflower	31 488.10	8 952.38	0	0	8 303.57	48 744.05
Groundnuts	26 213.40	12 228.02	0	0	7 101.65	65 543.07
Sesame	29 202.45	6 625.76	0	0	5 705.52	41 533.73
Pigeon peas	21 666.67	4 500.00	0	0	8 333.83	34 500.50
S. potatoes	33 548.39	17 354.84	0	0	7 419.35	58 322.58
Total average capital used						**366 288.37**

Source: scale-up Nutrition project, field data

4.2.3.2 Working capital requirement for poultry production enterprise

On average 80% of the villagers in Chamwino keeps rural chicken by scavenging method and whose average price is TZS 8 000 for a hen and TZS 10 000 for a cock (Kahimba *et al.*, 2015). The capital for poultry keeping can be seen from various angles. The inputs that are internal (factor input) and external (non-factor inputs) are under control of farming households. The capital is categorized into fixed and variable costs. Variable costs include feeds, veterinary vaccine and treatment and causal labour or family labour.

Fixed costs include taxes, insurance and depreciation of buildings and equipment (FAO, 2004). However, fixed costs were not considered in this study. The average capital for poultry enterprise by scavenging method is shown in Table 6.

Table 6: Average capital for poultry enterprise in Tanzania

Item	Quantity (Number)	price (TZS)	Total value of item (TZS)
Laying Hen	15	8 000	120 000
Cock	1	10 000	10 000
Vaccine	0	0	0
Treatment	0	0	0
Feed	0	0	0
Total average capital			**130 000**
Average capital/bird			**8 125**

Source: Appendix 13

4.3 Estimation of Subsistence-Oriented Constraints

4.3.1 Land required to produce food to meet household's threshold energy requirements

Households are constrained with food and nutrients in order to meet their minimum dietary requirement while generating income. Following this requirement, food and nutrition security situation was put into consideration and was found that, on average a single household of a smallholder farmer with an average size of 4 persons would need an average of 936.12 kg, 999.60 kg, 1 033.13 kg and 5 840.33 kg of maize, sorghum, millet and sweet potatoes respectively for consumption to meet their households minimum energy requirement per year. According to the study findings, the average yield per acre was 269 kg, 178 kg, 438.4 kg and 765 kg with the average land production size of 0.28 acres, 0.72 acres, 1.45 acres and 0.03 acres of maize, sorghum, millet and sweet potatoes respectively per household. Hence, this quantity of food requirement per household could be approximately obtained from 3.16 acres of maize, 5.62 acres of sorghum, 2.36 acres of millet and 7.63 acres of sweet potatoes as have shown in detail in Appendixes 14, 15, 16 and 17 and summarized in Table 7. In order to achieve both objectives of maximizing profit and of meeting household's nutrient requirement at the same time, the enterprise with small land size was taken as a minimum acreage for energy nutrient generation.

Table 7: Average land needed to produce food to meet minimum energy requirements

Enterprise Name	Average production (Kg/Acre)	Average food requirement (kg/ household/year)	Average Land required (Acre/household)
Maize	296.00	936.09	3.16
Sorghum	178.00	999.60	5.62
Millet	438.40	1 033.13	2.36
Sweet Potatoes	765.60	5 842.52	7.63

Source: Appendix: 14, 15 and 17

4.3.2 Land required to produce food to meet household's threshold protein requirements

The protein requirement was an important reason for a farmer to allocate land for enterprise production. In order to meet minimum protein requirement, on average, a single household of the average of 4 persons required an average of 275.90kg of groundnuts, 462.80 kg of pigeon peas, and a certain number of chicken per year. Also, according to the study findings, the average yield per acre in the study area was found to be 262.17kg of groundnuts and 168.67kg of pigeon peas with the average land production size of 0.61 acres of groundnuts and 0.23 acres of pigeon peas per household. Consequently, this quantity of protein requirement for households could be approximately obtained from 1.05 acres of groundnuts and 1.68 acres of pigeon peas as shown in detail in Appendixes 18 and 19 and summarized in Table 8 to show the importance of protein in the households, poultry keeping was included in the study as an important protein supplement and household's income generation. The results show that a single chicken requires 50m^2 which is equivalent to 0.0125 acres per bird and always around the household's house. Taking protein requirement into consideration, the enterprise that used small land size for enterprise production to meet household food was considered as a constraint for minimum protein. The study considered minimum acreage for the production of poultry enterprise as 0.2 acre of land per household, which is equivalent to at least 16 birds.

Table 8: *Average land needed to produce food to meet minimum protein requirement*

Enterprise Name	Average production (Kg/Acre)	Average requirement (kg per household per year)	Average of land required (Acre/household)
Groundnuts	262.165	275.90	1.05
Pigeon peas	168.67	462.80	1.68
Poultry	0.00	0.00	0.0125

Source: Appendix 13, 18 and 19

4.3.3 Land required to produce food to meet household's threshold of fat requirements

Sunflower and sesame were found to be farm enterprises with higher gross margins in the study area, because all the produce is normally sold to generate income used to purchase food. On the other hand, these crops are in the high potential category of providing fat which is needed by the households. Therefore, in order to ensure nutrition and food security of smallholder farmers, in terms of providing minimum fat, the minimum acreage requirement was established as constraint for the LP model. According to the study results, a single household of an average of 4 person required an average of 222.05 kg of sunflower and 244.84 kg of sesame per year. Also, according to the findings of the study, the average yield per acre in the study area was on average of 294.32 kg of sunflower and 103.82 kg of sesame with an average land production size of 0.28 acres of sunflower and 0.16 acres of sesame per household. Consequently, this quantity of fat requirement for households could approximately be obtained from 0.75 acres of sunflower and 2.36 acres of sesame as shown in detail in Appendices 20 and 21 and summarized in Table 9. In order to achieve both the objective of maximizing profit and at the same time meeting household's nutrient requirement, the enterprise with small land size was taken as minimum acreage for the generation of fat nutrient.

Table 9: *Average land needed to produce food to meet minimum fat requirement*

Enterprise Name	Average production (Kg/Acre)	Average requirement (kg per household per year)	Average of land required produced (Acres/household)
Sunflower	294.32	222.05	0.75
Sesame	103.82	244.84	2.36

Source: Appendix 20 and 21

4.4 Results of the Farm Enterprise Budgeting

The returns per acre in terms of gross margin coming from each enterprise with their requirements were summarized in the Table (10). The return coming from each enterprise was estimated separately using enterprise farm budget as shown in Appendixes 5, 6, 7, 8, 9, 10, 11 and13. The returns per acre coming from each enterprise vary significantly due to several reasons; one of the reasons was on the average production from the enterprises. For example, millet was produced at an average of 438.4kg per acre and attracted good return per acre in terms of gross margin of TZS 152 478.16 per Acre. The other reason was the price of the produce itself; for example, groundnuts was produced at an average of 262.17Kg per Acre and earned good returns per acre in terms of gross margin of TZS 265 504.55 per acre.

