DETERMINANTS OF TECHNICAL EFFICIENCY OF PIXIE PRODUCTION IN MAKUENI COUNTY, KENYA

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2024

DECLARATION

Students Declaration

This research thesis is my original work and has not been presented to any university or any other institution for any academic award.

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DEDICATION

This work is dedicated to my parents, my brother, and my sisters.

ACKNOWLEDGMENT

My heartfelt thanks to the Almighty God for the gift of life, guidance, and protection during the research thesis writing. Maasai Mara University's School of Business and Economics. Maasai Mara University's Department of Economics. Dr. Simon Mwaura and Mr. Christopher Maokomba for their tireless guidance, selfless dedication, and encouragement in making this research a reality throughout their study supervision. They have provided me with professional and moral support during my master's studies.

ABSTRACT

There exists a great potential for pixie production in Makueni County. The potential is 13,482 Kgs/Ha. However, various constraints such as costly inputs and lack of adoption of sustainable agricultural technologies hinder the production of pixie to the optimum potential. The average production is 4,000-10,000 Kgs/Ha. With regard to pixie farming in Kenya's Makueni County, the study sought to examine the factors that influence technical efficiency. Three specific goals were set out for the study: To determine the technical efficiency of pixie production; To investigate the effects of socioeconomic characteristics on technical efficiency; and to ascertain the influence of sustainable agricultural technologies on technical efficiency. Primary data was collected through the use of questionnaires and interview schedules. The sample size for the study was 311 pixie farmers who were sampled through purposive and simple random sampling techniques. Non-experimental cross-sectional research design was adopted. The Cobb-Douglas Stochastic Frontier model was used to determine the technical efficiency of the pixie farmers whereas a generalized linear regression model was fitted to determine the effect of socio-economic and adoption of sustainable agricultural technologies on technical efficiency. The study results found that the technical efficiency of the pixie farmers ranged from 0.359 to 0.942, with a mean technical efficiency of 0.750. It was discovered that the various socioeconomic characteristics of the farmers affected the pixie farmers' technical efficiency. Based on the results of the stochastic frontier production function, the maximum likelihood estimates of technical efficiency showed that labour, manure, and fertilizer were the factors that led to higher productivity. The mean technical efficiencies for those who adopted irrigation, IPM, and soil and water management were 0.771, 0.761, and 0.752 respectively. The non-adopters mean technical efficiencies were 0.738, 0.72, and 0.737 respectively. The study recommends for provision of extension services by the extension officers to the pixie farmers. To achieve a high pixie output, it is necessary to diversify various sources of revenue and encourage young farmers to take up pixie farming. The government should: Implement policies that facilitate farmers' access to credit; standardize loan repayment terms; and devise plans for those farmers who are highly productive to teach less productive farmers how to apply good agricultural practices and close the large productivity gap.

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ABBREVIATIONS AND ACRONYMS

ASAL-Arid and Semi-arid Lands

ASDS-Agricultural Sector Development Strategy

CIDP-County Integrated Development Plan.

GCP-Gross County Product

GDP-Gross Domestic Product.

GoK-Government of Kenya

IPM-Integrated pest management

KNBS-Kenya National Bureau of Statistics.

MC-Metric Tonnes

MTP-Medium Term Plan.

NGO-Non-Governmental Organization.

OPERATIONAL DEFINITION OF TERMS

Allocative efficiency -Allocative efficiency refers to the ability of a farm to use its inputs optimally given their respective prices and the production technology.

Economic efficiency- Economic efficiency refers to the optimum allocation of resources in the economy that yields an overall net gain to society and is a combination of both technical and allocative efficiency.

Pixie- Pixie fruit is a yellow mandarin orange fruit grafted from lemon seedlings in the class of citrus fruits.

Sustainable agricultural technologies-They are the best agricultural practices aimed at enhancing agricultural productivity while at the same time reducing the adverse environmental effects and safeguarding the natural resources.

Technical efficiency-Technical efficiency is the comparison of the ratio of the observed output to the maximum potential output which can be obtained from the given input and shows the potential of a firm to realize the optimum output level from a given set of inputs.

Value addition-It is the process of increasing the worth of agricultural products through modification and processing to create a competitive advantage before they reach the final consumers.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The study's background describes the origin, spread, and development of Pixie farming in Kenya. It addresses the key management strategies employed in Pixie production, with a focus on Makueni County, where Pixie farming has become significant. The study also explores the economic benefits that Pixie farming provides to Makueni County, enhancing both local income and regional agricultural development.

1.1.1 Origin of pixie farming

Pixie is a yellow-orange fruit. Pixie is grafted from lemon seedlings, where grafting of lemon seedlings is usually done a year after transplanting. Pixie fruits are in the class of citrus fruits. Citrus consists of oranges, lemons, tangerines, and pixie. Citrus, in the horticulture sector, is a crucial fruit crop in the global economy. This is attributed to its role in food and nutritional security. Its origin is from the tropical and sub-tropical regions of Asia and Oceania. Its production is mainly for commercial purposes in many tropical and sub-tropical regions of the world. The total annual production is above 115 million tonnes. China, Brazil, and the United States are the three main citrus-producing nations in the world Spreen et al. (2020). India, Mexico, and Spain are other citrus-producing countries.

With an annual production of almost 20 million tonnes, Brazil is the world's largest producer of citrus fruits. China comes second with an annual production of around 19.6 million tonnes, and the third largest citrus producer is the United States, with an annual production being above 10 million tonnes. Frost (1927) of the University of California

Citrus Research Center developed the pixie mandarin variety, but it was in 1965 when it was released. In the United States, California and Florida are the regions where pixie mandarin is mostly grown. The highest production levels are in California, in the Ojai Valley, where the pixie trees were originally planted in 1960. The region is known for producing quality pixie fruits. The production of the fruits is favourable in warm, Mediterranean climate with mild winters. In Africa, some of the pixie-growing countries are: South Africa, Egypt, Nigeria, Kenya, and Morocco.

1.1.2 Pixie farming in Kenya

The Kenyan economy is driven largely by the agriculture sector, accounting directly for about 26 percent of Kenya's GDP and another 27 percent indirectly (Kashindi, 2021). The agriculture sector creates jobs and employment opportunities for more than 40 percent of the total population and 70 percent of the rural people in the country (Agricultural Sector Development Strategy, 2010-2020). In Kenya, the value of the horticulture-marketed produce during the year 2022 was 146.1 billion (Economic Survey 2023). From the 2024 economic survey, the horticulture exports increased to Kshs 153.7 billion in 2023 (Economic Survey 2024). The rapid increase in the value of the marketed horticultural produce was attributed to an increase in horticulture exports to the international market. Pixie production in the country is practiced mainly in the arid and semi-arid regions of Makueni, Machakos, Kitui, Baringo, and the coastal regions of Kwale and Kilifi (Mulanda, 2022).

1.1.2.1 Management practices

The main requirements of pixie trees for them to realize optimum yield are: water, chemical pesticides, and manure (Muoki, 2022). With proper management of the pixie trees, they start bearing the pixie fruits in their second year after grafting. However, the pixie trees take almost seven years to reach their maturity. The productivity levels of a mature pixie tree range between 60-300 kgs. High yield is achieved in trees where management is done well. To minimize the growth of weeds in the trees, mulching, and planting cover crops are crucial to ensuring optimum output.

1.1.2.2 Ecological requirements

Different soil varieties are crucial for the growth of pixie trees. However, Sandy-loam soil is the best. Deep fertile and well-drained soils with a PH range of 6.5-7.3 are crucial for the attainment of optimum output level. The addition of organic manure into the soil boosts the fertility level. This, as a result, accelerates the growth of the pixie fruits and boosts productivity.

Temperatures affect the development of plants. The ripening of the fruits is facilitated by and favorably influenced by high temperatures. Given their recent discovery, the demand for pixie fruits is higher than the supply in Kenya. However, pixie fruits are extremely sensitive to extremely high or low temperatures. They also result in the pixie fruits becoming scarred and the fruits falling off the trees. They thrive well in low-altitude areas experiencing low to moderate rainfall. Up to 2100 meters above sea level are the growing conditions for the fruits.

The fruits thrive well in arid and semi-arid areas which receive low and moderate rainfall. Given the adverse effects of climate change, resulting in prolonged periods of drought and insufficient rainfall, productivity levels of the pixie decline. This is because upon flowering, the young fruits fall off due to insufficient water. In addition, the adverse effects cause changes in temperatures which lead to an effect on the quality and productivity levels of the pixie fruits. It calls for the need for adoption of sustainable agricultural technologies, such as irrigation, to help increase the pixie yield (Koech & Langat, 2018).

These adverse climatic conditions experienced in the semi-arid areas necessitate the need for farm water management. The climatic conditions result in low annual rainfall, limiting the production levels of the pixie trees. With the adoption of various sustainable agricultural technologies such as irrigation, integrated pest management, and soil and water management techniques, efficiency in pixie production can be achieved (Tripathi et al. 2020). Water management techniques such as mulching and planting cover crops help in the soil-water content, retention of water, and improvement of productivity levels. Mulching involves covering the soil around the trees with crop residues or plant materials to help reduce the evaporation rate, reduce the growth of weeds, and help ensure soil moisture. Cover crops prevent a lot of heat from the sun. Water harvesting is also key to ensuring maximum productivity of pixie especially in areas without access to irrigation water. This is because the harvested water can be used during the dry season. Soil conservation techniques such as putting terraces in the farms, especially sloppy farms are crucial as they help in the prevention of water run-off and to increase soil-water content (Kumawat et al.,2020) The adoption/non-adoption of sustainable agricultural technologies is greatly influenced by the socio-economic and demographic farmer characteristics.

1.1.3 Pixie farming in Makueni County

The agriculture sector in Makueni County accounts for 29% of the Gross County Product (GCP). Despite this, the sector productivity remains below potential due to low adoption of the appropriate technologies, low agricultural investments, high costs of obtaining production inputs and credit, overdependence on rainfall agriculture, inadequate extension services, and high pest and disease prevalence. Additionally, the negative impacts of climate change hinder the productivity of agricultural commodities in the County.

The agricultural sector in Makueni County has been entitled to the responsibility of developing the arid and semi-arid areas. Makueni County is one of the arid and semi-arid areas, hence the relevance of the sector towards developing the county. To achieve this, the county government, through its Vision 2025, has zoned the county based on agroecological suitability.

Table 1.1: Agriculture production per zone

Zone/ Production System	Fruits	Vegetables	Grains	Root Tubers	Industrial Crops	Livestock Production
Upper	Avocado & Passion	Tomatoes, Leafy Vegetables, Peas, French beans	–-	Arrow Roots	Coffee, Macadamia	Dairy & Poultry
Middle	Mangoes, Citrus, Pawpaw, Melon	Asian Vegetables, French Beans	Green Grams, Sorghum, millet, Pigeon Peas, Cow Peas	Cassava, Sweet Potatoes	Cotton, Sisal	Dairy, Poultry, Pasture Development
Lower	Mangoes, Water Melon, Paw Paws	Asian vegetables	Green Grams, Sorghum, Millet, Pigeon Peas, Cow Peas	Cassava, Sweet Potatoes	Cotton, sisal	Dairy, poultry, pasture development and fattening

Source: Makueni County Vision 2025

Zoning was done with much emphasis on increasing agricultural productivity, value addition, and agro-processing. The nine sub-counties were categorized into three zones. Kilungu, Mbooni East, Mbooni West and Mukaa sub-counties are located in the upper zone. Makueni and Nzaui sub-counties are in the middle zone while Kathonzweni, Kibwezi and Makindu sub-counties are located in the lower zone. Much focus has been given to agricultural commodities with high potential in their value chains. With the production of citrus fruits in the County being more favourable in the middle zone, the County government has focused on the development of the fruit niche within the county. This has been achieved by setting targets to double the citrus trees, establishing of certified seedling nurseries, and strengthening the provision of extension services in the fruit production areas. The focus is an increment in the production of citrus fruits (Government of Makueni County vision 2025, 2016)

The County Integrated Development Plan (CIDP) covering the period 2018-2022 has focused on the agriculture sector, with one of its strategies to increase productivity being the development of fruits and other horticultural crops and marketing. Through this, fruit nurseries, fruit orchards, and fruit producer-farmer cooperatives would be established and linked to the Makueni fruit processing plant through tailor-made extension services. The current County Integrated Development Plan (CIDP) covering the period 2023-2027 reveals a rapid improvement of the horticulture value chain in Makueni County. Diversification of farmers from mangoes into citrus fruit production has caused the area under citrus fruits to increase by 31% from 6570 Ha in 2018 to 8628 Ha in 2021. The production levels have also increased by 95% from 38,961 MT in 2018 to 75,854 MT in 2021. The high prices citrus has been fetching have acted as an incentive for the farmers to diversify into the citrus from mangoes.

Citrus fruits are crucial to their contribution to GDP. Citrus production has experienced rapid growth over the past years. According to the Ministry of Agriculture data, the number of households growing citrus in the County is 27,006. The estimate of the pixie households is thirty percent. Table 1.2 shows the acreage, production, and value of citrus production in Makueni County for the period between 2017-2021.

Table 1.2: Citrus acreage, production, and value in Makueni County

Year	**2017**	**2018**	**2019**	**2020**	**2021**
Acreage (Ha)	6,564	6,570	6,650	8,371	8,660
Production (MT)	38,963	38,963	39,985	202,728	192,335
Value 000’	974,087	974,107	974,150	4,777,700	2,493,125

Source: Department of Agriculture, Irrigation, Livestock, Fisheries & Cooperative Development, County Government of Makueni

The production of pixie is important among the residents and County government. Despite this growth, there still exists a high potential for increment in productivity of the fruits. They have the potential of producing 13,482Kgs/Ha in Makueni County. However, despite the high potential for high productivity, the average of most of the small-scale farmers in the county is 4000-10,000Kgs/Ha (Munywoki et al. 2022). This makes the study on technical efficiency crucial, as the potential of the farm to realize an optimum output level from the given set of inputs will be determined.

Pixie production has a lot of promise in Makueni County. Wote, Nzaui, and Mumbuni are the County's principal growth regions. Pixie mandarin oranges are farmed economically in these regions, where they augment household earnings. During the year 2018, the area under the production of the fruit increased from 622 to 2,296 Ha in 2021. The rapid expansion of the area under production makes the County one of the leading suppliers in the country. Despite the rapid expansion of the area under production of pixie in the country, several factors hinder the production of high-quality pixie fruits.