Table 10: *Gross margin per acre and their market and subsistence requirements*

Enterprise Name	Gross Margin Per Acre (TZS)	Land Used (Acre)	Labour Per Acre (Man Day)	Capital Per Acre (TZS)	Minimum energy (Acre)	Minimum protein (Acre)	Minimum fat (acre)
Maize	23 800.13	1	20.2	48 398.93	3.16	0	0
Sorghum	39 392.68	1	24.87	34 228.09	5.62	0	0

Millet	152 478.16	1	34.88	35 017.42	2.36	0	0
Sunflower	43 636.57	1	22.27	487 44.05	0	0	0.75
Groundnuts	255 504.55	1	32.18	65 543.07	0	1.05	0
Sesame	101 885.56	1	21.39	41 533.73	0	0	2.36
Pigeon Peas	83 597.53	1	22.56	34 500.50	0	1.68	0
Sweet potatoes	58 837.07	1	37.51	58 322.58	7.63	0	0
Poultry	10 553.125	0.0125	30.63	8125.00	0	**0.2**	0
AVAILABLE		**7**	**246.79**	**374 413.37**	**2.36**	**1.05**	**0.75**

Source: Source: scale-up Nutrition project, field data

4.5 Linear Programming Model Results

The coefficient which were used in the LINGO Optimization software to generate an optimum enterprise mix that maximizes total gross margin while ensuring the minimum subsistence food requirement for the households in the study area were obtained from Table 10. The results generated by the optimization software are summarized in Table 11. The results in Table 11 show that, for a small household's farmer to maximize total farm gross margin while providing food security in the household for meeting their nutrient requirement in a given year a 2.40 acres of millet (X_3), 0.75 acres of sunflower (X_4), 3.65 acres of groundnuts (X_5) and 0.2 acres of land under poultry birds (X_9) should be produced to generate TZS 1 383 878 while meeting the minimum subsistence macro nutrient food requirements. Maize (X_1), sorghum (X_2), sesame (X_6), pigeon peas (X_7) and sweet potatoes (X_8) enterprises were not included in the optimal solution.

Table 11: Optimal enterprise mix

Optimal enterprise name	Acres or birds
Millet (X_3)	2.40
Sunflower (X_4)	0.75
Groundnuts (X_5)	3.65
Poultry (X_9)	16

Source: Appendix 22

For the resources, the optimum farm plan shows that, some of the resources were not exhausted as summarized in Table 12.

Table 12: *Resources used in the optimal farm plan*

Resource	Available	Used	Unused/slacks
Land	7.00	7.00	0.00
Labour	246.79	230.39	16.40
Capital	374 413.79	374 413.79	0.00

Source: Appendix 22

4.6 Results of Sensitivity Analysis, Reduced Cost

Sensitivity analysis can reveal which pieces of information should be estimated most carefully. For example, if it is blatantly obvious that a certain product is unprofitable, then little effort needs to be expended in accurately estimating its costs. The first law of modelling is "do not waste time accurately estimating a parameter if a modest error in the parameter has little effect on the recommended decision". The quantity associated with each variable in any solution is known as the reduced cost. If the units of the objective function are in Tanzania shillings (TZS) and the units of the variable are the average land in acre or number of poultry birds, then the units of the reduced cost are TZS per acre or TZS per number of birds (poultry). The reduced cost of a variable is the amount by which the profit contribution of the variable must be improved (e.g., by reducing its cost) before the variable in question has a positive value in the optimal solution (Lindo system inc, 2003). Obviously, a variable that already appears in the optimal solution will have a zero reduced cost.

It is apparent that the reduced cost is the rate at which the objective function value will deteriorate if a variable, which is currently at zero in the optimal solution, is arbitrarily forced to increase a small amount. Suppose the reduced cost of maize was TZS

173 841.60 per acre, this means, if profitability was increased by producing 1 acre of maize in combination with the enterprise which is at the optimal level, TZS 173 841.60 could be brought into the solution, the total profit would be reduced by TZS 173 841.6 without altering its original profit contribution. This is because smallholder farmers have other objectives apart from maximizing profit (Mlambiti, 1985). Thus, when deciding to produce other enterprises, whose values were not at optimal level, they were supposed to pay extra money to produce in the reduced cost for each acre which they decide to produce as the result, the optimal profit obtained for example for maize be reduced by the same cost of producing it relative to the optimal profit which would decrease to TZS 1 210 000.4 from TZS 1 383 878 as shown in Table (13).

However, producing the enterprise at the reduced price, the enterprises automatically reduce the current maximum value of optimal profit attained. As a result, farmers would receive smaller amounts of money generated from optimization; this is because, in the process of optimization, some resources such as labour remained idle since the optimal was not there. This would in turn increase the underutilization of resources. This situation would lead into low income level and saving to farmers which would consequently result into low food production. In order for these enterprises to enter the optimal solution, more capital resources are required until they are able to attain the net revenue. This low optimal profit obtained by producing enterprises combination implies that farmers were producing below the optimal level which might be due to low level of inputs use.

Table 13: Optimal profit when households produce enterprises at reduced cost

Enterprise name (Xi)	Reduced cost (TZS/Acre)	Optimal return after optimization Xi (TZS)	Optimal return after Xi Produced in reduced cost (TZS)
Maize	187 239.70	1 881 384.00	1 694 144.30
Sorghum	138 547.10	1 881 384.00	1 742 836.90
Millet	27 416.78	1 881 384.00	1 853 967.22

Sunflower seed	170 258.10	1 881 384.00	1 711 125.90
Groundnuts	0.00	1 881 384.00	1 881 384.00
Sesame	94 149.70	1 881 384.00	1 787 234.30
Pigeon Peas	95 016.96	1 881 384.00	1 786 367.04
Sweet potatoes	178 782.90	1 881 384.00	1 702 601.10
Poultry	0.00	1 881 384.00	1 881 384.00

Source: Appendix 22

4.7 Results of Sensitivity Analysis; Objective Coefficient Ranges

The objective coefficient ranges show the interval within which the farmer will be able to adjust in decreasing or increasing the production to remain within the optimal profit limits. The current coefficient of X_1, X_2, X_4, X_6, X_7, X_8 and X_9 has no economic meaning since it does not reflect the range within which the coefficient should be allowed to decrease and the farmer to remain within the profitable region as shown on Lingo ranges in Appendix 23. The rational economic ranges for the current coefficient for farmer to remain in the optimal production are millet (X_3) and groundnuts (X_5). The interpretation of these coefficient ranges relies on the quick "what if" analysis, this is because it helps the farmer to make decision on what to produce within the limit of the lower and upper limit.