Lack of sufficient knowledge on the type of chemical pesticides to apply to control the pests and diseases is a major threat to the productivity of the fruits. The pixie fruits require frequent spraying of chemical pesticides as they are prone to attacks by pests and diseases. Timing of the spraying of the chemicals in the fruit is very key, as the delay in the chemical pesticides causes a decline in the production of the fruit. The result will be inefficiency in their production.

With Makueni county being an arid and semi-arid area, it is prone to pests and diseases as thrip insurgence in the pixie fruits is very high. If not well controlled, productivity can significantly be reduced. This calls for the need for agronomists and extension officers to provide adequate and useful knowledge on the best chemical pesticides to use. Nationally, the current extension staff -to- farmer ratio is 1:1000, while at the county level is at best 1:2000 (Kinyua, 2019). The extension staff-to-farmer ratio hinders the promotion and adoption of farm technologies. They can help ensure efficiency in production through the dissemination of knowledge to the farmers on how they can better use the integrated pest management practices to obtain maximum productivity gains.

Inefficiency in the use of inputs, inadequate use of modern farm technologies, and poor access to credit are other constraints that lead to low pixie productivity. The high costs of inputs and low-quality inputs are some reasons behind the inefficiencies in pixie production. Increased pixie output can be made possible through the use of inputs in the best way possible.

1.1.4 Economic benefits of pixie in Makueni County

The production of fruits is of great relevance. This is because they have the potential to contribute up to 18 percent of the average household income of the farmers (Wangithi, 2019). Pixie fruits are of nutritional value as they are a source of vitamin A and vitamin C, which helps strengthen the immune system. Pixie farming in the region is beneficial as it has helped in the eradication of poverty among the farming households through the household incomes. Many families have been able to sustain themselves in the County through the farming of the pixie. The average initial cost of starting a hectare of a pixie farm is around Kshs 150,000 for the purchase of seedlings and labour for planting. Despite their severity to pests and diseases and the high cost of maintenance through the purchase of inputs, the pixie fruits retail at an average price of Kshs 80 per kilogram at the farm gate level. For farms operating efficiently, an acre of land is capable of generating a turnover of up to Kshs 1,200,000 in a year, making the production profitable. The earnings from the pixie fruit in Makueni County during the year 2019 was Kshs. 595 million (Maundu, 2021).

The study was carried out among the pixie farmers in Makueni County. The study's main goal was to examine the factors that influence technical efficiency in the production of pixies in Makueni County, Kenya. The study aims to identify the parameters that impact the technical efficiency of pixie production to achieve the highest possible output level.

1.2 Statement of the problem

The ideal production of pixie fruits in Makueni County is 13,482 Kgs/Ha, which is attainable with the optimum utilization of the production inputs. However, the average production among the farmers ranges between 4,000-10,000 Kgs/Ha (Munywoki et al. 2022). The likelihood of pests and diseases, costly inputs, limited access to financial facilities, unpredictable weather patterns, and inadequate extension services all play a role in the production gap that exists between the County's optimum production and actual production. Previous studies such as Madau (2020) and Ho et al. (2022) have shown production inefficiencies in citrus production. However, they found conflicting causes for the inefficiency. The study by Madau, 2020 found pests and diseases as a major cause of inefficiency in pixie production. They cause the flowers to drop off during flowering, reducing the fruits below their optimum potential. Inaccessibility to credit access and poor extension services are other constraints. Poor extension services make the farmers lack relevant knowledge on the adoption of sustainable agricultural technologies. However, the study by Ho et al. (2022) found the inefficiency to be attributed to various socio-economic characteristics of the farmers such as gender roles. The roles restrict ownership of resources, causing variation in productivity (Kijima & Tabetando, 2020). The combination of these variables has created an environment viable for the underproduction of Pixie in Makueni. The average production among small-scale pixie farmers is between 4,000-10,000 Kgs/Ha, from a potential of 13,482 kgs/ha (Munywoki et al. 2022). With the average production being far below the potential production in the County, the implication is that pixie production is not at its optimum. In addition, the conflicting causes of inefficiency create the need for the study to examine the determinants of technical efficiency among the pixie households. The study will, therefore, lead to an understanding of the factors contributing to the underproduction of pixie in Makueni County. Previous studies on citrus (Madau, 2020 and Ho et al. 2022) have been conducted at different times and regions. Given that technical efficiency can differ in different times and regions and also that a study on technical efficiency and its determinants in pixie production in Makueni County has not been conducted, justifies the need for the study.

1.3 Objectives of the study

1.3.1 General objective

To analyze the determinants of technical efficiency in pixie production in Makueni County, Kenya

1.3.2 Specific objectives

i. To determine technical efficiency in pixie production in Makueni County, Kenya
ii. To examine the effect of socio-economic characteristics on technical efficiency in pixie production in Makueni County, Kenya
iii. To determine the effect of adoption of sustainable agricultural technologies on technical efficiency in pixie production in Makueni County, Kenya

1.4 Research questions

i. What is the technical efficiency in pixie production in Makueni County, Kenya?
ii. What are the effects of socio-economic characteristics on technical efficiency in pixie production in Makueni County, Kenya?
iii. How does the adoption of sustainable agricultural technologies impact technical efficiency in pixie production in Makueni County, Kenya?

1.5 Significance of the Study

Presently, much focus is being placed on improvement in pixie productivity in the county (Makueni County Annual Development Plan, 2019). This will be achieved through various interventions in the agriculture sector. With agriculture being a devolved function, the findings of the study will be of great significance in Makueni County in developing policy strategies to ensure that Makueni County sells in its agriculture sector from the pixie fruits. The study is guided at attaining two sustainable development goals. These include; End hunger, achieve food security and improved nutrition and promote sustainable agriculture through increased pixie productivity and the second one to end poverty in all its forms everywhere. This would be achieved through the sale of pixie fruits. The study findings hope to be useful to National and County Governments, policymakers as well as researchers. To the National and County Government and the policy makers, the findings are useful in developing a policy document, strategies, and standards and guidelines to address the inefficiencies in production. Good policies and guidelines will also go a long way in promoting improved pixie production in the ASAL region, with which the County is located. To the researchers, the study will help them review the work and look for research gaps that will necessitate further research.

1.6 Scope of the study

The research was restricted to the pixie farmers in Makueni County. The information was obtained from the pixie farmers in both Nzaui and Makueni sub-counties. The findings, discussions, conclusions, and recommendations were drawn from analysis of primary data which was obtained from the pixie farmers in the two sub-counties. The data was collected from May-August, 2023.

1.7 Justification of the study

The study findings contribute to new knowledge to the body of existing knowledge. Production of pixie is of great relevance given the arid and semi-arid climatic conditions of Makueni County which favour their production. This is despite the climatic conditions discouraging the production of other food crops. Several empirical research on technical efficiency in citrus such as Madau (2020) and Ho et al. (2022) and other agricultural commodities Ambetsa et al. (2020), Mwangi et al. (2020) and Nalini et al. (2020) have been conducted in different regions and times. Through the study on the determinants of technical efficiency in pixie production in Makueni County, information will be updated with regard to the factors which impact the technical efficiency of the pixie farmers. The current productivity level in pixie production in Makueni was determined, given that productivity changes at different times and regions. Thus, the study advances our knowledge of pixie production's technical efficacy in Makueni County, Kenya.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This section provides a review of the work done by others which is relevant to the study. The chapter comprises the introduction, the concept and measurement of efficiency, theoretical literature, empirical literature, an overview of the literature, research gaps, and conceptual framework. The chapter appreciates the work done by others on efficiency in agriculture and how the study intends to stand out and build on the previous research studies on efficiency in agricultural production.

2.1 Theoretical literature

2.1.1 Production theory

Frisch (1964) came up with the production theory. The production theory is a microeconomic theory. It focuses on production of goods from a given set of inputs. The theory of production explains how much inputs or factors of production will be employed in production of a given set of output. The theory aims at output production at the least cost possible. Following optimal utilization of the inputs in the production process, maximum output is realized and hence technical efficiency. This will help the producer realize maximum gains from the production. All technically effective manufacturing methods are included in the production method. The technology of an industry or a farm is represented by the production function. The production function specifies how inputs cooperate in order to produce a particular output level. For a farm using "n" inputs, the general form of the production function is given as:

$q = f(X_1, X_2, X_3, \ldots.., X_n)$……………………………………………………Equation 2.1

Where;

q=output level

$X_1, X_2, X_3, \ldots\ldots, X_n$ represent the inputs used to produce output

The production function describes the production process. The theory of production describes the farms operating efficiently and those operating inefficiently. If a farm is operating by use of various production inputs, and uses less of some inputs as compared to another without using other additional units, then that farm is said to be technically efficient. That farm doing production with more production inputs is said to be technically inefficient compared to the other. Thus, the theory of production focuses only on the efficiency of production.

The theory of production is of great relevance to this study as it indicates the technology of production employed by the farm, through the production function. Through this, the relationship between the inputs and output is described. The technological relationship between the cause variables and the outcome is shown by the production function. The production function shows the maximum output capable of production, given the inputs available. It is an efficiency relation. Thus, the production function is of great relevance in the study of technical efficiency in pixie production. This is because, through it, inputs will be transformed towards the production of output, example, the amount of organic fertilizer and inorganic manure used to produce a given unit of pixie by the farmer. Maximum gains and efficiency in production will also be realized. In addition, the production function requires no change in production technology used. This makes the production theory suitable for the study of technical efficiency. The production theory will help ensure technical efficiency in pixie production and hence eliminate the inefficiencies that exist in pixie production.

Despite the production theory's relevance in determining technical efficiency, it has some critiques. Production theory usually assumes gradual changes in technology over time or models it as a fixed factor in the short term. This does not take into consideration the disruptive, quick inventions that can drastically change production methods. In addition, externalities resulting from production activities, such as social costs or environmental harm, are frequently disregarded by production theory.

2.1.2 Cobb-Douglas Production Theory

The Cobb-Douglas production function theory was used by Cobb and Douglas in the explanation of the production theory. The link between inputs and outputs is displayed by the Cobb-Douglas production function. It shows the maximum output, from a given combination of inputs. It is one of the most commonly used functions in efficiency studies. The Cobb-Douglas production function is expressed in the form:

$Q = AL^{\alpha}K^{\beta}$ ……………………………………………………………Equation 2.2

where L=quantity of labour used, K=quantity of capital used; which for purposes of fitting the model can be incorporated to include: seedling, manure, fertilizer, and chemical pesticides. A, α, and β are constants which are positive. A is the efficiency parameter which shows the state of the technology used. The efficiency parameter measures the change in output which is not caused by the inputs. α and β are the distribution parameters. They reflect the output elasticity, which is the change in output as a result of a change in labour or capital.

For estimation purposes, the Cobb-Douglas production function can be transformed into a logarithmic form to treat it as a linear relationship. The transformed equation thus becomes;

$\log Q = \log A + \alpha \log L + \beta \log K$ ……………………………………………Equation 2.3

The above function is a linear function with unknown parameters log A, α and β.

The Cobb-Douglas production function theory is beneficial in the study of technical efficiency due to the reason that estimation of the production function is easy. This is despite the reason that the production function is constrained by the assumption of the constant elasticity of substitution between the inputs.

2.1.3 Stochastic Frontier Approach Model (SFA)

The SFA method was introduced by Aigner et al. (1977) and Van Den Broeck (1977). The stochastic frontier analysis allows for statistical noise. Estimation of stochastic frontiers is done only by econometric techniques. In SFA the premise of producers being restricted to a single output is made. This is a result of production technology constraints or the aggregation of various inputs to a single output index. The stochastic frontier model is parametric and takes into consideration random errors as opposed to the DEA model which is non-parametric. Factors beyond the control of the farmer e.g., variations in weather conditions have an impact on the level of output. This makes it possible to determine if variations in the production from the output frontier are a result of external random factors or specific farm factors. The equation for the stochastic production function can be expressed as shown in 2.4:

$y_j = f(x_i \beta). \exp(v_j) . TE_j$ ………………………………………………Equation 2.4

Where:

$f(x_i\beta).\exp(v_j)$represents the stochastic production frontier

$\text{Exp}(v_j)$ is the random shocks, which are beyond the farmer's control.

TE_j is the technical efficiency of the jth farmer

Therefore, $TE_j = \frac{y_j}{f(x_i\beta).\exp(v_j)}$……………………………………………Equation 2.5

The technical efficiency will be one if output production is at $\{f(x_i\beta).\exp(v_j)\}$. If not, there exists technical inefficiency.

The stochastic frontier approach requires functional form specification and distributional assumptions to estimate the technical inefficiency (Ruggiero, 1999). The error term for the stochastic frontier production model comprises of the inefficiency and random effects, which are beyond the control of the production unit. With the stochastic frontier, estimation of standard error and hypothesis testing is possible.

To measure technical efficiency using this model, the production function is used. There are various production functions; with Cobb-Douglas and the Translog functional forms being the most frequently used. They both have their advantages and disadvantages. The choice of the best production function is made after taking into consideration both the inefficiency and random error factors.

2.2 The concept and measurement of efficiency

Farrell (1957) defines the concept of efficiency as the potential of a farm to achieve an optimum output level from a given set of inputs. The efficiency is measured by yield per hectare. According to him, efficiency comprises two components: technical and allocative efficiency. Technical efficiency measures the potential of a farm to realize the maximum possible output from a given set of inputs. A farm's ability to maximize production from a specific set of inputs is referred to as its technical efficiency. A farm's ability to generate a given level of production while requiring the fewest possible inputs is another definition of it. A farm producing at the frontier is termed as technically efficient. Deviations from the frontier make the farm inefficient.

Technical efficiency is concerned with the comparison between the observed and optimum output values and inputs in a production unit (Sadoulet & Janvry, 1995). It can be described as a comparison between the ratio of the observed output to the highest potential output that can be obtained from the given input, the ratio of the lowest potential to the observed output that is necessary to produce a particular set of output, or as a combination of the two. A farm is termed to be technically inefficient if, given the inputs utilized in production, the maximum possible output is not realized or from its output, more production inputs than required are used.

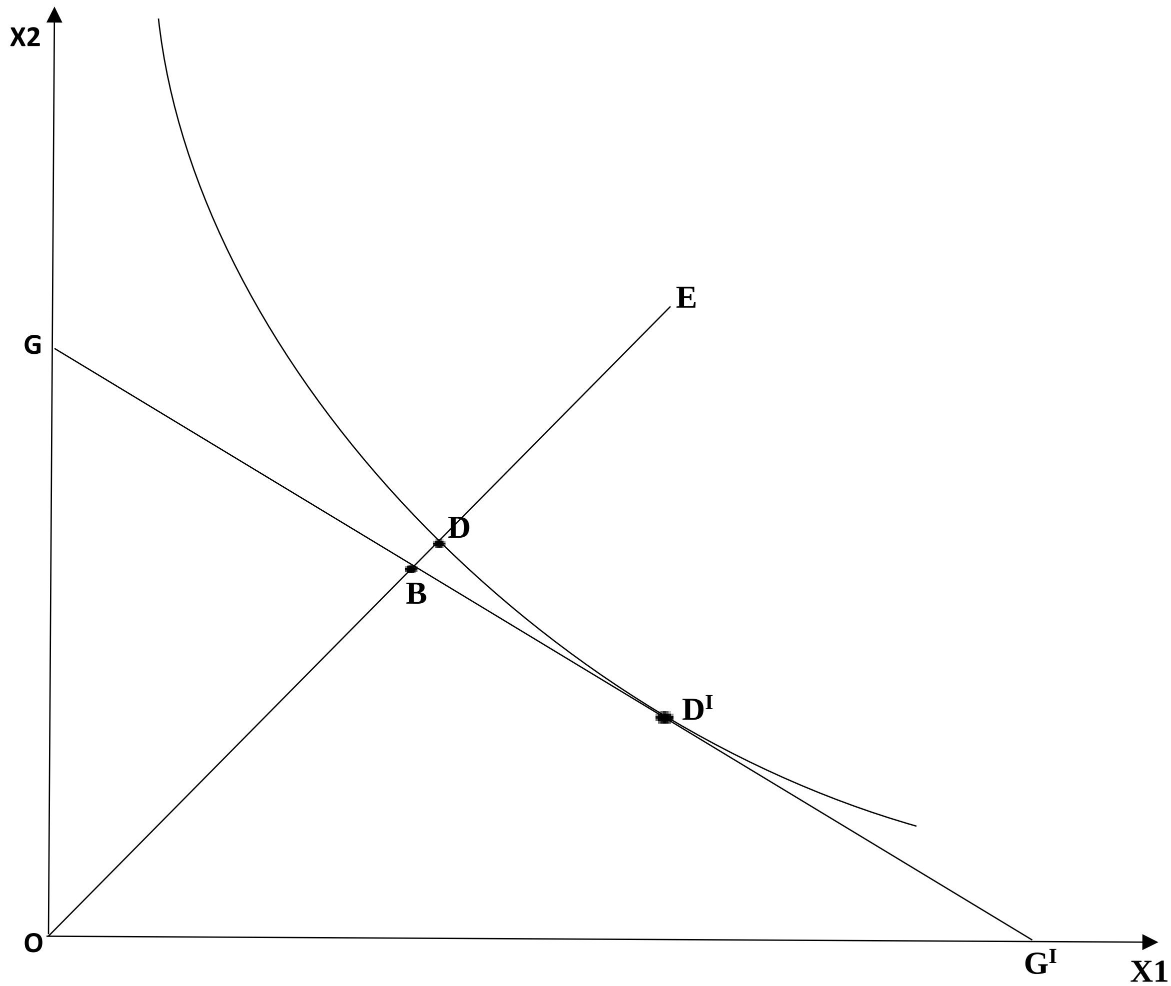
Allocative efficiency shows the ability of a farm to use its inputs optimally given their respective prices and the production technology. A farm is termed to be allocatively inefficient if it is not utilizing the combination of inputs minimizing the production cost at a given output (Sadoulet & Janvry, 1995). The two combined, technical and allocative efficiency, comprise economic efficiency. The concepts of productivity and efficiency are commonly used in the measurement of a farm's performance. Agricultural productivity represents the effectiveness of the production process, under the premise of technical efficiency (Ateka, et al. 2018).

Policies should therefore focus on increasing efficiency. Better use of the existing technologies can result in improved agricultural productivity with regard to changing to a new technology (Khudoynazarovich, 2021). Therefore, technical efficiency quantifies a farm's ability to produce at its highest level given a specific set of inputs. It represents the proportion by which inputs can be reduced without reducing the output level. At a given technological level, technical efficiency relates the physical input with the optimum output level achievable. The efficiency is measured by yield per hectare. The efficiency of production can be associated with the costs of production. Technical inefficiency can be caused by high costs of production. A firm is said to be technically efficient if its technical efficiency is one. But, if the technical efficiency of the firm is less than one, then the farm is technically inefficient (Tenaye, 2020).

In the measurement of efficiency, Farrell came up with two approaches: the input-oriented approach and the output-oriented approach.

2.2.1 Input-oriented efficiency measures

In this approach, two inputs (X_1 and X_2) are used in the production of a single output (Q), under the premise of constant returns to scale. The isoquant curve of an efficient farm makes it possible for the measurement of technical efficiency. Any farm producing output at any point on the isoquant is technically efficient. With the premise of a farm producing at point E in Figure 2.1, the same output level by the fully efficient farm is produced.



Source: Timothy et al 2005
Figure 2.1: Technical and allocative efficiencies using input-oriented approach

Technical inefficiency is represented by the distance DE. This distance represents the amount with which the inputs used in the production process should be cut without lowering the output level. The ratio $^{DE}/_{OE}$ can also be used to express the technical inefficiency. The technical efficiency will be measured by the ratio: $TE = {}^{OD}/_{OE}$. The value ranges from 0-1, with 1 representing a technically efficient farm. The farm is technically efficient at point D because production is at the isoquant. The farm is inefficient if the value is less than one.

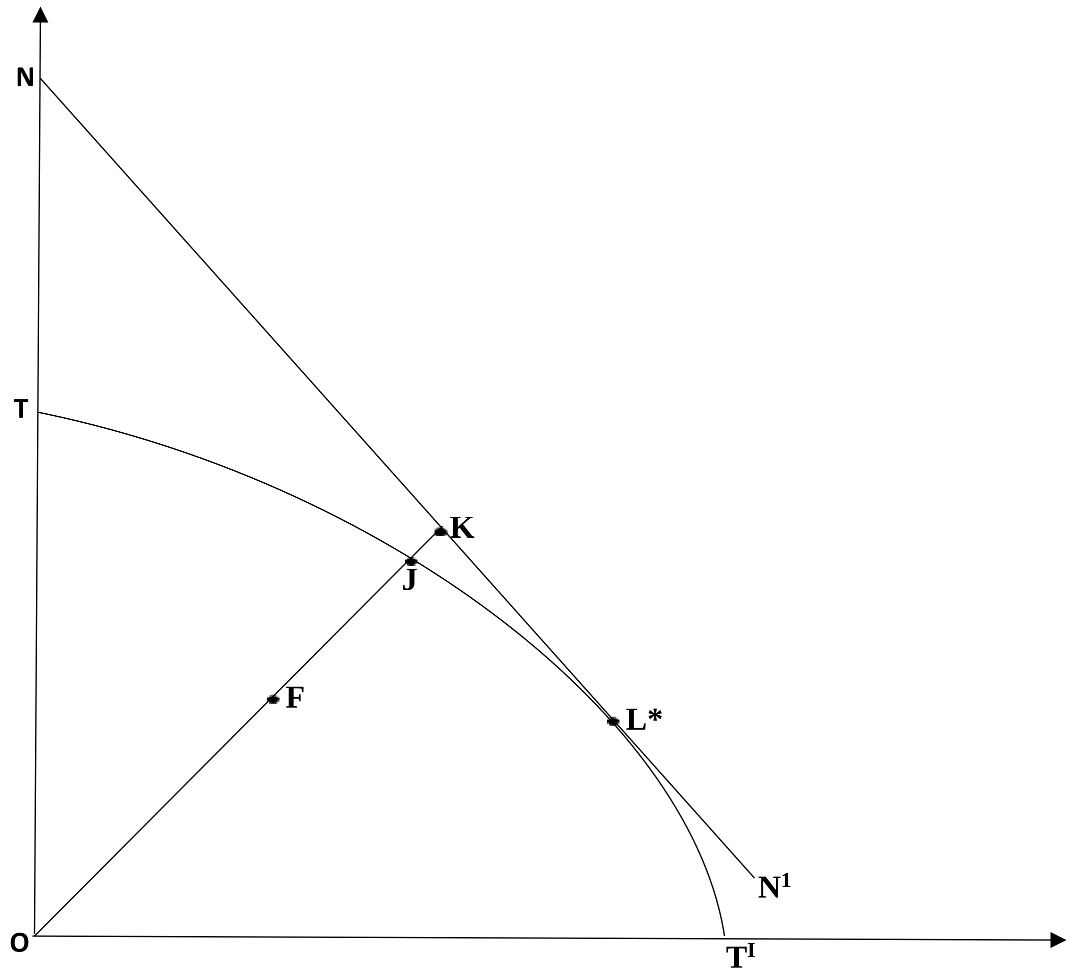
Input prices are used to calculate allocative efficiency. At D^1, the iso-cost line is tangent to the isoquant curve. The iso-cost line GG^1 indicates all possible quantities of inputs X_1 and X_2, that, at their respective prices, could be used by the farm while still costing the same amount. This is because the slope of the iso-cost line represents the input price ratio. The allocative efficiency is thus determined by $AE = {}^{OB}/_{OD}$. If the production process takes place at the allocatively and technically efficient point D^1, as opposed to the technically efficient but allocatively inefficient point D, then the distance BD represents the reduction in production costs.

The combination of technical and allocative efficiency yields economic efficiency:

$$E.E = {}^{OD}/_{OE} \times {}^{OB}/_{OD} = {}^{OB}/_{OE}.$$

2.2.2 Output-oriented efficiency measures

This approach is used to determine the level with which output can be increased without alteration of the inputs used in production. Figure 2.2 is used to explain the concept of both technical and allocative efficiency using the output-oriented approach. Two outputs q_1 and q_2 and one input is involved. A production possibility curve (TT^1) represents the different combinations of two outputs that are produced from the use of a given level of input (X_1). A farm producing at any point on the PPC is technically efficient. At point F, the farm is operating inefficiently. The distance between F and J is technical inefficiency, representing the amount of output that could be increased without requiring extra inputs. $TE = {}^{OF}/_{OJ}$



Source: Timothy et al,2005
Figure2.2: Technical and allocative efficiencies using output-oriented approach

With price information, allocative efficiency can be determined. The iso-revenue line is represented by the line NN^1 and it is tangent to the PPC at L*. Line OF intersects the iso-revenue line at K. Thus, AE will be; $AE = {}^{OJ}/_{OK}$. The economic efficiency will be the product of technical and allocative efficiency. Thus, it will be represented by: $E.E = {}^{OF}/_{OJ} \times {}^{OJ}/_{OK} = {}^{OF}/_{OK}$.

2.3 Empirical literature

Various researches have been conducted by different researchers. The need for efficiency researches is to help in the identification of the causes of inefficiencies in production and the need for policy reforms in the agriculture sector.

2.3.1 Determination of technical efficiency in pixie production

This section provides literature review from previous studies on technical efficiency. With the use of frontier model, the production inputs are incorporated as the predictor variables whereas the output as dependent variables to generate technical efficiency. Consequently, the part examines research on production inputs and technical efficiency.

Muchara and Oluwatayo (2018) conducted a study on technical efficiency of citrus farmers in South Africa using a stochastic frontier approach. Primary data was collected with the use of structured questionnaires from a sample of 150 citrus farmers. The study findings indicated that access to credit facilities, farm size, and extension services had a positive impact on the technical efficiency. In addition, the production inputs labour and fertilizer application were found to have a negative effect on technical efficiency among the citrus farmers. For purposes of improving technical efficiency in citrus production, the study recommended for better access to credit and extension services provision.

Wambui and Majiwa (2019) conducted a study on the evaluation of technical efficiency of edible oil production using stochastic production frontier approach. Cross-sectional research design was adopted. A sample size of 50 canola farmers was selected using simple random sampling technique. The study adopted the Cobb-Douglas production function given its widespread use in the farm efficiency studies, both in developed and developing countries. The study was conducted to evaluate the efficiency of production in Kenya where amount of canola production, the land size under production, quantity of fertilizer, labour and canola seeds were measured. The study findings indicated a mean technical efficiency of 0.97; with an implication that there only existed a 0.03 potential for increasing canola production. The actual canola production was 1930.65 kg/ha from a potential production of 1965.92 kg/ha; indicating a yield gap of 35.26 kg/ha. The study also examined the socio-economic characteristics of the canola farmers. Different aspects affecting canola production such as gender, age, number of households, years of schooling and training services were examined. The study found out that the production of canola in the area was profitable and recommended for the need for policy makers to promote more production of the crop in the area in order to replace crops such as maize and coffee which had lower returns.

Munywoki (2022) carried out an explorative survey on challenges facing citrus farmers in Makueni County, Kenya. The design was crucial in gaining insights in understanding the problems faced by farmers. Primary data was collected from 150 citrus farmers and other key informants from the Makueni sub-county. The sample was purposively selected. The research revealed that there were difficulties associated with citrus production in Kenya, particularly in Makueni County. Problems with pests and diseases, inadequate or nonexistent agricultural extension services, low prices due to fierce competition from Tanzania, inadequate farmer organizations, insufficient sustainable commercialization, high production input costs, restricted access to credit facilities, unpredictable weather patterns, ineffective marketing, subpar land use and road infrastructure, and traditional tenure system were among the difficulties. Most of the farmers had not received any extension services in the present, and for those who had received them, the services were provided by extension officers from agro-chemical companies whose motives were to contribute to increased profitability of their products through increased sales. Also, with pesticides being prevalent, most of the farmers faced the challenge of ensuring the quality of the fruits through proper spraying of the fruits. This was attributed to the high costs of the farm chemicals which were expensive to purchase. Therefore, the result was huge losses. The findings are important in the development of appropriate regulations to expand citrus production in the nation.

2.3.2 The effect of socio-economic characteristics on technical efficiency

Madau (2015) conducted research on technical and scale efficiency in Italian citrus farming. A sample size of 107 Italian citrus farms was used, with the Data Envelopment Analysis being conducted using the output-oriented approach. A comparison between the Stochastic Frontier Approach (SFA) and the Data Envelopment Analysis (DEA) was made. Greater efficiency was on scale efficiency. The mean estimated technical efficiency was 0.711; while the mean estimated scale efficiency was 0.894. With the imposition of the non-increasing returns to scale condition, the study found out that most farms exhibited increasing returns to scale. Thus, scale inefficiency was a result of farms operating at sub-optimal levels. There was a 28.9% potential for increment of citrus production at the current technological conditions. Tobit regression model was used to explain both the technical and scale efficiency variations. Maximum likelihood estimates for the preferred model were obtained and a generalized likelihood ratio test was used to test the proposed efficiency model. The study found the returns to scale to be increasing at 1.14. The implication was that the citrus farmers needed to increase their production by 14.4% on average to increase their productivity. The study examined different causes of inefficiency such as the age of the farmer, the farm size, the altitude of each farm, the farm location, and the number of plots of land. The socio-economic characteristics are a determinant of farmer skills and experience.