For instance, if the coefficient of groundnuts (X_5) decreases to TZS 20 000, the farmer will be in the optimal region since the allowable decrease is TZS 68 689.21, so TZS 20 000 is within the allowed decrease and new profit would decrease from the current coefficient of TZS 255 504.50 to the new coefficient of TZS186 815.29. Depending on the resources' availability, the farmer is able to increase the profit from the current coefficient of TZS 255 504.50 per acre up to the new coefficient of TZS 285 397.28. On the other hand, the farmer will remain in the profit region when the current coefficient of millet (X_3) decrease up to TZS 10 000 per acre from the current coefficient of TZS 39

392.68 per acre, this change will cause the optimal profit to decrease accordingly. Also, the optimal profit will increase from the current coefficient of TZS 39 392.68 per acre to a new coefficient of TZS 72 276.78 per acre. In addition, the farmer would remain in the optimal profit region when the current coefficient of return per acre changes to any value that is within the boundary of upper and lower limit of the optimal value enterprises Millet (X_3) and groundnuts (X_5). Table 14 shows the range of objective coefficient within which the farmer will be allowed to decrease or increase the returns and remain within the profitable region. These limits apply under the assumption that the other factors remained constant throughout the production period.

Table 14: Objective coefficient r*anges in production*

Enterprise (Variable)	Final value (Acre)	Current Coefficient (TZS)	Allowable increase (TZS)	Allowable decrease (TZS)	Upper limit (TZS)	Lower limit (TZS)
Maize (X_1)	0.00	23 800.13	173 841.60	1E+30	197 641.73	1E+30
Sorghum (X_2)	0.00	39 392.68	110 421.30	1E+30	149 813.98	1E+30
Millet (X_3)	2.40	152 478.20	72 276.78	15 978.70	224 754.98	136 499.50
Sunflower (X_4)	0.75	43 636.57	155 170.00	1E+30	198 806.57	1E+30
Groundnuts (X_5)	3.65	255 504.50	29 892.78	68 689.21	285 397.28	186 815.29
Sesame (X_6)	0.00	101 885.60	72 585.56	1E+30	174 471.16	1E+30
Pigeon peas (X_7)	0.00	83 597.53	67 135.88	1E+30	150 733.41	1E+30
Sweet Potato (X_8)	0.00	58 837.07	172 297.80	1E+30	231 134.87	1E+30
Poultry (X_9)	16.00	10 553.125	17 298.04	1E+30	27 851.165	1E+30

Where; 1E+30 represent infinity.
Source: Appendix 23

The optimal value of enterprise, reduced cost and the ranges of the objective coefficient reveal optimal profit result from different gross margin of the objective function. The gross margin from different enterprises which built the objective function does not contribute the same value to the optimal profit. Therefore, concerning with the research question that started “What are the returns from the existing farm enterprise mix that uses the available resources in the study area?” was answered as follows, the farmers produce enterprises for the optimal return of TZS 1 383 878 obtained by producing millet, sunflower, groundnuts and poultry birds' enterprises. On the other hand, maize, sorghum, sesame, pigeon peas and sweet potatoes did not constitute to optimal profit as shown in Appendix 22.

4.8 Slack or Surplus Constraints

The slack or surplus shows how close in satisfying the constraints. The model shows the constraints for land which is used in producing enterprises and capital were satisfied and their slack was zero while the land for minimum fat and poultry enterprises were satisfied and their slack was zero as well. This means that the constraint fit for the objective function, on the other hand, the model shows unsatisfied constraint for labour and land for minimum energy and land for minimum protein. The slacks had a positive value meaning that those resources were surplus or underutilized in the production process as shown in Appendix 22 and summarized in Table 15 and explained in detail below.

4.8.1 Household labour (Man days)

Household labour, was measured in terms of man-days. According Table 15, the surplus labour was 16 man-days per acre. This means that the smallholder farmers had idle man days which were not utilized fully in the enterprise production activities. As a result, people were under employment in enterprise production hence leadings to relaxation during the season. Therefore, it is through enterprise diversification by producing different enterprises in the farm where these idle man-days can be fully utilized in the production system and in other off and nonfarm activities. However, although labour diversification has taken place it was at the low level even on the part of off and nonfarm systems since households largely depend on farm activities. This situation results in to the diseconomies of scale and f size in the agricultural production system. Therefore, to make a firm produce under the economies of scale there was a need of readjusting the labourintensive activities in order to reallocate the family labour into a full-time employment all year around. However, due to low economic development of the District this surplus labour would likely remain under-utilized; and gradually increase each day due the high population growth in the District accompanied by shifting of central government to Dodoma region.

4.8.2 Land for producing food to meet minimum energy requirements (Acres)

The total land area for minimum energy enterprise production was an important factor in determining the level of production in meeting the minimum energy requirement among smallholder farmers. According to Table 15, the potential total land area available for the production of food that meets minimum energy requirement was found to be on the average of 2.36 acres per a household. However, according to the LP results, there was a surplus land of 0.04 acres, which was not used in the production of food for minimum energy requirements, per a household. This implies that, since a household would allocate 2.36 acres to optimize profit while maintaining thresholds energy requirement, there is an opportunity for them to use the extra available land for more production of food which are the sources of energy while generation income.

Table 15: *Sensitivity result for constraints used in optimization model*

Resource	Available	Used	Unused/slacks
Land	7.00	7.00	0.00
Labour	246.79	230.39	16.40
Capital	374 413.79	374 413.79	0.00
Land for minimum energy	2.36	2.32	0.04
Land for minimum fat	0.75	0.75	0.00
Land for minimum protein	1.05	1.05	0.00
Land for poultry	0.20	0.20	0.00

Source: Appendix 22

4.9 Dual Prices under Production Scenario

In sensitivity analysis, a quantity associated with each constraint is known as the dual price. The dual price of a constraint implies the rate at which the objective function value will improve at the right-hand side or the constant term of the constraint is increased in a small amount. For example, if the units of the objective function are Tanzania shillings (TZS) and the units of the constraint in question are the size of land in acre, then the units of the dual price would be Tanzania shillings per acre (TZS/Acre). Different optimization programs may use different sign conventions with regards to the dual prices. The LINGO computer program uses the convention that a positive dual price means increasing the right-hand side in question to improve the objective function value. On the other hand, a negative dual price means an increase in the right-hand side which will cause the objective function value to deteriorate, a zero dual price means changing the right-hand side in a small amount will have no effect on the solution value (Lindo system inc, 2003).

The Lingo gives the dual prices (shadow prices) figure for each constraint as the amount that the objective function improves by constant term if the constraints were increased by 1 unit provided other factors remained the same. In other words, the dual prices are known as shadow prices because they show how much the farmer is willing to pay for any additional of unit resource. In addition, the resulting higher shadow prices (Table 16) of the production factors encourage farmers to seek for trade extra units of inputs or resources. Farmers look for more land to produce the enterprise beyond the optimal profit. For example, any increase of the unit land improves the profit by TZS 34 291.49. On the other hand, any decision of increasing an extra unit of capital in terms of money (1TZS) would result in the additional of TZS 3.38 to the optimal value; and one unit increase in the land allocated for producing food to meet fat nutrient requirement would result in a decrease of optimal value by TZS 155 170.00 and one unit increase in the number of flock size of poultry would result in the deterioration of optimal value by TZS 17 298.04. Any decision to hire an extra unit of labour and extra land for producing minimum food to meet energy and protein nutrient requirement would result in the non-increase of the optimal profit as shown in Table (16). This addition was subject to the assumption that other factors which are needed for enterprise production remained constant for the whole production process.