Ambetsa et al. (2020) conducted research on technical efficiency and its determinants in sugarcane production among smallholder sugarcane farmers in Malava Sub-County, Kenya. Stochastic frontier analysis and tobit regression analysis were applied with the use of STATA. Questionnaires were used to collect data from a sample of 384 farmers. Systematic random sampling was used. The study findings indicated a mean technical efficiency value of 0.7069. The implication was that, the average sugarcane farmer had a 29.31% potential of improving sugarcane production. The maximum likelihood estimates indicated that fertilizer use, labour, size of the farm, and seeds had a significant positive effect at 1% level in the determination of technical efficiency. The socio-economic characteristics studied were education, family size, credit access, farming experience, and extension services. The tobit regression analysis showed that they had a positive and significant effect on their contribution to technical efficiency. The recommendations of the study were for the formulation of policies that would focus on the provision of quality extension services, education to the smallholder sugarcane farmers, increased credit access, and a review of contract engagement policies for the sugarcane farmers.

Ho et al. (2022) conducted research on production efficiency and effect of sustainable land management practices on the yield of oranges in northwest Vietnam. Two stage random sampling method was used to collect primary data from a sample of 174 orange groves. To examine the differences in yield and efficiency levels, the Data Envelopment Analysis model was employed. The approach was suitable given that it can be applied where there exist various inputs and outputs with different units. In addition, DEA has both the input orientation and output orientation. The mean technical efficiency was 79%; indicating that there existed a 21% potential to increase the efficiency of production through technical efficiency and scale adjustments among the farming households. This could be achieved through raising the production scale. With technical efficiency score ranging between 0 and 1, tobit regression model was applied to show the effect of socio-economic characteristics on efficiency levels. The determinants of the production of oranges studied were: ethnicity, extension, education, credit, experience, and sustainable land management use. All the socio-economic characteristics, apart from credit, had a significant positive effect on the improvement of production efficiency. The reason why access to formal credit sources did not significantly affect production efficiency was attributed to that only a few farmers had obtained credit for agricultural production.

2.3.3 The effect of adoption of sustainable agricultural technologies on technical efficiency

Baglan et al. (2020) did a study on towards cleaner production: certified seed adoption and its effect on technical efficiency. To achieve cleaner output, the study concentrated on the deployment of innovative agricultural technologies. Cross-sectional data was used in the evaluation of the adoption of certified seeds and its effect on efficiency gains. A sample size of 225 farmers was used in the study, who were selected using both multistage and simple random sampling techniques. Cross-sectional research design was adopted. Stochastic production frontier was applied for robust estimation where the findings revealed that increased crop income, credit access, and education to have had a positive impact on the adoption of certified seeds. In addition, distance from the market and membership in cooperatives had a negative effect. The study recommended the adoption of certified seeds towards increased production levels.

Mwangi et al. (2020) conducted research on technical efficiency in tomato production among the smallholder farmers in Kirinyaga County, Kenya, using the production function approach. The study adopted a cross-sectional survey design. Data on the use of inputs, production of tomatoes, and demographic characteristics of the farmers was collected from a sample of 384 farmers. Multistage Stratified and probability proportionate to size sampling procedures were used. The maximum likelihood estimation procedure was used to help enhance efficiency levels and to estimate the production frontier by the use of the stochastic Cobb-Douglas production function. In the determination of the farmer characteristics which cause technical efficiency, tobit multiple regression was used. The average technical efficiency was 39.55%. There was a potential to increase tomato production by more than 60 percent. Greater efficiency was found to exist in the production of tomatoes in the greenhouse than in the production from an open field system. Technical efficiency was significantly and positively affected by the production system, extension services, household size, type of seeds, fertilizer, and market information. The study findings found that the access to extension services was not adequate. Only 21.87% of the respondents had access to extension services despite the importance of extension service provision to disseminate knowledge to the farmers on the adoption of the current farm technologies. This would help achieve technical efficiency and ensure maximum output in tomato production, given the current technology.

Nalini et al. (2020) conducted a study on the sustainable agricultural practices, input use, and technical efficiency in Florida citrus production. The stochastic frontier analysis (SFA) approach was used to estimate technical efficiency in Florida citrus production and to examine the impact of sustainable agricultural practices on technical efficiency. The study used a sample size of 194 citrus farmers. The research findings indicated that the adoption of sustainable agricultural technologies such as irrigation and integrated pest management (IPM) caused an increase in technical efficiency in citrus production. The adoption of integrated pest management resulted in a 6.9 percent increase in technical efficiency while the adoption of irrigation was attributed to a 4.4 percentage increase in technical efficiency. The adoption of sustainable agricultural technologies was found to cause a reduction in production input costs. IPM adoption reduced pesticide costs by 21.5% while precision irrigation reduced the cost of water by 7.3%. In order to enhance citrus production, the study advised citrus growers to implement sustainable farming practices.

Moura (2021) conducted a study on the adoption of sustainable agricultural practices and technical efficiency in citrus production in Brazil using both the stochastic frontier approach model and the probit model. The stochastic frontier approach model was used to estimate the technical efficiency in citrus production while the probit model was used to analyze the effect of adoption of sustainable agricultural practices on technical efficiency. The study findings indicated that the adoption of sustainable agricultural practices positively impacted technical efficiency. Farmers adopting sustainable agricultural practices were found to be efficient in their production process. In addition, the study revealed that credit access and education level of the farmers had an impact on technical efficiency. The study recommended the need for the increased acceptance of the farmers to adopt sustainable agricultural practices for the increased production of citrus.

Dahal et al. (2023) conducted a study on Determinants of adoption of multiple sustainable agriculture practices among mandarin producing farmers in Salyan District of Karnali Province, Nepal. Primary data was collected, with face-to-face interview being used to collect information from 120 mandarin producing farmers. Both quantitative and qualitative approaches were used to collect data from the farmers. The findings revealed that the adoption of sustainable agricultural technologies such as irrigation, mulching, and biological pest control mechanisms to have contributed to higher production among the farmers. Several factors; age, gender, and schooling of household head, access to the Internet, distance of market for farm inputs, and availability of human labor were found to have increased the chances of adopting the sustainable agricultural technologies among the mandarin farmers. The study recommended effective formulation and implementation of farm-level policies which is necessary to ensure the spread of integrated nutrient and pest management techniques.

Wangithi et al. (2021) conducted a study on the adoption and dis-adoption of sustainable agriculture, with a case of farmers' innovations and integrated fruit fly management in Kenya. Survey data from 165 growing households selected using simple random sampling technique was used. The study findings indicated that 90 percent of the farmers rely on chemical pesticides to manage pests. The study also found out that 35 percent of the farmers used indigenous methods to manage the pests. The uptake of integrated pest management strategies among the farmers was very low, despite their knowledge of IPM strategies. Regression results indicated IPM to have a positive relationship with gender, education of household held, knowledge of pests, training, use of a minimum of one non-pesticide practice to manage fruit flies and contact with an extension officer. The study recommended increased access to training programs and extension services to enhance the adoption of sustainable management practices.

2.4 Overview of the literature

Different research studies have used different models to estimate technical efficiency. The different models have also focused on how the socioeconomic and agro-climatic characteristics influence the efficiency levels. The study of efficiencies in different regions is crucial in designing good policies towards increased production. The different studies have indicated how various factors impact efficiency in different areas.

Ho et al. (2022) empirically evaluated the production efficiency and effect of sustainable land management practices on the yield of oranges in northwest Vietnam. They employed Data Envelopment Analysis model. The empirical findings indicate that the current level of production efficiency was affected by the socio-economic characteristics. However, technical efficiency analysis using tobit regression model revealed that ethnicity, extension services, education, experience and sustainable land management use positively and significantly had an effect on production efficiency. Conversely, credit had a detrimental impact. They concluded the socio-economic characteristics to be very crucial in the study of production and technical efficiency. Mwangi (2020) empirically investigated technical efficiency in tomato production in Kirinyaga County, Kenya while employing the production function approach. The findings reveal that the socio-economic characteristics reviewed to have had a significant positive effect. How the production inputs were used also had an effect on the overall efficiency levels. Baglan et al. (2020) critically examined the adoption of certified seeds and its effect on technical efficiency using cross-sectional data. Stochastic frontier model was applied and the study findings indicated that increased crop income, credit access and education to have had a positive impact on the adoption of certified seeds. The study recommended on the adoption of certified seeds towards increased production levels. Wambui and Majiwa (2019) empirically evaluated technical efficiency of edible oil production, employing stochastic production frontier approach. An analysis was conducted on the socio-economic factors that impact the technological efficiency of canola production. They concluded that to encourage more production, good policy measures be put into place. Muchara and Oluwatayo (2018) conducted a study on technical efficiency of citrus farmers where examination of how production inputs influence efficiency was examined. Suggestions were offered to enhance the availability of extension services and financial access.

From the review of the prior studies, it has been found out that both parametric and non-parametric approaches have been used in the efficiency studies. The findings reveal that production inputs and most of the socio-economic characteristics to have had a positive and significant effect on the efficiency of production, while others have had insignificant effects. In addition, most studies have recommended the need for putting in place good policies in place to help boost both production and efficiency levels.

2.5 Conceptual framework

The conceptual framework provides a visual picture mostly in the form of a graph that illustrates the core concepts of the study and shows the interrelationship between the variables. The agricultural policies are the intervening variables as they have an impact on agricultural activities and indirectly influence pixie productivity. The availability and accessibility of production inputs are determined by the policies in place. Through the theory of production, the way in which the inputs of production are utilized in the production of the pixie output is determined. The theory helps ensure that maximum output is realized, while at the same period focusing on the efficiency of production. An effective production system will be achieved. In addition, the agricultural policies promote a favourable environment for the farmers to adopt sustainable agricultural technologies. The farmers will, therefore, adopt sustainable technologies such as irrigation and integrated pest management techniques. The efficient production of pixies is the result of adopting sustainable agricultural technology and making the best use of production inputs. Technical efficiency is also influenced by socioeconomic variables. With efficiency in pixie production achieved, the pixie farmers benefit from both social and economic benefits. This is realized in terms of increased yields, which in turn contribute to high income among the pixie farmers. With high income among the pixie farmers, poverty is eradicated.

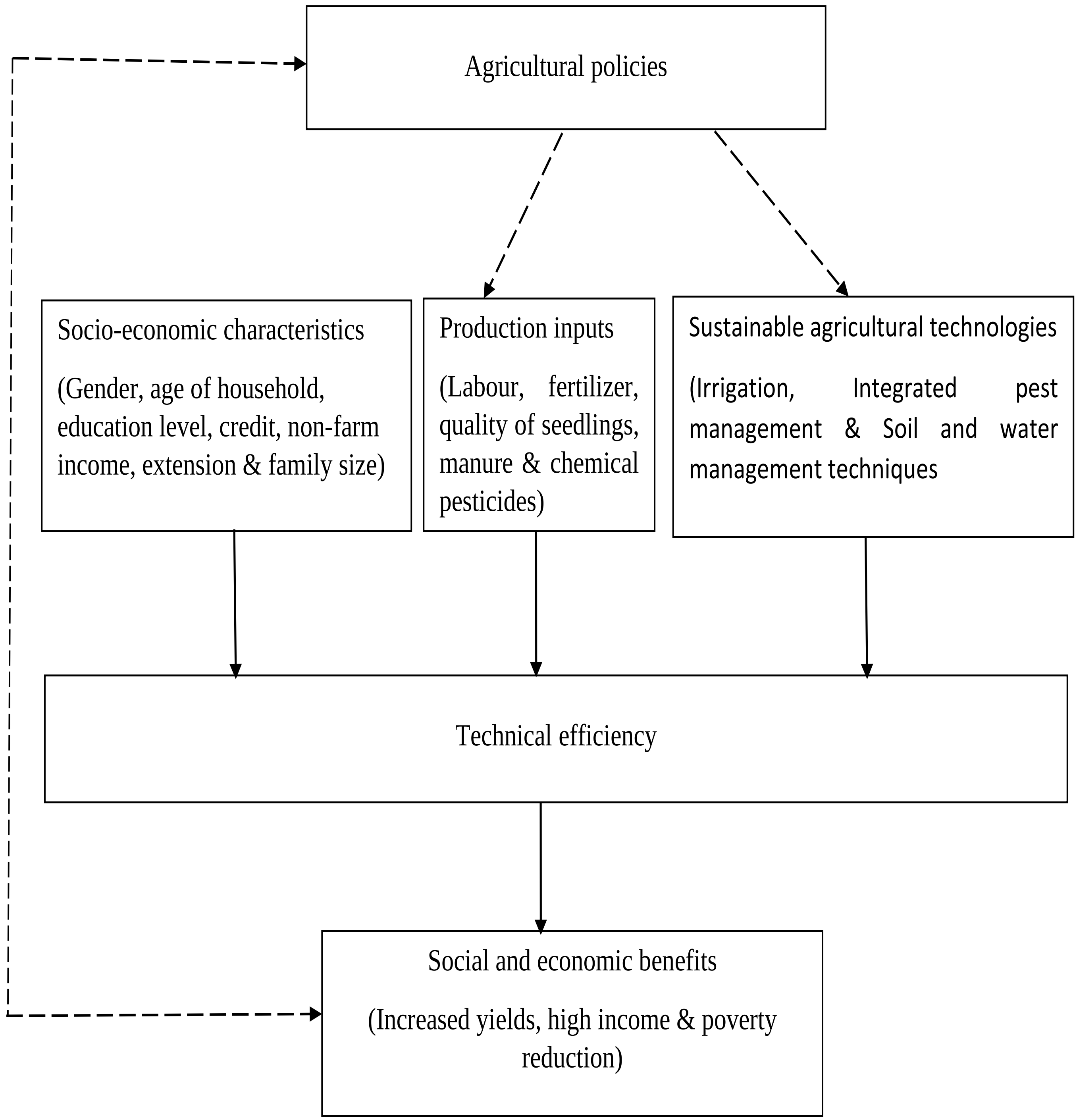


Figure 2.3: Conceptual framework

2.6 Research Gap

The literature review reveals gaps in the area of technical efficiency in pixie production, with which the study intended to fill. Wambui and Majiwa (2019) studied the evaluation of technical efficiency of edible oil production. The study focused on canola production. Mwangi et al. (2020) conducted a study of technical efficiency in tomato production among small-scale farmers in Kirinyaga County and Ambetsa et al. (2020) on technical efficiency and its determinants in sugarcane production among the smallholder sugarcane farmers in Malava sub-county, Kenya.