Table 16: Shadow prices

Resources	**Optimal profit (TZS)**	**One unit increase in resources (TZS)**	**Optimal profit increase as the result of unit increase of resource (TZS)**
Land for crops (acre)	1 496 067.00	25 504.50	1 521 571.50
Land for poultry (0.5 acre)	1 496 067.00	322 000.00	1 818 067.00
Labour	1 496 067.00	0.00	1 496 067.00
Capital	1 496 067.00	0.00	1 496 067.00
Land for Producing energy food	1 496 067.00	-51 513.19	1 444 553.81
Land for producing protein food	1 496 067.00	0.00	1 496 067.00
Land for fat (food+income)	1 496 067.00	-211 868.00	1 284 199.00

Source: Appendix 22

4.10 Right Hand Side Ranges of the Constraints

As discussed on the objective ranges, the right-hand side ranges show the interval of resources within which the farmer could be able to adjust in decreasing or increasing the production resources to remain within the optimal profit limit. Appendix 23 shows that the row 3, 5 and 7 the right-hand side ranges have no economic limits at the right-hand side and therefore they were not considered in the discussion. The current RHS on row 2, 4, 6 and 8 had economic limits on the right-hand side of the constraints and therefore these were considered in the current study. It is worth noting that, the right hand side represents the constraint in the market and subsistence oriented scenario in rows 2, 3, 4, 5, 6, 7 and 8 stands for constraints of land, labour, capital, land estimated to produce sufficient energy food, land estimated to produce sufficient fat food, land estimated to produce sufficient protein food and the number of birds per household respectively.

The average land for producing enterprise was 7 acres and for the households to remain within the optimal profit limit was allowed to decrease up to 6.81 acres and allowed to increase the utilization of the land up to 7.43 acres, row 4 was the average capital constraints which was TZS 374 413.4 and for the farmer to remain in the profit limit the capital was allowed to decrease up to TZS 289 006.49 and allowed to increase up to TZS 375 622.93. Similarly on row 6 which represents 0.750 acres of the total average land which was used to produce food for meeting household fat nutrient requirement while generating some income and for the households to remain within the optimal profit limit, the households were not allowed to decrease the land for producing fat nutrient in order for them to continue producing at the optimal profit limit. Also, the households were allowed to increase the land for producing fat nutrient up to 0.82 acres from the available average land of 0.75 acres.

Moreover, it was found that the households could be able to keep rearing the average of 16 birds or poultry for them to meet their nutrient requirement (protein) while selling part of the product to generate some income. In order to remain within the optimal profit area while consuming part to attain minimum protein requirement, smallholder farmers were allowed to decrease the number of poultry birds up to 2 birds in the lower limit and to increase the number of poultry birds to 56 birds. These limits were applied under the assumption that the other factors remained constant throughout the production period more details are shown in Table 17.

Table 17: Right hand side ranges of production requirement

Resources (Row)	Current RHS	Allowable increase (TZS)	Allowable decrease (TZS)	Upper limit (TZS)	Lower limit (TZS)
2	7.00	0.30	1.76	7.30	5.25
3	0.50	0.32	0.00	0.82	0.50
4	246.79	1E+30	9.71	1E+30	237.08
5	496 288.40	1E+30	60 868.48	1E+30	435 419.92
6	4.69	3.51	3.99	8.20	0.70
7	1.90	1.76	1E+30	3.66	1E+30
8	1.00	1.76	0.98	2.76	0.02

Where; 1E+30 represent infinity.
Source: Appendix 23

The slacks or surplus, dual prices or shadow prices together with ranges of changes between the right-hand side of the constraints reveal optimal combination of enterprises production was important to the change (improve) the optimal profit while ensuring adequate supply of households' food when other factors in the production process remain the same. Therefore, concerning with the research question that stated "Is the existing enterprise mix utilizing the available resources efficiently to maximize profit while meeting household nutrient requirements? If not, what is the optimal enterprise mix that maximizes profit while meeting household's nutrient requirements?" was answered as follows, the existing enterprise mix utilizing the available resources efficiently to maximize profit while meeting household nutrient requirements was not optimally maximizing profit while ensuring adequately supply of household nutrient requirements, in that regards, the optimal combination for enterprise to maximize profit while meeting household nutrient requirement were millet, sunflower, groundnuts and poultry birds produced at 2.40 acres, 0.75 acres, 3.65 acres and at least 16 number of poultry birds (0.2 acres land under of poultry birds) respectively in the study area.

4.11 Linear Programming Model Validation

As explained in section 2.2.3, two types of validation may be applied to linear programming models. These are validation by construct and validation by results. Validation by construct involves assessing the procedures which are used in the model construct whereas validation by results involves comparing model solutions with the corresponding real world outcomes (McCarl and Spreen, 1997). The linear programming model which was used in the present study was validated by construct through the following guidelines;

First, the model was constructed using appropriate procedures which are believed to be right by other model builders. This included construction of the model based on experience from previous researchers' models and writings and based on theory. Moreover, data which were used in the model were specified using reasonable scientific estimations and accounting procedures. Furthermore, the raw data were obtained through a detail survey which conducted with smallholder farmers of Chamwino District.

Second, nominal examination of model results was done and found that they do not contradict the model builder's, users and/or associated experts' perceptions of reality. For example, in the resource constraint, which assumes that agricultural inputs (land, labour and capital) are the only limiting factors that shape the farmer's decision-making, it was assumed that farmers maximize the value of their output net return subject to their resource constraints. What was found in Chamwino District is that; farmers allocate the maximum land for production of enterprises per household of 7 acres, maximum labour available to work the land per acre of 246.79 man-days and maximum capital that was available to farmer disposal per acre of TZS 374 413.37 (Table 10) to maximize profit. Because farmers are constrained by family food, profit maximization without considering this requirement would be unrealistic and therefore, nutrient for fulfilling their livelihood in the subsistence constraint was valid and an important component in model.

Third, subsistence constraints were imposed in order to restrict the model to realistic solutions. The imposition of minimum nutrient requirement of energy, protein and fat to be 2.36 acres, 1.05 acres and 0.75 acres respectively was important because farmers do not only aim at profit maximization; they have other objectives such as ensuring family food adequacy. Hence, imposition of minimum nutrient requirement for energy, protein, and fat was to ensure that the household has enough food which is produced to satisfy the family's nutrient requirement and that farmers are able to earn some income makes the model valid by construct.