Muchara and Oluwatayo (2018) study on technical efficiency of citrus farmers in South Africa, Madau's (2020) study on technical and scale efficiency in Italian citrus farming, Moura's (2021) study on adoption of sustainable agricultural practices and technical efficiency in citrus production in Brazil and Ho et al. (2022) study on production efficiency and effect on sustainable land management practices on the yield of oranges in northwest Vietnam are similar to the current study.

However, it has not yet been established whether the causes of technical efficiency would remain consistent, considering that the studies were conducted in varying geographical regions. In addition, the effect of the socio-economic characteristics on technical efficiency may have varying results. The conflicting causes of technical efficiency and the yield gap between the actual and potential output create the need for the study to have an understanding on the factors influencing the technical effectiveness of Makueni County's pixie production. The causes of inefficiency would, thus, be identified.

Given that efficiency can vary from year to year, there is need to conduct a study on technical efficiency in pixie production to determine whether it is increasing or decreasing and the current productivity level. From the succeeding analysis, it is evident that a study on technical efficiency in pixie production, with the case of Makueni County, is not a duplication of similar studies. The study would, thus, contribute to new knowledge on the determinants of technical efficiency in pixie production in the country.

CHAPTER THREE

METHODOLOGY

3.1. Introduction

The study's instruments and research methodologies are presented in this chapter, with the following key topics of interest; the research design, description of the study area, population of the study, sampling frame, sample and sampling techniques, research instruments, pilot testing, data collection procedure, model specification, functional form selection, data processing and analysis and definition and measurement of variables.

3.2. Research Design

The study was a non-experimental cross-sectional research design. Non-experimental cross-sectional research design is an approach to research where data is gathered at one time from a particular population or sample. The design does not involve manipulation of variables. The research design was helpful since it made it possible to gather data on the home farm, socioeconomic, and demographic traits; which are crucial in efficiency analysis. Given that the focus of the study was to analyze the determinants of technical efficiency in pixie production while determining the technical efficiency among pixie households, the non-experimental cross-sectional research design was appropriate. The research design helps in the understanding of the current characteristics of the population. The design entails no control of the environment, as information is obtained as it naturally occurs. Several studies on technical efficiency such as Lampach et al. (2021) and Wanzala et al. (2023) have used non-experimental cross-sectional research design.

3.3. Description of study area

Makueni County, which is the study area, is located in the Eastern part of the country. Makueni County lies between Latitude 1° 35' and 2° 59' South and Longitude 37° 10' and 38° 30' East. The county borders Kitui to the east, Machakos to the north, Kajiado to the west, and Taita Taveta to the south. It is comprised of nine Sub Counties which include: Makueni, Kathonzweni, Mbooni East, Mbooni West, Nzaui, Mukaa, Kilungu, Makindu, and Kibwezi. The County has a population of 987,653 persons (Kenya National Bureau of Statistics, 2019). Out of this, 489,691 are male and 497,962 are female. The average population density in the County is 120.8 persons/km^2. The County is mainly arid and semi-arid and experiences a bimodal rainfall pattern. The short rains occur in the period between October-December and the long rains in March to May. The average temperature in the County ranges between 15^0C – 26^0C and annual rainfall ranges between 250mm to 400mm per annum in the lower regions of the county and the higher region receives rainfall ranging from 800mm to 900mm per annum.

Agriculture is the main economic activity in the County. Through zoning, different areas are suitable for different agricultural products. The climatic conditions of the County favour horticulture, with the main horticultural crops being vegetables and fruits. The main fruits grown in the County are: mangoes, avocados, citrus, pawpaw, banana, and watermelon. Pixie fruits, in the class of citrus, are grown mainly for commercial purposes. They are produced both for local and export markets. The arid and semi-arid climatic conditions experienced in the county favour the production of pixie fruits. Pixie fruit has been in the recent years crucial in the County. The fruit creates income among the residents of the County. In 2020, the income generated from the pixie fruits in the county was 595 million. The area under production of pixie has also increased from 622 hectares in 2018 to 2296 hectares in 2022. The pixie productivity of a mature pixie tree ranges between 60-300 kgs, with the performance being well in deep fertile, well-drained soils whose PH ranges between 6.5-7.3 in the arid and semi-arid regions. High temperatures are favourable for the ripening of pixie. They thrive well in low-altitude areas which receive low to moderate rainfall and in altitudes of up to 2100 M above the sea level. The study was conducted in Makueni County due to the reason that the average production among the farmers is far below the potential level. Thus, the need for the study to analyze the determinants of technical efficiency in pixie production in the study area and to determine the current productivity level.

3.4. Population of the study

The study population encompassed all the pixie households in the study area. They comprise the 8,102 households who farm pixie in the study area. Target population study is a study of a group of individuals taken from the general population who share a common characteristic, such as age, sex, or health condition. The target population comprised all the pixie household farmers in the County from which the inference was made. The target population was 311 pixie households.

3.5. Sampling technique and sample size

Both purposive and simple random sampling techniques were used in the study. Nzaui and Makueni Sub-Counties were purposively selected. This was due to their production of pixies for commercial purposes. In addition, the two Sub-Counties are located in the middle zone of the County which is favourable for the production of pixie fruits. A sample size of 311 pixie farmers was selected using a simple random sampling technique. Fischer's formula as in Kothari (2004) was used in the sample size determination. The formula is as shown in equation 3.1:

$$n_0 = \frac{z^2(p)(q)}{E^2} \text{……………………………………………………………Equation 3.1}$$

where;

n_0 is the sample size, z=1.96 which is the tabulated z value for 95% confidence level, p is the assumed proportion of residents who farm pixie, q is the assumed proportion of residents who do not farm pixie and E is the margin of error. With the premise of 30% probability that the farmers have the characteristics being measured, the sample size was determined as shown below in equation 3.2:

$$n_0 = \frac{1.96^2(0.3)(1-0.3)}{0.05^2} = 323 \text{…………………………………………………Equation 3.2}$$

For purposes of correcting the infinite sample size in to a finite sample, the equation 3.3 below for finite population correction proportions was used. It is used to reduce the sample size slightly.

$$n = \frac{n_0}{1+\frac{(n_0-1)}{N}} \text{……………………………………………………………Equation 3.3}$$

Where:

n is the sample size and N is the population size. From the above equation, we have:

$$n = \frac{323}{1+\frac{(323-1)}{8102}} = 311 \text{…………………………………………………Equation 3.4}$$

3.6. Sampling Frame

The sampling frame comprised of pixie farmers selected from Nzaui and Makueni Sub-Counties. The proportional sampling allocation technique (Cochran, 1977) was used in the selection of sample size of pixie farmers from the two Sub-Counties. The formula is shown below in Equation 3.5:

$$n_i = \frac{N_i \times n}{N} \qquad \text{Equation 3.5}$$

where;

n_i is the number of pixie households interviewed in the Sub-Counties selected, N_i is the population of households in the selected Sub-Counties, n is the sample size for the study and N is the total household population in the study area. From this, the sampling frame is as shown below:

Table 3.1: Sampling frame

Sub-County	Households farming pixie	Sample
Nzaui	3993	153
Makueni	4109	158
Total	8102	311

Source: Department of Agriculture, Irrigation, Livestock, Fisheries & Cooperative Development, County Government of Makueni

3.7. Research instruments

Both primary and secondary data were employed in the investigation. Questionnaires and interview schedules were used to gather the primary data. A questionnaire was used to obtain information from the pixie farmers. The survey instrument provided a guide to the researcher while covering the technical efficiency of agricultural production of the pixie farmers. The key areas of focus were to determine how various variables influenced the efficiency of the production in the county. Interview schedules were used to collect data on illiterate and semi-illiterate respondents to obtain sufficient information from them. Secondary data, where necessary, was used in the study.

3.8. Pilot testing

Pilot testing was conducted on 20 pixie farmers in Kitikyumu area, which was not one of the study areas. The pixie farmers have the same characteristics as those from the study area. This helped in the avoidance of the carry-over effect. After pre-testing, refinement, modifications, and improvements were made to the instruments.

3.9. Data collection procedure

Utilizing questionnaires and interview schedules that the researcher gave to the respondents, primary data was gathered. Interviewing the pixie farmers was crucial for obtaining information on demographic characteristics and socio-economic characteristics which were assumed to cause variation in efficiency of production. The questionnaires consisted of questions which intended to answer the questions relating to the objectives of the study. The questionnaires were administered to the literate respondents while the interview schedules to the illiterate/semi-illiterate respondents. The questions were both close-ended to enhance uniformity and open-ended to ensure that maximum data was obtained. The questions were administered to the small-scale pixie farmers. Also, secondary data was used from different publications to help in deriving effective results. The researcher was involved in the data collection process.

3.10 Data analysis

Both descriptive and econometric analysis were employed. Descriptive statistics such as mean, standard deviation, and percentages were used to give a summary of both socio-economic and demographic characteristics of pixie farmers and the frequency distribution of technical efficiency levels. The econometric analysis was applied as the stochastic frontier analysis model was applied to analyze the technical efficiency among the pixie farmers while a generalized linear regression model was fitted to determine the effect of socio-economic characteristics and adoption of sustainable agricultural technologies on technical efficiency.

3.10.1 Cobb-Douglas Stochastic Frontier Approach

With the study focusing on the technical efficiency in pixie production, a Cobb-Douglas Stochastic Frontier Approach model was applied. The approach has been recently used in the study of technical efficiency for agricultural products in different countries, under different production systems and agroclimatic regions. This is based on the reason that the technical efficiency is affected by factors that are random and beyond the control of the farm. The model divides the error term into two. It differs from the other parametric methods due to the inclusion of a random error term and an individual inefficiency term. The random term takes into consideration the potential of emergence of some shocks which can result to a lag between the observed production and the optimum output, given the production technology. The stochastic frontier analysis connects the output to the number of inputs used via the production technology. The general form of the stochastic frontier model is shown in equation 3.6:

$$y_j = f(x_{ij}\beta). \exp(v_j) . TE_j \text{ .... Equation 3.6}$$

The model binds the output by the random variable $exp\{X_{ij}\beta + V_j\}$. In the specific model of the Cobb-Douglas stochastic frontier model, the natural logarithm is introduced. Through introduction of the natural logarithm, the non-linear multiplicative function is transformed into a linear additive function. By making the Cobb-Douglas stochastic frontier model linear, the estimation process is simplified. In addition, it helps improve the interpretability of the coefficients. The coefficient represents elasticity; which is the percentage change in output attributed to a one-percentage change in the inputs used. The specification model was expressed as:

$$\ln Y_j = \beta_0 + \sum \beta_{ij} \ln X_{ij} + e_j \qquad \text{Equation 3.7}$$

Where: ln-The natural logarithm, j - j^{th} farmer in the sample size, i - i^{th} input, Y_j-Output of pixie production of the j^{th} farmer, Xij-i^{th} input used by the j^{th} farmer and $e_j = V_j - U_j$-Its error term, taking into consideration two components

V_j is believed to be the realization of a symmetric random variable with a mean of zero. U_j is the inefficiency term and it is always positive. The implication is that the observed output will always be equal to or lower than the technically efficient output. When there exist no inefficiencies, we have a simple production function that assumes technical efficiency.

Single-stage maximum likelihood estimator was used to obtain the parameters of β_i for efficient estimates. It also helped in obtaining the parameter coefficients on in/efficiency effects. The approach adopted was in the form of a Cobb-Douglas function. This was despite the limitations associated with it, including the restrictive features such as constant returns to scale and elasticity of production being equal to one. Other functions used in efficiency studies such as the trans log function have proved to be inferior in comparison to the Cobb-Douglas production function due to the multicollinearity and the degree of freedom problems associated with it.

For purposes of generating technical efficiencies, the Cobb-Douglas stochastic frontier model was used. The dependent variable was the pixie output per household in (Kgs/ha), and the independent variables were the inputs used in the production of the pixie fruits. They included: seedlings, amount of manure, amount of fertilizer, the total labour force, and chemical pesticides used.

From this, the Cobb-Douglas production function was of the form:

$$\ln Y = \beta_0 + \beta_1 \, lnX_1 + \beta_2 lnX_2 + \beta_3 lnX_3 + \beta_4 lnX_4 + \beta_5 lnX_5 + V_j - U_j \ldots\ldots \text{Equation 3.8}$$

Where: Y is pixie output, X_1 is seedling, X_2 is labour used, X_3 is manure, X_4 is fertilizer and X_5 represents chemical pesticides. V_j is the two-sided error term, while U_j is the one-sided error term/the technical inefficiency. The technical inefficiency was found by subtracting the technical efficiency from one.

From the Cobb-Douglas stochastic frontier model, the technical efficiency was determined by the following formula in equation 3.9:

$$TE_j = {}^{Y_j}\!/_{Y_j *} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.9}$$

Where: TE_j is the technical efficiency of the jth household in pixie production

Y_j is the actual output of the jth household in pixie production

Y_j* is the frontier output of the j^th^ household in pixie production

From the technical efficiencies derived from the frontier output, the regression equation can be developed. The effect of the socio-economic farmer characteristics and adoption of sustainable agricultural technologies on technical efficiency can be determined. The linear function of the socio-economic and management factors helps in the determination of the predictor variables' impact on technical efficiency. The original equation incorporates the effect of the socio-economic characteristics on technical efficiency. It was determined from equation 3.10 below:

$$TE = \delta_0 + \sum_{k=1}^{6} \delta_k Z_{kj} \quad \text{.......... Equation 3.10}$$

Where: TE is technical efficiency effect, δ_k represents the independent variable coefficients and Z_j are the characteristics of the socio-economic variables of the farm explaining the efficiency of the j^{th} farmer.