Validation by results was not used in the present study because of less clarity obtained from the real-world outcomes. For example, it was not easy to get the correct amount of capital available to a farmer because farmers could easily cheat. Therefore, in this study, it was just assumed that the amount of capital used by a farmer in the production of both farm enterprises was the amount of capital available to the farmer. This discredits validation by results in the present study because it is possible that the amount of capital used in the production of farm enterprise is not the only amount of capital available to the farmer. Hence, validation by construct was chosen as the best option.

4.12 Importance of other Sources of Income in Household's Dietary Requirement

Diversifying income sources by generating income from other income source activities either through a wage job or through creating a household enterprise may increase productivity of the farm and helps reducing farmers' vulnerability to exogenous weather or price shocks. Non-farm rural incomes therefore play a key role in both fostering rural development and in alleviating food security risks (NBS, 2014). The findings of the current study revealed that small household farmers have other activities that indirectly contribute to their daily welfare in terms of income and food requirements. Households mainly received incomes from sources other than farms such as off farm employment, non-farm activities, Government/NGO supports and remittances. Table 18 shows, the average incomes which were earned by small holder farming households outside their farms in 2015/2016.

Table 18: Average income generated outside household farms

Type of outside farm income generating activities	Average income earned in the households (TZS/Year)
Off farm employment	376 653.69
Non farm employment	2 309 944.89
Government or Non-Government organization support	62 738.15
Remittance	156 884.76

Source: Field data

The income generated outside household farms may affect the general objective of linear programming optimization model and the requirement in the model. The income generated from non-farm income could be included in the general objective to yield feasible solution. The off-farm employment may affect the labour which was used for households' farms, since the labour which was required in their farm was sold outside to other farms within the district to generate wages as a source of households' income, the same applies for non-farm employment. Other incomes were generated from Government or Non-government organization support and remittances. Some activities may affect the capital requirement of the model, for instance the capital from other sources of income can be used to purchase farm inputs such as seeds which are required in the farm.

Due to the important contribution of other sources of income in influencing optimal profit and their contribution to ensuring adequate food availability among small household farmers in the study area, these other income generating activities within the household in the study area were not included in the optimization model this is because, these sources of income were not reliable and sustainable as sources of household income because the off farm income is always periodic and only arises when there is high competition of labour during farming season. Furthermore, it is difficult to anticipate that the government, NGO or relatives would continue with their support in the households for years and therefore we cannot model in the policy analysis and in the recommendation for public utilization. Thus, it is shown in this section to recognize its important contribution to household’s food requirement and income.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study aimed at establishing the optimum enterprise mix that utilizes the available resources efficiently to maximize total gross margin while ensuring adequate supply of food to meet household's nutritional requirements in the study area. The linear programming results show that the households in Chamwino District can meet their nutritional food requirements if the resources available to them are optimally allocated to the existing crop and livestock enterprises. The optimum enterprise mix that maximizes returns consists of 2.40 acres of millet, 0.75 acres of sunflower, 3.65 acres of groundnuts and at least 16 poultry birds. Besides, being in the optimal enterprise mix, the three crop enterprises are suitable enterprises for semi-arid areas while the local chicken birds are a cheap source of protein for rural households.

5.2 Recommendations

i. The government in collaborations with development partners are implementing Agricultural Sector Development Program I and II (ASDP I and II). These programs are recommended to be directed to enhance productivity of farm enterprises that are in the priority crop and livestock in central zones of Tanzania such as millet, sunflower, groundnut and poultry.

ii. The results show that enterprises such as maize, sorghum, sesame, sweet potato and pigeon peas are suitable in semi-arid areas but were not produced at optimum enterprise mix that means reducing the optimal profit for the households. However, are very important in providing food nutrients. The study recommends government agencies and development partners to subsidize these farm enterprises to enhance food security and reduced malnutrition.

iii. The results reveal that, there was unused household labour throughout the production period. The study recommends to promote off-farm activities such as industrial activities, rural businesses and off-season farm activities (Horticultural farming) together with designing policies for better utilization of unused household labour resources in the District.

iv. The results show that, the decision to increase one unit of land and capital utilization resources would result in positive increase of farm profit. The study recommends for the households to strive for more utilization of unit land and capital resources that increase the optimal farm profitability while generating adequate nutritional requirements in the District.

v. The study was conducted in semi-arid central regions of Tanzania where farmers produce farm enterprises by depending on rain fed which is not reliable. The study recommends establishing irrigation technologies such as rain water harvesting technology, so that water can be available for irrigation of enterprises and horticultural crops to absorb the unused labour capacity in the District.

vi. The result shows low average farm enterprises production, this might be due to low improved seed and other input utilization. In order to increase farmers' access to improved seed and other input, additional capital access should be improved. For example, financial institutions should be encouraged to motivate smallholder farmers to take loans by offering trainings and favourable conditions in the process of taking loans. In addition, the study recommends to the government to take deliberate action to establish rural banks and support SACCOS existing in rural areas in the District.

5.3 Suggestions for Further Studies

This study managed to generate options to minimize the prevalence of chronic malnutrition by the reallocation of households' resources in favour of crop and livestock enterprises with high nutritional contents in nutrient deficient areas and practicing farming for business purpose in order to increase households' income as the secondary source of food. However, the options generated by this study relied on macro nutrient contribution on reducing malnutrition only and mainly relying on the ones that are produced on the farm. It is thus suggested that for serving the same purpose of minimizing malnutrition by improving household food security and adequate nutrient intake, future studies need to consider both macro and micro nutrients from agricultural or food system optimization generated from both farm and off farm sources. This would broaden an understanding about nutrient combinations that farmers need from the agricultural or food systems for the minimization of malnutrition especially for children under 5 and women of reproductive age. Moreover, further studies must focus on linking institutional and agricultural policies to explore options for farm optimization that improve households' living standards, for the better design and implementation of nutrition programs, especially those that focus on agriculture or food systems to ensure the best nutrient intakes by households.

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APPENDICES

Appendix 1: *Average labour required and labour cost for land preparation per acre*

Enterprise Name (X_i)	Required Labour per Acre (Man-day per Acre)	Total labour cost per Acre (TZS/Acre)	Labour cost (TZS/Man day)
Maize	3.42	17 100.00	5 000.00
Sorghum	3.32	16 586.94	5 000.00
Millet	4.15	20 760.47	5 000.00
Sunflower seed	3.07	15 333.33	5 000.00
Groundnuts	3.89	19 428.57	5 000.00
Sesame	3.71	18 540.11	5 000.00
Pigeon peas	3.15	15 758.17	5 000.00
Sweet potatoes	10.49	52 437.28	5 000.00
		Total	40 000.00
Average labour cost for land preparation			5 000.00

Appendix 2: Average labour required and labour cost for planting per acre

Enterprise Name (*Xi*)	Required Labour per Acre (Man-day per Acre)	Total labour cost per Acre (TZS/Acre)	Labour cost (TZS/Acre)
Maize	4.16	20 814.09	5 000.00
Sorghum	1.96	9 798.23	5 000.00
Millet	3.45	17 257.67	5 000.00
Sunflower seed	4.16	20 789.67	5 000.00
Groundnuts	7.59	37 958.75	5 000.00
Sesame	3.40	17 000.00	5 000.00
Pigeon peas	3.91	19 547.38	5 000.00
Sweet potatoes	9.49	47 456.86	5 000.00
Total			**40 000.00**
Average labour cost for land preparation			**5 000.00**

Appendix 3: Average labour required and labour cost for weeding per acre

Enterprise Name (*Xi*)	Required Labour per Acre (Man-day per Acre)	Total labour cost per Acre (TZS/Acre)	Labour cost (TZS/Acre)
Maize	9.02	45 079.01	5 000.00
Sorghum	12.49	62 473.58	5 000.00
Millet	17.38	86 889.54	5 000.00
Sunflower seed	8.30	41 488.10	5 000.00
Groundnuts	8.35	41 730.76	5 000.00
Sesame	8.13	40 674.84	5 000.00
Pigeon peas	8.50	42 475.66	5 000.00
Sweet potatoes	10.42	52 096.77	5 000.00
Total			**40 000.00**
Average labour cost for land preparation			**5 000.00**

Appendix 4: Average labour required and labour cost for harvesting per acre

Enterprise Name (*Xi*)	Required Labour per Acre (Man-day per Acre)	Total labour cost per Acre (TZS/Acre)	Labour cost (TZS/Acre)
Maize	3.90	19 507.84	5 000.00
Sorghum	7.09	35 462.48	5 000.00
Millet	9.90	49 476.74	5 000.00
Sunflower seed	6.74	33 690.48	5 000.00
Groundnuts	12.35	61 730.77	5 000.00
Sesame	6.13	30 674.85	5 000.00
Pigeon peas	7.00	35 000.00	5 000.00
Sweet potatoes	9.81	49 064.52	5 000.00
Total			**40 000.00**
Average labour cost for land preparation			**5 000.00**

Appendix 5: Average yield, revenue, costs and gross margin per acre of maize production

Item	Value (TZS)
Average yield (Kg per acre)	296.00
Average selling price (TZS) per Kg	600.00
Average revenue (TZS per acre)	**177 600.00**
Average cost of ploughing (TZS/acre)	25 090.91
Average cost of purchasing seeds (TZS/acre)	16 631.07
Average cost of planting (TZS/acre)	20 814.09
Average cost of weeding (TZS/acre)	45 079.01
Average cost of purchasing fertilizer (TZS/acre)	0.00
Average cost of fertilizer application (TZS/acre)	0.00
Average cost of purchasing agrochemicals (TZS/acre)	0.00
Average cost of agrochemical application (TZS/acre)	0.00
Average Harvesting cost (TZS/acre)	19 507.84
Average transportation cost (TZS/acre)	6 676.95
Average cost of hiring land (TZS/acre)	20 000.00
Average total cost (TZS/acre)	**153 799.87**
Average gross margin (TZS/acre)	**23 800.13**

Appendix 6: Average yield, revenue, costs and gross margin per acre of sorghum production

Item	**Value (TZS)**
Average yield (Kg per acre)	178.65
Average selling price (TZS) per Kg	1 080.00
Average revenue (TZS per acre)	**192 942.00**
Average cost of land preparation (TZS/Acre)	16 586.94
Average cost of ploughing (TZS/acre)	26 610.84
Average cost of purchasing seeds (TZS/acre)	1 059.91
Average cost of planting (TZS/acre)	9 798.23
Average cost of weeding (TZS/acre)	47 473.58
Average cost of purchasing fertilizer(TZS/acre)	0.00
Average cost of fertilizer application(TZS/acre)	0.00
Average cost of purchasing agrochemicals(TZS/acre)	0.00
Average cost of agrochemical application (TZS/acre)	0.00
Average Harvesting cost (TZS/acre)	25 462.48
Average transportation cost (TZS/acre)	6 557.34
Average cost of hiring land (TZS/acre)	20 000.00
Average total cost (TZS/acre)	**153 549.32**
Average gross margin(TZS/acre)	**39 392.68**

Appendix 7: Average yield, revenue, costs and gross margin per acre of millet production

Item	**Value (TZS)**
Average yield (Kg per acre)	438.40
Average selling price (TZS) per Kg	700.00
Average revenue (TZS per acre)	**306 880.00**
Average cost of land preparation (TZS/Acre)	20 760.47
Average cost of ploughing (TZS/acre)	26 858.30
Average cost of purchasing seeds (TZS/acre)	2 121.95
Average cost of planting (TZS/acre)	7 257.67
Average cost of weeding (TZS/acre)	46 889.54
Average cost of purchasing fertilizer(TZS/acre)	0.00
Average cost of fertilizer application(TZS/acre)	0.00
Average cost of purchasing agrochemicals(TZS/acre)	0.00
Average cost of agrochemical application (TZS/acre)	0.00
Average Harvesting cost (TZS/acre)	24 476.74
Average transportation cost (TZS/acre)	6 037.17
Average cost of hiring land (TZS/acre)	20 000.00
Average total cost (TZS/acre)	**154 401.84**
Average gross margin(TZS/acre)	**152 478.16**

Appendix 8: Average yield, revenue, costs and gross margin per acre of sunflower production

Item	Value (TZS)
Average yield (Kg per acre)	294.32
Average selling price (TZS) per Kg	760.00
Average revenue (TZS per acre)	**223 682.20**
Average cost of land preparation (TZS/Acre)	15 333.33
Average cost of ploughing (TZS/acre)	31 488.10
Average cost of purchasing seeds (TZS/acre)	8 952.38
Average cost of planting (TZS/acre)	20 789.67
Average cost of weeding (TZS/acre)	41 488.10
Average cost of purchasing fertilizer(TZS/acre)	0.00
Average cost of fertilizer application(TZS/acre)	0.00
Average cost of purchasing agrochemicals(TZS/acre)	0.00
Average cost of agrochemical application (TZS/acre)	0.00
Average Harvesting cost (TZS/acre)	33 690.48
Average transportation cost (TZS/acre)	8 303.57
Average cost of hiring land (TZS/acre)	20 000.00
Average total cost (TZS/acre)	**180 045.63**
Average gross margin(TZS/acre)	**43 636.57**

Appendix 9: Average yield, revenue, costs and gross margin per acre of groundnuts production

Item	Value (TZS)
Average yield (Kg per acre)	262.16
Average selling price (TZS) per Kg	1 800.00
Average revenue (TZS per acre)	**471 896.47**
Average cost of land preparation (TZS/Acre)	19 428.57
Average cost of ploughing (TZS/acre)	26 213.40
Average cost of purchasing seeds (TZS/acre)	12 228.02
Average cost of planting (TZS/acre)	27 958.75
Average cost of weeding (TZS/acre)	41 730.76
Average cost of purchasing fertilizer(TZS/acre)	0.00
Average cost of fertilizer application(TZS/acre)	0.00
Average cost of purchasing agrochemicals(TZS/acre)	0.00
Average cost of agrochemical application (TZS/acre)	0.00
Average Harvesting cost (TZS/acre)	61 730.77
Average transportation cost (TZS/acre)	7 101.65
Average cost of hiring land (TZS/acre)	20 000.00
Average total cost (TZS/acre)	**216 391.92**
Average gross margin(TZS/acre)	**255 504.55**