With adoption of the sustainable agricultural technologies affecting technical efficiency, the generalized regression model with the dependent variable being technical efficiency and independent variables being the socio-economic farmer characteristics can be modified. Three sustainable agricultural technologies: irrigation, integrated pest management techniques, and soil and water management are included in the model. To fit them in the regression model, they are converted into a dummy variable for both the adopters and non-adopters of the specific sustainable agricultural technologies. Thus, we have equation 3.11:

$$TE = \delta_0 + \sum_{k=1}^{6} \delta_k Z_{kj} + \sum_{l=1}^{3} \alpha\, m_j \quad \text{.......... Equation 3.11}$$

Where:

TE is technical efficiency effect, δ_k presents the independent variable coefficients, Z_j are the socio-economic characteristic variables of the farm explaining the efficiency of the j[th] farmer, α represents the predictor variable coefficients and m_j are the sustainable agricultural technologies adopted by the j[th] pixie farmer. The specific model was expressed in equation 3.12:

$$TE = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + \alpha_1 m_1 + \alpha_2 m_2 + \alpha_3 m_3 \quad \text{Equation 3.12}$$

Thus, technical efficiency was explained by the following determinants: Z_1 is off-farm/other sources of income, Z_2 represents extension services, Z_3 is gender, Z_4 is age, Z_5 is education level and Z_6 represents credit access. m_1 represents irrigation, m_2 is integrated Pest Management techniques and m_3 is soil and water management techniques.

3.11. Definition and measurement of variables

The section provides information on the variables used in the measurement of technical efficiency and their definitions. The unit of measurement of each of the variables is also included in the table. The table is presented in Appendix 1

CHAPTER FOUR

DATA PRESENTATION AND ANALYSIS

4.1 Introduction

This chapter presents the research findings, results, and discussions. The chapter starts with an explanation of descriptive results on the socio-economic and demographic characteristics of the sampled pixie farmers, production inputs used, and the sustainable agricultural technologies adopted. In the second section, we have results on the explanation of the study's goals. The first goal was achieved through the application of a stochastic cobb douglas production frontier model. The second and third objectives were answered by the use of a generalized linear model. The regression analysis model was fitted with the technical efficiency being the dependent variable whereas the socio-economic characteristics and sustainable agricultural technologies being the independent variables.

4.2 Demographic and socio-economic characteristics of the sampled households

Table 4.1: Descriptive Statistics of the Study Sample

Dummy & categorical Variables			
Variables	Values	Frequency	Percentage %
Gender	Male	243	78.1
	Female	68	21.9
Age	21-30 years	57	18.3
	31-40 years	100	32.2
	41-50 years	111	35.7
	51 years and above	43	13.8
Education level	None	23	7.4
	Primary	22	7.1
	Secondary	111	35.7
	College	63	20.3
	University	92	29.6
Source of income	Farming	156	50.2
	Business person	62	19.9
	Employment income	93	29.9

Source: Authors computation 2023

Descriptive statistics in the form of frequency tables were used in the explanation of the socio-economic and demographic characteristics and explanation of the variables used in the stochastic production frontier. Table 4.1 above provides a summary of the data.

4.2.1 Gender

From the information on gender distribution of the respondents, male were 243 which accounted for 78.1% while the female respondents were 68, accounting for 21.9%. The majority of the pixie farmers were male and this could be attributed to the various responsibilities of female off the farm which make them have little time to engage in agricultural activities. Also, the traditional land tenure system where majority of the men have land ownership rights as compared to the female could be a reason for the greater percentage of farmers being male.

4.2.2 Age

Age is crucial in efficiency studies as it is an indicator of the experience level of the farmers and has an impact on how the farmers adopt or fail to adopt sustainable agricultural technologies. The majority of farmers age-wise are active. From the sample of 311 pixie farmers, 57 of them are within the age group of 21-30 years accounting for 18.3%. 100 respondents (32.2%) within 31-40 years, 111(35.7%) of the respondents between 41-50 years, and 43 respondents (13.8%) were 51 years and above. Young farmers are more adaptive to change and more likely to adopt sustainable agricultural technologies as compared to older farmers. They have high chances of exploring new ideas and farming innovations in production activities.

4.2.3 Education level

The level of education of the farmers is an important indicator of adoption of sustainable agricultural technologies among the farmers. Educated farmers are more likely to adopt the sustainable agricultural technologies, and hence realize higher productivity compared to the illiterate farmers. From the survey results, 23 (7.4%) of the respondents did not achieve any level of formal schooling, 22 (7.1%) had acquired the primary education, 111 (35.7 %) had learnt up to secondary level, 63 (20.2%) had obtained the college education level and 92 (29.6%) had attained university education. With education, the farmers are equipped with basic knowledge to apply in pixie farming.

4.2.4 Source of income

The farmers were asked their sources of income where 156 pixie farmers (50.2%) reported that they derived their income from mainly farming activities, 62 pixie farmers (19.9%) from business enterprises and 93 pixie farmers (29.9%) derived income from employment income. Majority of the farmers derived income from agricultural activities. Income derived from other sources apart from agricultural activities could also be used in pixie farming and thus contribute to pixie productivity.

4.2.5 Household size

The household size has a mean of 4.56 persons per homestead with the minimum number being 1 and the maximum number being 8. The mean almost conforms to the county's average household size of 4 .0 (KNBS 2019). The household size is crucial in provision of labour force for agricultural activities. The standard deviation of the household size is 1.564. Families with large household members are expected to realize greater pixie output as the members provide the required labour force in pixie farming. It is a cheap source of labour.

Table 4.2: Household size

	N	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Household size	311	1	8	4.56	0.096	1.564

4.2.6 Farm characteristics

The farm characteristics discussed were distance of the farm from home, area under production and the harvest realized per hectare of land. The results are given in Table 4.3.

Table 4.3: Farm characteristics

	Minimum	Mean	Standard Deviation	Standard Error of Mean	95.0% Lower CL for Mean	95.0% Upper CL for Mean	Maximum
Distance of the farm from home (kms)	0.1	3.26	3.414	0.194	2.88	3.64	20
Total area under pixie production (Ha)	0.5	1.86	1.353	0.077	1.71	2.01	8
Output realized (Kgs)	1200	10329.23	11252.465	640.130	9069.64	11588.81	62500
Quantity of Pixie in Kgs/Ha	1500	5051.76	2288.221	130.172	4795.62	5307.90	12780

4.2.6.1 Distance of the farm from home

The distance of the farm from home is a key indicator in efficiency study as more time would be spent in production activities for a farm near home and no costs would be incurred to move to the farm. The minimum distance of the farm from home was 0.1 kilometers while the maximum distance of the farm from home was 20 kilometers. More attention was expected on farms near home than those far from home as much time would be spent caring for farms near home than those far from home, given the costs of transportation and time spent to go to the farm.

4.2.6.2 Area under production

The land area under production is a crucial indicator in measuring production efficiency. High output is realized from farmers with large tracts under production compared to farmers with small areas because of economies of scale benefits. The minimum area under production of pixie was 0.5 hectares while the maximum area under farming of pixie was 8 hectares. The mean average area under production was 1.86 while the standard deviation was 1.353. The low acreage under production of pixie among the farmers could be attributed to the resource constraints where it is much easier for production on a small scale where the farmer has difficulties in credit access.

4.2.6.3 Output realized

The minimum output in Kgs/Ha realized from the respondents was 1500 while the maximum output was 12,780 kilograms. Inefficient agricultural practices and inadequate resources among the pixie farmers could be attributed to the low output. In addition, high output was realized by efficient farmers and this could be as a result of adoption of the sustainable agricultural technologies. The mean output in kgs/ha was 5051.76 kgs and the standard deviation was 2288.221 kgs. The results are consistent with the findings by Munywoki et al., (2022) whose findings revealed the average production levels to range between 4,000-10,000 Kgs/Ha.

4.3 Description of the production variables

Descriptive statistics of the production inputs used in pixie farming which include; labour, fertilizer, quality seedlings, manure, and chemical pesticides are indicated in Table 4.4.

Table 4.4: Descriptive Statistics of the production input

Dummy & categorical Variables

Variables	Values	Frequency	Percentage %
Labour	Family	94	30.2
	Hired	141	45.3
	Both	76	24.5
Fertilizer	Yes	123	39.5
	No	188	60.5
Seedlings	Non-certified	214	68.8
	Certified	97	31.2
Manure	Yes	280	90.0
	No	31	10.0
Chemical pesticides	Yes	296	95.2
	No	15	4.8

Source: Authors computation 2023

4.3.1 Labour

Hired labour was the main source of labour, constituting 45.3% of the total labour force used in the farming of pixie. Family labour constituted 30.2% of the total labour force while the remaining percentage of 24.5% was sourced from both family and hired labour. Majority of the farmers rely on external labour in pixie farming. This could be attributed to the reason that production of pixie fruits is mainly for commercial purposes. The farm may gain from specialized skills or expanded labor capacity if a significant portion of the labor is hired; this could result in higher yields and overall farm production. Family labour is a cheap source of labour. This helps in reduction of the production cost, as the farmers do not hire labour for pixie farming.

4.3.2 Fertilizer application

The research results indicate a low adoption of fertilizer in pixie farming as only 39.5% of the respondents applied fertilizer. This percentage comprised 123 pixie farmers while the remaining 188 pixie farmers (60.5%) did not apply fertilizer during the production season. There is low adoption of fertilizer in pixie farming despite the importance of fertilizer adoption in providing the nutrients required in pixie fruits. The low adoption rate could be attributed to the lack of credit access among the pixie farmers to purchase the fertilizers which are costly.

4.3.3 Quality of Pixie Seedlings

The respondents obtained their seedlings from either certified or non-certified seedling companies. 214 pixie farmers who accounted for 68.8% of the respondents sourced their seedlings from non-certified seedling companies while the remaining 97 pixie farmers (31.2) of the respondents from certified seedling companies. Certified seedlings are of higher quality, yield more, and are resistant to pests and diseases. They are resilient to climate change effects. The majority of the farmers sourced their seedlings from non-certified seedling companies. They may experience lower yields and higher production costs as a result of attacks by pests and diseases.

4.3.4 Application of manure

The findings showed that the vast majority of farmers applied manure in their pixie trees as 280 pixie farmers (90%) applied and only 31 pixie farmers (10%) failed to use manure. The quantity of manure applied was measured in terms of wheelbarrows/tree where the minimum quantity applied per tree was one wheelbarrow and the maximum was four wheelbarrows. The mean quantity of farmyard manure used was 2 and the standard deviation was 1. The application of manure in the pixie orchard provides the trees with the required nutrients for fruit development and growth. The result will be high pixie output.

4.3.5 Chemical pesticides

The findings indicated that 296 pixie farmers (95.2%) applied chemical pesticides during the production season. Only 15 respondents who accounted for 4.8% did not apply chemical pesticides. The high use of chemical pesticides by the farmers was expected to have positive impacts on the productivity levels of the farmers since it would help combat the pests and diseases that affect the fruits. However, the timing of spraying and the frequency with which the pesticides are applied would have the most significant effect on productivity.

4.4 Adoption of sustainable agricultural technologies

Table 4.5 comprises the descriptive statistics on the sustainable agricultural technologies that were examined in the study which included: irrigation, integrated pest management techniques, and soil and water management techniques.

Table 4.5: Descriptive Statistics of the sustainable agricultural technologies

Dummy Variables			
Variables	Values	Frequency	Percentage %
Irrigation	Yes	107	34.4
	No	204	65.6
Integrated Pest Management	Yes	214	68.8
	No	97	31.2
Soil & Water Conservation	Yes	251	80.7
	No	60	19.3

Source: Authors computation 2023

4.4.1 Irrigation

The findings revealed that 107 pixie farmers (34.4) adopted irrigation whereas the remaining 204 farmers (65.6%) never adopted irrigation in pixie farming. There was a low adoption of irrigation as one of the sustainable agricultural practices in pixie farming. Low adoption of irrigation by the majority of the respondents could have been one of the causes of low pixie productivity among the farmers in the region. With irrigation, the overreliance on rain-fed agriculture is eradicated. Non-irrigated farms tend to be more vulnerable to climate change effects. This affects the quality and quantity of the fruits, as they fall off due to lack of water. To help reduce the yield variabilities, there is need for the pixie farmers to adopt irrigation.

4.4.2 Integrated Pest Management Techniques

Various integrated pest management techniques were adopted in pixie farming: commercial biopesticides, cultural practices, physical control, and the use of plant extracts. 214 pixie farmers adopted the integrated pest management techniques. This comprised 68.8% of the pixie farmers while 97 pixie farmers (31.2%) never used the integrated pest management techniques in pixie farming. IPM helps reduce overreliance on chemical pesticides by combining various pest control methods such as biopesticides, cultural practices, and plant extracts. This can lower the cost of chemical inputs, making farming more cost-effective and improving profit margins. IPM techniques, in addition, help attain environmental sustainability.

4.4.3 Soil and water conservation

Soil and water management techniques were the third sustainable agricultural technology under consideration. Several soil and water management techniques were considered: Mulching, the use of semi-circular bunds, planting of cover crops, water harvesting, and terracing. 251 pixie farmers who accounted for 80.7% adopted different soil and water management techniques while the remaining 60 pixie farmers (19.3%) never adopted the soil and water management techniques. The high adoption rate of the different soil and water management techniques could be a cause of higher technical efficiency among the pixie farmers. Farmers who adopt these management techniques are likely to benefit from long-term farm sustainability. These practices help prevent soil erosion, improve nutrient cycling, and conserve water, ensuring the land remains productive over time. This contributes to the long-term economic viability of their farms. In contrast, farmers who do not use soil and water management techniques may experience soil degradation, reduced fertility, and water scarcity, leading to declining productivity and potential economic losses over time.

4.5 Determination of technical efficiency in pixie production

The first objective of the study was to determine the technical efficiency in pixie production in Makueni County. The stochastic frontier model was fitted to with the pixie output per hectare being the dependent variable and the production inputs used in pixie farming as the independent variables to determine the frontier output.

Table 4.6: Parametric estimates of the stochastic frontier production function

Ln harvest	Coefficient	Std. Err.	z	P>z	[95% conf. interval]	
Ln seedling	0.016	0.023	0.680	0.495	-0.061	0.030
Ln man hours	0.342	0.039	8.820	0.000	0.266	0.418
Ln manure	0.346	0.060	5.780	0.000	0.229	0.463
Ln fertilizer	0.015	0.008	1.950	0.052	-0.000	0.030
Ln pesticide	0.036	0.024	1.500	0.134	-0.083	0.011
constant	7.817	0.217	35.970	0.000	7.391	8.243
Sigma u	0.400	0.040	9.930	0.000	0.328	0.487
Sigma v	0.219	0.021	10.290	0.000	0.181	0.265
lambda	1.825	0.057	32.270	0.000	1.715	1.936

Source: Authors computation 2023

The stochastic frontier model's output is displayed in Table 4.6. The inputs under consideration are: seedlings, labour, manure, fertilizer, and chemical pesticides. Of the five production inputs, three of them (labour, manure, and fertilizer) were significant. Labour and manure were significant at 99% confidence level whereas fertilizer was significant at 90% confidence level. The three production inputs had positive coefficients thus contributing positively to increased pixie productivity. The coefficient of labour was 0.342 and statistically significant at 99% confidence level. The implication is that for a 1% increase in labour, the pixie productivity increases by 0.342%. Manure has a positive coefficient of 0.346, which is significant at 99% confidence level. This indicates that for a 1% increase in the amount of manure applied to the pixie fruits, the pixie productivity increases by 0.346%. Fertilizer has a coefficient of 0.015 and is significant at 90% confidence level. The implication is that a 1% increase in fertilizer application contributes to an increased pixie productivity by 0.015%. The value of the intercept is 7.817. It represents the natural log of harvest when all the other factors included in the model are zero. The coefficient is statistically significant at 99% confidence level and captures all the factors not considered in the model. The lambda value (λ) is 1.825. This indicates that 1.825% difference between the actual and potential output is a result of inefficiency among the study respondents sampled. The results are consistent with earlier revelation made by Muchara and Oluwatayo (2018) in provoking the relevance of production inputs in enhancement of increased output among the farming households. Also in their study, Mwangi et al. (2020) revealed that optimum utilization of production inputs resulted to increased output. These findings are in concord and could sink with the Cobb-Douglas Stochastic Frontier Model on indicating the influence of production inputs towards the attainment of increased output. Through the model, the production inputs are incorporated towards realization of high yield (Cobb and Douglas, 1928). To improve pixie production, there is need for incorporation of the production inputs optimally within the framework of the Cobb-Douglas Stochastic Frontier Model.

4.5.1 Mean technical efficiency

The mean technical efficiency of the pixie farmers was determined and the results presented in Table 4.7.

Table 4.7: Mean technical efficiency

Variable	Obs	Mean	Std. Dev.	Min	Max
efficiency	308	.75	.12	.359	.942

Source: Authors computation 2023

The estimated results on the technical efficiency of the farmers indicated the mean efficiency level of the pixie farmers was 75%. This implied that the average farmer has a potential of increasing pixie productivity by 25% if he/she utilizes the resources well. The minimum efficient farmer was operating at 35.9% efficiency level while the maximum efficient farmer operated at 94.2% technical efficiency. This implied that if the resources were utilized well, there only existed a 5.8% potential of increasing the productivity level for the most efficient pixie farmer to be efficient.

Table 4.8: Frequency distribution of technical efficiency

Technical efficiency	N	%
0.25 < to < 0.50	8	2.6
0.50 < to < 0.75	124	40.3
0.75 < to < 1.00	176	57.1
Total	308	100.0

Source: Authors computation 2023

Table 4.8 shows the distribution of technical efficiency among the sampled pixie farmers. 8 pixie farmers who accounted for 2.6% were operating at an efficiency level ranging between 0.25 < to < 0.50. 124 pixie farmers (40.3%) were in the efficiency range 0.50 < to < 0.75 while the remaining 176 pixie farmers constituting 57.1% operated within the range 0.75 < to < 1.00. The majority of the pixie farmers were operating at an efficiency level greater than 75% and only 2.6% operated below the 50% efficiency level.

Table 4.9: Technical efficiency from adoption of the sustainable agricultural technologies

		TE			
		Minimum	Mean	Standard Deviation	Maximum
Irrigation	Yes	0.549	0.771	0.088	0.942
	No	0.359	0.738	0.134	0.939
Integrated Pest Management techniques	Yes	0.513	0.761	0.099	0.921
	No	0.359	0.72	0.16	0.942
Soil and water management techniques	Yes	0.359	0.752	0.122	0.942
	No	0.546	0.737	0.109	0.915

Source: Authors computation 2023

The technical efficiency was also computed for the farmers who had adopted the different sustainable agricultural technologies. This was done to determine whether the adoption of different sustainable agricultural technologies affected productivity with regard to those who never adopted sustainable agricultural technologies. The mean technical efficiency realized by farmers who adopted irrigation in their pixie farms was 77.1% while those who never adopted irrigation had a mean technical efficiency of 73.8%. This revealed that the adoption of irrigation influenced productivity. The second sustainable agricultural technology was the use of natural pest control mechanisms where the mean technical efficiency of the farmers who adopted natural pest control mechanisms was 76.1% while for the non-adopters was 72%. The last sustainable agricultural technology reviewed was the use of soil and water management techniques. For the farmers who used the techniques, the mean technical efficiency realized was 75.2% while the mean technical efficiency for the non-adopters of the soil and water management techniques was 73.7%. Therefore, the findings in Table 4.9 indicated that the adoption of the sustainable agricultural technologies reviewed contributed to higher technical efficiency as adopters had higher technical efficiencies compared to non-adopters.

4.6 The effect of Socio-economic characteristics on technical efficiency

The impacts of the pixie farmers' socioeconomic traits and adoption of sustainable farming technologies on technical efficiency were explained by fitting a generalized linear regression model. Technical efficiency is the dependent variable while the predictor variables are the socio-economic characteristics and the sustainable agricultural technologies. The results are shown in Table 4.10.

Table 4.10: Generalized linear regression model of the socio-economic factors and sustainable agricultural technologies on T.E

Technical Efficiency	**Coef.**	**St. Err**	**t-value**	**p-value**	**[95% Conf Interval**		**Sig**
Socio-economic characteristics							
Other Sources of Income	.082	.014	5.78	0.000	.054	.11	***
Extension	.033	.020	1.63	0.039	-.007	.072	**
Gender: Female	.053	.014	3.68	0.000	.025	.081	***
Aged 31-40 years	.099	.021	4.62	0.000	.057	.141	***
Aged 41-50 years	.045	.024	1.87	0.062	-.002	.093	*
Aged 51 years and above	.039	.031	1.25	0.211	-.022	.101	
Primary	.074	.024	3.10	0.002	.027	.121	***
Secondary	.004	.023	-0.15	0.877	-.048	.041	
College	.038	.033	-1.16	0.248	-.102	.026	
University	.045	.029	1.54	0.125	-.012	.102	
Credit	.035	.018	1.96	0.046	.000	.07	**
Sustainable agricultural technologies							
Irrigation	.011	.019	0.61	0.045	-.025	.048	**
IPM	.088	.020	4.52	0.000	.052	.125	***
Soil and Water	-.055	.028	-1.98	0.001	-.109	-.000	***
Constant	.595	.035	16.82	0.000	.526	.665	***

**** p<.01, ** p<.05, * p<.1*

Source: Authors computation 2023

Off-farm income is a dummy variable with those whose income is only from agriculture as the base group and those with other sources as the other category. Having other sources of income other than agricultural income as the only source of income is crucial in increasing the efficiency of the pixie farmers (p-value<0.001). The implication is that there is a difference in technical efficiency between pixie farmers with other sources of income as compared to those whose main income is from agricultural activities. Pixie farmers with other income sources are associated with increased efficiency as compared to having agricultural income as the only source of income in agricultural activities. Thus, diversification among the pixie farmers should be encouraged. Diversification can lead to increased efficiency as the pixie farmers having other sources of income can learn about good husbandry practices. The husbandry practices can be crucial in pixie farming, thus leading to increased productivity. In addition, income generated from other sources of income can be invested in agriculture to purchase the production inputs required in pixie farming and adopt the costly sustainable agricultural technologies. In the theory of production, off-farm income enhances the efficiency of pixie farmers by providing additional financial resources that can be invested in better inputs and technologies, leading to higher productivity compared to farmers solely dependent on agricultural income. The findings contradict the findings by Ji et al. (2023) who found a negative relationship between off-farm income and technical efficiency. Their study implied that pixie farmers with other sources of income had lower technical efficiency as compared to pixie farmers whose source of income was only from agricultural activities. This could sink with the production theory which incorporates the inputs towards high productivity, thus increased technical efficiency. To improve technical efficiency, diversification need to be encouraged as the income can be reinvested in agriculture.

Extension is a dummy variable with two categories: those who have received extension services and those who haven't received extension services. Extension services are an important determinant of technical efficiency (p-value=0.039). The implication is that there is a difference in technical efficiency between pixie farmers who have received extension services and those who did not receive extension services. Extension services by the extension officers equip the pixie farmers with the knowledge of the best practices to apply in pixie farming. The pixie farmers receive education on the necessity of implementing sustainable farming practices and the methods for utilizing the production inputs in an optimum way to realize maximum output. Through the training programs, the marginalized groups in the society are educated by the extension officers. This helps them have the required education and equal opportunities to practice pixie farming. The outcomes align with the conclusions by Ambetsa et al. (2020) who found a difference in technical efficiency between sugarcane farmers who had received extension services and those who had not received the extension services. This has the implication that extension services are crucial towards increased technical efficiency among the farmers. Through the theory of production, extension services act as a key determinant of technical efficiency by equipping farmers with the knowledge and skills needed to optimize input use and adopt sustainable agricultural technologies. The positive impact of extension services on pixie farmers, as reflected in improved efficiency, indicates that those receiving these services achieve higher productivity through better resource management and sustainable practices. At 99% confidence level, there was a difference in technical efficiency between female pixie farmers and male pixie farmers (p-value=0.001). The positive coefficient implies that female pixie farmers are more efficient as compared to male pixie farmers. The high technical efficiency could be attributed to the openness of the women in adopting the new sustainable agricultural technologies. The adoption of such techniques sustainably enhances pixie productivity, thus achieving high output. The findings coincide with the research findings by Wambui and Majiwa (2020) whose results indicated that male farmers were less efficient in comparison to female farmers. The findings, however, contradicted the research findings by Madau (2015) and Ho et al. (2022) whose findings revealed that male farmers were more efficient as compared to female farmers. This was attributed to the engagement of women in off-farm activities, leaving them with little time to engage in agriculture and also, the nature of the enterprises.

Age is a categorical variable and for purposes of converting it to fit in the regression model, we converted it into a dummy variable. Farmers within the age group of 21-30 years were the reference category. In terms of efficiency, there is a notable distinction between pixie farmers in the age group 31-40 years and those between 21-30 years (p-value<0.001). Pixie farmers within this age group are more technically efficient as opposed to pixie farmers in the base group. Within this age group, the pixie farmers have been exposed to a wide depth of information on the best practices to adopt in pixie farming. They are open to new innovations and the best practices to adopt in the farming of the fruits. There is a difference in technical efficiency between the pixie farmers within the age group 41-50 years from those in the reference category. However, the difference is declining (p-value=0.062). The pixie farmers above 51 years are not statistically different in terms of technical efficiency from those in the reference category. This could be attributed to the reason that older farmers are less inclined to resist change and more open to adopting new technologies in agriculture. The most efficient age of farming is between 31-40 years. The study's findings align with those of Ambetsa et al. (2020) whose findings revealed older farmers to have had lower efficiencies.

Education level is a categorical variable with the following levels: no school, primary level, secondary, college, and university. For purposes of fitting, it was converted into a dummy variable with those who never went to school as the base category. There is a statistical difference in terms of efficiency between the pixie farmers who have primary education and those who have no education (p-value=0.001). The implication is that pixie farmers with primary education have higher efficiency as compared to those with no education.

Credit access is a dummy variable of two categories: those with credit access and those without credit access. Pixie farmers without credit access were the base group. Having credit access was important in pixie production (p-value=0.046). The implication is that pixie farmers with credit access have higher efficiency as compared to the efficiency of those without access to credit facilities. With credit access, pixie farmers could be in a position to purchase costly production inputs. In addition, adoption of the sustainable agricultural technologies was also possible. The results are in agreement with the findings by Ambetsa et al. (2020) who found sugarcane farmers with credit access to have had a higher efficiency compared to those without credit access. This implied that credit contributed to a higher technical efficiency among the pixie farmers as they could be in a better position to purchase the inputs required. In the theory of production, credit access improves the efficiency of pixie farmers by enabling them to invest in costly production inputs and adopt sustainable agricultural technologies, leading to higher output and productivity compared to farmers without credit access.

4.7 The effect of the adoption of sustainable agricultural technologies on technical efficiency

Three sustainable agricultural technologies were included in the model: irrigation, integrated pest management, and soil and water management techniques. Irrigation adoption contributed to higher efficiency as compared to non-adoption. The adoption of irrigation was important in pixie farming (p-value=0.045). This suggests that the adoption of irrigation and its non-adoption differ significantly in terms of technological efficiency. Adoption of irrigation in pixie farming is crucial for an increment in pixie productivity in the County. With the County being an arid and semi-arid region, the insufficient rainfalls experienced have an impact on the quality and quantity of pixie output realized. They cause the fruits to fall off during the flowering stage, thus reducing productivity. Irrigation helps the pixie trees maintain their fruits up to their maturity. Thus, a high yield is realized. The effect is an improvement in the technical efficiency. The results are consistent with the findings by Blumberg et al. (2024) who found irrigation adoption to contribute to high yield. The result was a higher technical efficiency for the farmers who had adopted irrigation in their agricultural activities. This could sink with the theory of production as using irrigation boosts technical efficiency by guaranteeing a steady supply of water, making the best use of inputs, and increasing agricultural productivity, which results in a larger output than in areas without irrigation (Nalini et al. 2020).

There is a difference in terms of efficiency between integrated pest management adoption and integrated pest management non-adoption (p-value<0.001). The implication is that the IPM adopters have higher technical efficiency as compared to the IPM non-adopters. Adoption of IPM techniques is crucial as they help reduce overreliance on chemical pesticides. This provides economic benefits as less costs are incurred as opposed to the purchase of costly chemical pesticides. In addition, IPM techniques are crucial in reducing adverse environmental concerns. The study results are consistent with the findings by Wangithi et al. (2021) whose findings revealed that adoption of IPM techniques contributed to higher efficiency than non-adoption. The findings are in concord with the theory of production as adoption of Integrated Pest Management (IPM) enhances technical efficiency by optimizing input use, reducing overreliance on chemical pesticides, and improving sustainability, leading to higher productivity compared to non-adopters of IPM techniques (Baglan et al. 2020).

There is a difference in terms of technical efficiency between soil and water management adoption and soil and water management non-adoption (p-value=0.001). There exist different soil and water management techniques such as planting of cover crops, mulching, water harvesting, terracing etc. The adoption of soil and water management techniques is expected to contribute to higher efficiency. However, the study findings found the soil and water management techniques to have contributed to lower efficiency. The study findings contradict findings by Dhraief et al. (2021) who found soil and water management techniques to have contributed to higher efficiency. With soil and water management techniques adoption, high output is realized. The soil conservation techniques helps in maintenance of required nutrients in the soil while water management techniques aid in ensuring that the pixie fruits have the required water for high pixie output.