Appendix 10: Average yield, revenue, costs and gross margin per acre of sesame production

Item	Value (TZS)
Average yield (Kg per acre)	103.82
Average selling price (TZS) per Kg	2 700.00

Average revenue (TZS per acre)	**280 309.09**
Average cost of land preparation (TZS/Acre)	18 540.11
Average cost of ploughing (TZS/acre)	29 202.45
Average cost of purchasing seeds (TZS/acre)	16 625.76
Average cost of planting (TZS/acre)	17 000.00
Average cost of weeding (TZS/acre)	40 674.84
Average cost of purchasing fertilizer(TZS/acre)	0.00
Average cost of fertilizer application(TZS/acre)	0.00
Average cost of purchasing agrochemicals(TZS/acre)	0.00
Average cost of agrochemical application (TZS/acre)	0.00
Average Harvesting cost (TZS/acre)	30 674.85
Average transportation cost (TZS/acre)	5 705.52
Average cost of hiring land (TZS/acre)	20 000.00
Average total cost (TZS/acre)	**178 423.53**
Average gross margin(TZS/acre)	**101 885.56**

Appendix 11: Average yield, revenue, costs and gross margin per acre of pigeon peas production

Item	**Value (TZS)**
Average yield (Kg per acre)	168.67
Average selling price (TZS) per Kg	1 500.00
Average revenue (TZS per acre)	**253 005.00**
Average cost of land preparation (TZS/Acre)	15 758.17
Average cost of ploughing (TZS/acre)	21 666.67
Average cost of purchasing seeds (TZS/acre)	6 625.76
Average cost of planting (TZS/acre)	19 547.38
Average cost of weeding (TZS/acre)	42 475.66
Average cost of purchasing fertilizer(TZS/acre)	0.00
Average cost of fertilizer application(TZS/acre)	0.00
Average cost of purchasing agrochemicals(TZS/acre)	0.00
Average cost of agrochemical application (TZS/acre)	0.00
Average Harvesting cost (TZS/acre)	35 000.00
Average transportation cost (TZS/acre)	8 333.83
Average cost of hiring land (TZS/acre)	20 000.00
Average total cost (TZS/acre)	**169 407.47**
Average gross margin(TZS/acre)	**83 597.53**

Appendix 12: Average yield, revenue, costs and gross margin per acre of sweet potatoes production

Item	**Value (TZS)**
Average yield (Kg per acre)	765.56
Average selling price (TZS) per Kg	300.00
Average revenue (TZS per acre)	**229 666.67**
Average cost of land preparation (TZS/Acre)	18 888.89

Average cost of making ridges (TZS/acre)	33 548.39
Average cost of purchasing seeds (TZS/acre)	17 354.84
Average cost of planting (TZS/acre)	22 456.86
Average cost of weeding (TZS/acre)	17 096.77
Average cost of purchasing fertilizer(TZS/acre)	0.00
Average cost of fertilizer application(TZS/acre)	0.00
Average cost of purchasing agrochemicals(TZS/acre)	0.00
Average cost of agrochemical application (TZS/acre)	0.00
Average Harvesting cost (TZS/acre)	34 064.52
Average transportation cost (TZS/acre)	7 419.35
Average cost of hiring land (TZS/acre)	20 000.00
Average total cost (TZS/acre)	**170 829.62**
Average gross margin(TZS/acre)	**58 837.05**

Appendix 13: *The income (Gross margin) from production of local chicken in Tanzania*

Item	Parameter
Average flock per household	16
Average local lying hen	15
Average local cock	1
Average egg output (flock-1year-1)	450
Average egg per clutch per hen	12
Eggs incubated by broodily hen per year	120
Old day chick produced from incubated eggs	100
Chick to reach maturity (70% rearing loss)	30
Number of cockerels yielded	15
Number of pullets yielded	15
The annual income from the average flock can be calculated	
Income = 300egg + 10old hens + 1 old cock +14cockreles	
Price of local egg at household gate (TZS)	300
price of local old hen at household gate (TZS)	8 000
price of local old cock at household gate (TZS)	12 000
price of local cockerels at household gate (TZS)	10 000
Income = 300egg + 10old hens + 1 old cock +14cockreles (TZS)	**32 2000**
Total cost of labour (opportunity cost) (TZS)	**15 3150**
Gross Margin (TZS)	**16 8850**
The average gross margin from poultry (TZS/poultry)	**10 553.125**

Source: FAO (2004); Goromela (2009)

Appendix 14: *The average land needed to produce maize to meet minimum energy requirement for households*

Item	Value
Adult equivalent [kcal/day]	2 200.00
Energy from 100g of raw maize [Kcal]	362.00
Amount of raw maize required to generate minimum energy [g/day/person]	607.73
Amount of raw maize required to generate minimum energy [g/year/person]	221 823.20
Amount of raw maize required to generate minimum energy [Kg/year/person]	221.82
Average household size [Number]	4.22
Amount of raw maize required to generate minimum energy [Kg/year/household]	936.09

Average maize production [Kg/Acre]	296.00
Total area should household produce to meet energy requirement [Acre]	**3.16**

Appendix 15: *The average size of land needed to produce Sorghum to meet minimum energy requirement for households*

Item	Value
Adult equivalent [kcal/day]	2 200.00
Energy from 100g of raw maize [Kcal]	339.00
Average raw sorghum required to generate minimum energy [g/day/person]	648.97
Average raw required to generate minimum energy [g/year/person]	236 873.16
Average raw sorghum required to generate minimum energy [Kg/year/person]	236.87
Average household size [Number]	4.22
Average raw sorghum required to generate minimum energy [Kg/year/household]	999.60
Average production [Kg/Acre]	178.00
Total area household produce to meet energy requirement [Acre]	**5.62**

Appendix 16: *The average size of land needed to produce Millet to meet minimum energy requirement for households*

Item	Value
Adult equivalent [kcal/day]	2 200
Energy from 100g of raw maize [Kcal]	328
Average raw Millet required to generate minimum energy [g/day/person]	670.7317
Average raw Millet required to generate minimum energy [g/year/person]	244 817.1
Average raw Millet required to generate minimum energy [Kg/year/person]	244.8171
Average household size [Number]	4.22
Average raw Millet required to generate minimum energy [Kg/year/household]	1 033.128
Average production [Kg/Acre]	438.4
Total area household produce to meet energy requirement [Acre]	**2.357**

Appendix 17: *The average size of land needed to produce Sweet potatoes to meet minimum energy requirement for households*

Item	Value
Adult equivalent [kcal/day]	2200
Energy from 100g of raw maize [Kcal]	58
Average raw Sweet potatoes required to generate minimum energy [g/day/person]	3793.103
Average raw Sweet potatoes required to generate minimum energy [g/year/person]	1 384 483
Average raw Sweet potatoes required to generate minimum energy [Kg/year/person]	1 384.483
Average household size [Number]	4.22
Average raw Sweet potatoes required to generate minimum energy [Kg/year/household]	5 842.517

Average production [Kg/Acre]	765.6
Total area household produce to meet energy requirement [Acre]	**7.631**

Appendix 18: *The average size of land needed to produce groundnuts to meet minimum Protein requirement for households*

Item	Value
Adult equivalent [g/day]	65.20
Protein from 100g of raw groundnuts [Kcal]	36.40
Amount of raw groundnuts required to generate minimum protein [g/day/person]	179.12
Amount of raw groundnuts required to generate minimum protein [g/year/person]	65 379.12
Amount of raw groundnuts required to generate minimum protein [Kg/year/person]	65.38
Average household size [Number]	4.22
Amount of raw groundnuts required to generate minimum protein [Kg/year/household]	275.90
Average groundnuts production [Kg/Acre]	262.17
Total area household produce to meet protein requirement [Acre]	**1.05**

Appendix 19: *The average size of land needed to produce pigeon peas to meet minimum Protein requirement for households*

Item	Value
Adult equivalent [g/day]	65.20
Protein from 100g of raw pigeon peas [Kcal]	21.70
Amount of raw pigeon peas required to generate minimum protein [g/day/person]	300.46
Amount of raw pigeon peas required to generate minimum protein [g/year/person]	109 668.20
Amount of raw pigeon peas required to generate minimum protein [Kg/year/person]	109.67
Average household size [Number]	4.22
Amount of raw pigeon peas required to generate minimum protein [Kg/year/household]	462.80
Average pigeon peas production [Kg/Acre]	275.90
Total area household produce to meet protein requirement [Acre]	**1.68**

Appendix 20: *The average size of land needed to produce sunflower to meet minimum fat requirement for households*

Item	Value
Adult equivalent [g/day]	79.00
Fat from 100g of raw sunflower [g]	54.80
Amount of raw sunflower required to generate minimum fat [g/day/person]	144.16
Amount of raw sunflower required to generate minimum fat [g/year/person]	52 618.61
Amount of raw sunflower required to generate minimum fat [Kg/year/person]	52.62
Average household size [Number]	4.22
Amount of raw sunflower required to generate minimum fat [Kg/year/household]	222.05

Average sunflower production [Kg/Acre]	294.32
Total area household produce to meet fat requirement [Acre]	**0.75**

Appendix 21: *The average size of land needed to produce sesame to meet minimum fat requirement for households*

Item	Value
Adult equivalent [g/day]	79.00
Fat from 100g of raw sesame [g]	49.70
Amount of raw sesame required to generate minimum fat [g/day/person]	158.95
Amount of raw sesame required to generate minimum fat [g/year/person]	58 018.11
Amount of raw sesame required to generate minimum fat [Kg/year/person]	58.02
Average household size [Number]	4.22
Amount of raw sesame required to generate minimum fat [Kg/year/household]	244.84
Average sesame production [Kg/Acre]	103.82
Total area household produce to meet fat requirement [Acre]	**2.36**

Appendix 22: The Lingo optimization solution.

Equation for the empirical linear programming model

Objective function and three constraints equation

Objective function;

$$\text{Maximize } Z = 23800.13X_1 + 39392.68X_2 + 152478.16X_3 + 43636.57X_4 + 255504.55X_5 + 101885.56X_6 + 83597.53X_7 + 58837.07X_8 + 10553.125X_9 \quad (14)$$

Subject to

First constraints: Resources constraints

(i). Land constraints

$$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + 0.0125X_9 \leq 7.0 \quad (15)$$

(ii). Labour constraints

$$20.50X_1 + 24.87X_2 + 34.88X_3 + 22.27X_4 + 32.18X_5 + 21.39X_6 + 37.56X_7 + 22.51X_8 + 30.63X_9 \leq 246.79 \quad (16)$$

(iii). Capital constraints

$$48398.93X_1 + 34228.09X_2 + 35017.45X_3 + 48744.05X_4 + 45543.07X_5 + 41533.73X_6 + 34500.50X_7 + 58322.58X_8 + 8125X_9 \leq 374413.37 \quad (17)$$

Second constraints: Subsistence constraints

Enterprise production for food and nutrition security and requirement
(iv) Minimum Energy requirement constraints

$X_3 \leq 2.36$……………………………………………………………………………(18)

(v) Minimum fat requirement constraints

$X_4 \leq 0.75$……………………………………………………………………………(19)

(vi) Minimum Protein requirement constraints

$X_5 \leq 1.05$……………………………………………………………………………(20)

$X_9 \leq 0.2$ (16) ……………………………………………………………………………(21)

Third constraints: Subsistence constraints

$X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9 \geq 0$

Global optimal solution found.

Objective value:	1383878.
Infeasibilities:	0.000000
Total solver iterations:	4
Elapsed runtime seconds:	1.08
Model Class:	LP
Total variables:	9
Nonlinear variables:	0
Integer variables:	0
Total constraints:	8
Nonlinear constraints:	0
Total non zeros:	40
Nonlinear non zeros:	0

Variable	Value	Reduced Cost
X1	0.000000	173 841.6
X2	0.000000	110 421.3
X3	2.399624	0.000000
X4	0.7500000	0.000000
X5	3.647876	0.000000
X6	0.000000	72 585.56
X7	0.000000	67 135.88
X8	0.000000	172 297.8
X9	0.2000000	0.000000

Row	Slack or Surplus	Dual Price
1	1383878.	1.000000
2	0.000000	34 291.49
3	16.40397	0.000000

4	0.000000	3.375079
5	0.3962357E-01	0.000000
6	0.000000	-155 170.0
7	0.000000	54 850.0
8	0.000000	-17 298.04

Appendix 23: The Lingo objectives coefficient and RHS ranges under production scenario

Variable	Current Coefficient	Allowable increase	Allowable decrease
X1	23 800.13	173 841.6	INFINITY
X2	39 392.68	110 421.3	INFINITY
X3	152 478.2	72 276.78	15970.70
X4	43 636.57	155 170.0	INFINITY
X5	255 504.5	29 892.78	68689.21
X6	101 885.6	72 585.56	INFINITY
X7	83 597.53	67 135.88	INFINITY
X8	58 837.07	172 297.8	INFINITY
X9	10 553.12	17 298.04	INFINITY

Right hand Side Ranges:

Row	Current RHS	Allowable Increase	Allowable Decrease
2	7.000000	0.4319413	0.1845404E-01
3	246.7900	INFINITY	16.40397
4	374 413.4	1 209.534	85 406.91
5	2.360000	0.3962357E-01	INFINITY
6	0.7500000	0.7200028E-01	0.7500000
7	1.050000	2.797876	INFINITY
8	0.2000000	0.5284112	0.1655601