CHAPTER FIVE

DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The study was on determinants of technical efficiency in pixie production in Makueni County. The study sought to achieve three distinct goals, namely; assessing technical efficiency in pixie production, investigating the impact of socio-economic factors on technical efficiency, and analyzing the influence of sustainable agricultural technologies on technical efficiency in pixie production. A non-experimental cross-sectional research design was adopted in the study and a sample of 311 pixie growing households selected. Both purposive and simple random sampling techniques were used in the study.

5.2 Summary of findings

The comparison of the research findings with other related studies is done in this section. The comparison is conducted to find out whether the findings are in agreement or disagreement with other studies.

5.2.1 Determination of technical efficiency in pixie production

Determining the technical effectiveness of pixie production in Kenya's Makueni County was the study's primary goal. The parametric estimates of the stochastic production frontier model coefficients were used to explain the first objective on the determination of technical efficiency in pixie production. From the stochastic frontier model, the technical efficiencies of the sampled pixie farmers were generated. Five production inputs were fitted in the stochastic production frontier to determine the technical efficiencies of the sampled pixie farmers. The stochastic frontier model explained whether the production inputs were crucial or not crucial in the explanation of increased pixie productivity in Makueni County.

The production inputs considered were: the quality of seedlings, labour, manure, fertilizer, and chemical pesticides.

The coefficient of the labour force is positive and statistically significant at 99% confidence level. The implication is that labour force is a crucial determinant of pixie production in the study area. Increased labour force in the pixie farms contributed to increased pixie productivity in the farms. The findings are similar to the research findings by Mwangi et al. (2020) and Ambetsa et al. (2020) who found labour force to positively and significantly influences productivity. They found out that families with a large number of both family and hired labour were more efficient as compared to families with a smaller number of the labour force.

The coefficient of manure is positive and statistically significant at 99% confidence level(p-value<0.001). The findings reveal that the increased application of manure has a significant effect on increased pixie productivity among the farmers in Makueni County. Manure application helps increase the nutrients required to realize high output and also helps in the improvement of soils' water-holding capacity. In addition, manure application is a sustainable measure for increased pixie productivity. The findings are similar to the findings by Ndambi et al. (2019) whose findings revealed manure application as a sustainable and efficient approach towards increased productivity.

The coefficient of fertilizer is positive and statistically significant at 90% confidence level (p-value$=0.052$) which was <0.1. The implication is that increased use of fertilizer in pixie farming increases the productivity of pixie thus contributing to higher technical efficiency. The study results are in agreement with the findings by Wambui and Majiwa (2019) who found out fertilizer application contributes to increased pixie productivity. This creates a justification for the pixie farmers in Makueni County to apply fertilizer in their farms to contribute to increased productivity thus resulting in increased efficiency in pixie production.

The coefficient for chemical pesticides is positive but not statistically significant. This implies chemical pesticides were not very crucial in the explanation of pixie productivity in the area. However, their application led to increased pixie output. The study findings are similar to those of Mwangi et al. (2020) who found chemical pesticides to not statistically influence productivity.

The coefficient for the quality of seedlings is not significant. The implication is that the productivity of the pixie farmers won't statistically be influenced by the quality of the pixie seedlings used. Several studies have been conducted on the quality of seedlings. The findings contradict the findings by Wambui and Majiwa (2020) and Ambetsa et al. (2020) who found the quality of seedlings to have had a significant effect, thus crucial in the explanation of improved productivity.

The mean technical efficiency among the pixie farmers was 75%. The implication is that the average pixie farmer has a 25% potential to increase pixie productivity to become technically efficient. The lowest efficient farmer operated at 35.9% efficiency level while the highest efficient farmer at a 94.8% efficiency level. The implication was that there only existed a 5.8% potential for the highest efficient pixie farmer to become efficient. The majority of the pixie farmers, who accounted for 57,1%, operated at an efficiency level greater than 75%.

5.2.2 The effect of socio-economic characteristics on technical efficiency in pixie production

The second objective is on the socio-economic characteristics and how they impact technical efficiency.

Off-farm income had a significant difference in the determination of technical efficiency. Pixie farmers with other income sources were more efficient as compared to those whose only income source was from agriculture. The higher technical efficiency could be attributed to the reason that the pixie farmers with other income-generating activities used the profits generated from the other income sources to invest in agriculture. Given adoption of sustainable agricultural technologies is costly, the pixie farmers used the profits to invest in the costly agricultural technologies and for purchase of the production inputs. Pixie farmers with other sources of income could also have benefited from good husbandry practices realized from those sources. The practices could have been useful in pixie farming. The study findings contradict the findings by Ji et al. (2023) who found a negative relationship between off-farm income and technical efficiency. This implied that the technical efficiency realized by farmers having other sources of income was lower compared to that of farmers whose income was from agricultural activities.

There was a difference in technical efficiency between pixie farmers who received extension services and those who never received the extension services. The implication was that extension services played a crucial role in the contribution to technical efficiency as pixie farmers who received extension services had higher efficiency compared to pixie farmers who never received extension services. The high efficiency was attributed to the knowledge and skills on the best practices to apply in pixie farming obtained from the extension officers. The findings conformed to the research findings by Ambetsa et al., 2020 who found extension services to have contributed to higher technical efficiency.

Female pixie farmers were found to have had difference in terms of efficiency as compared to the male pixie farmers. Despite the limitations on access to resources such as land ownership, women tend to utilize the resources in an optimum way. In addition, they are more open to adopting new technologies in pixie farming. The results are consistent with the findings by Wambui and Majiwa (2020) who found female farmers to have had higher technical efficiency compared to male farmers. The results, however, contradict with results of Madau (2015), Muchara and Oluwatayo (2018) and Ho et al. (2022) where men had higher technical efficiency as compared to female.

Pixie farmers in the age range 31-40 years were found to have had a difference in technical efficiency as compared to the pixie farmers in the reference category (21-30 years). This implied that they had a higher efficiency as opposed to those in the base category. In addition, pixie farmers who were in the age group 41-50 had a difference in terms of efficiency as compared to those in the base category. However, the difference was declining. Older farmers above 51 years were not significantly different from those in the base category. With older farmers more receptive to change, they have lower chances of adopting sustainable agricultural technologies as compared to younger farmers. This could have contributed to the lack of difference in terms of efficiency between the two categories of farmers.

Having primary education contributed to a higher efficiency as compared to having no education. Pixie farmers who had primary education level had the basic education to apply in agriculture as compared to the illiterate pixie farmers which could have contributed to higher efficiency. Pixie farmers with secondary, college, and university education were not significantly different in terms of efficiency from those who never attended school. This could have been attributed to the fact that the majority are in formal employment and hence employ people with no education or primary education to take care of the orchards. Thus, not directly involved in pixie farming.

In terms of technical efficiency, having credit access among the pixie farmers was important as compared to a lack of credit access. Pixie farmers with access to credit facilities realized a higher technical efficiency as opposed to those who lacked credit access. The study findings were in agreement with the study findings by Ambetsa et al. (2020) who found sugarcane farmers with credit access to have had a significant difference in terms of efficiency as opposed to those who lacked credit access. This was attributed to the reason that credit access enables farmers to have adequate resources to purchase the production inputs and adopt the costly sustainable agricultural technologies.

5.2.3 The effect of adoption of sustainable agricultural technologies on technical efficiency in pixie production

The regression analysis's findings demonstrated how pixie farming's technical efficiency was enhanced by the use of sustainable agricultural methods. Three sustainable agricultural technologies were examined namely: irrigation, IPM, and soil and water conservation techniques. Different IPM techniques were examined which included the use of commercial biopesticides, plant extracts, cultural practices, and physical control methods. Also, different soil and water conservation techniques were examined which included mulching, use of semi-circular bunds, cover crops, water harvesting, and terracing.

The mean technical efficiencies of farmers who adopted irrigation, IPM, and soil and water management were 77.1%, 76.1%, and 75.2% respectively. They were much higher than for those who never adopted the sustainable technologies which were 73.8%, 72%, and 73.7% respectively. The higher technical efficiencies from adoption of the sustainable agricultural technologies were similar to Moura's (2021) findings who found that adoption of the sustainable agricultural practices led to increased technical efficiency in citrus production. Adopters of irrigation have a 3.3% increase in technical efficiency compared to the non-adopters of irrigation. The findings are consistent with Nalini et al. (2020) who found adoption of irrigation to have contributed to a 4.4% increase in technical efficiency. For IPM, a distinction existed between adoption and non-adoption. Pixie farmers who adopted different IPM techniques were found to have had higher efficiency compared to those who never adopted them.

Soil and water management adoption led to a 1.5% increase in technical efficiency after comparison with the non-adopters of the soil and water management techniques. The findings were similar to the findings by Dhraief et al. (2021) who examined different soil and water management practices and found that they contributed to increased technical efficiency in citrus production. Composting and intercropping contributed to a 10.6% and 8.2% increase in technical efficiency respectively.

5.3 Conclusion

5.3.1 Determination of technical efficiency in pixie production in Makueni County, Kenya

Labour is a crucial determinant of technical efficiency in pixie production, with the implication that the quantity and quality of labour force affects the pixie output. The findings reveal the importance human resources play in the production of the pixie fruits. The positive correlation between labour and output indicates that increasing the number of workers or hours worked leads to higher productivity. This could be due to more tasks being completed promptly, such as pruning, and maintenance, which are essential in pixie production.

Manure has a major impact on pixie production yield, since it enhances soil fertility and plant health, which in turn leads to increased technical efficiency. Pixie crops depend on manure as a natural source of key minerals like potassium, phosphate, and nitrogen for healthy growth. Manure restores soil nutrients, improving soil structure, moisture retention, and microbial activity, as seen by the positive output impact. Given manure is made from recycled organic waste, using it as fertilizer also supports sustainable farming methods. Regular application can improve soil health over time and lessen reliance on artificial fertilizers.

Fertilizer application is a significant determinant of output in pixie production. This implies that the appropriate use of fertilizers is crucial for achieving high levels of technical efficiency. Fertilizers provide plants with specific nutrients that may be deficient in the soil. In pixie production, fertilizers supply key nutrients like nitrogen, phosphorus, and potassium, all of which are essential for maximizing yield. With the increasing focus on sustainable agriculture, precision farming techniques optimize fertilizer use by applying the appropriate quantity in the appropriate moment and location.

The study results indicated high technical efficiency among the pixie farmers. The mean technical efficiency was 75%. There was only a 25% chance that pixie farming could be made more efficient. The mean technical efficiency of the pixie farmers who adopted irrigation was 77.1%. The distribution of the technical efficiency was in the range of 35.9% to 94.2%. The majority of the pixie farmers (176) operated between 75-100% efficiency level.

5.3.2 The effects of socio-economic characteristics on technical efficiency in pixie production

Off-farm income is a significant determinant of technical efficiency in pixie production. This creates the justification for the farmers to engage in other income-generating activities as they tend to have had a higher technical efficiency. income from those sources is invested back in agriculture for the purchase of production inputs, hiring of labour, and aid in adoption of better technologies in pixie farming. Farmers that have revenue from sources other than farming are in a better position to handle risks including crop failure, price swings, and unfavorable weather.

Access to extension services significantly increases technical efficiency in pixie production, as it facilitates the dissemination of agricultural knowledge, best practices, and innovations to the pixie farmers. Through extension services, farmers are introduced to new technologies that can significantly enhance pixie output and efficiency. This creates the need for extension officers to provide the relevant knowledge to the pixie farmers on the best practices to adopt in pixie farming to benefit from increased productivity.

Age is an important determinant of technical efficiency, with younger farmers generally being more technically efficient due to their willingness to adopt new technologies and practices. Farmers within the age group 21-30 years formed the base group. The findings revealed that farmers within age group 31-40 years to be more efficient. Young farmers are characterized with their openness in adopting sustainable agricultural technologies, hence realization of higher output and as a result, high efficiency.

The education level of farmers is a significant factor in determining technical efficiency in pixie production. The study found out farmers with primary education to have had a higher efficiency as compared to those without formal education. Farmers with primary education are more likely to comprehend and apply agricultural best practices, which improves their technical efficiency. They are more likely to keep a good track of their records, which makes them track their expenses and make informed decisions towards attainment of higher efficiency.

Credit access is a key determinant of technical efficiency in pixie production, as it enables farmers to invest in productivity-enhancing inputs and technologies. pixie farmers with credit access realized a higher efficiency as opposed to those who lacked credit access. With credit access, the pixie farmers are in a better position to purchase the production inputs and adopt the costly sustainable agricultural technologies. In addition, credit provides farmers with the financial flexibility to manage risks associated with farming, such as adverse weather conditions or pest outbreaks.

5.3.3 The effect of adoption of sustainable agricultural technologies on technical efficiency in pixie production

Various sustainable agricultural technologies were examined in the study: irrigation, integrated pest management, and soil and water management techniques. From the study findings, the adoption of the three sustainable technologies was crucial. This was because their adoption contributed to higher technical efficiencies as compared to the technical efficiencies for the non-adopters of the technologies.

Pixie farmers who adopted irrigation in their farms had a mean technical efficiency of 77.1% while those who never adopted realized a mean technical efficiency of 73.8%. There is a 3.3% difference in technical efficiency between the adopters and non-adopters of irrigation as a sustainable agricultural practice in pixie farming. The difference indicates that adoption of irrigation has a notable positive influence of the performance of the farm.

The second sustainable agricultural technology was integrated pest management where the adopters had a technical efficiency of 76.1% and non-adopters had a technical efficiency of 72%. The 4.1% increase in technical efficiency for adopters indicates that the use of IPM enhances the efficiency with which farmers manage pests and diseases, likely reducing crop losses and improving resource utilization. This suggests that IPM practices are effective in optimizing input use, leading to better production outcomes. They are more environmentally friendly as opposed to the use of chemical pesticides.

Lastly, adopters of soil and water management techniques realized a mean technical efficiency of 75.2% while the non-adopters had a mean technical efficiency of 73.7%. There exists 1.5% difference in technical efficiency between adopters and non-adopters of soil and water management techniques. This creates the need for farmers to be educated on the need for adoption of the different soil and water management techniques to benefit from high yield. Adoption of irrigation had the highest mean technical efficiency.

5.4 Recommendations

5.4.1 Determination of technical efficiency in pixie production in Makueni County, Kenya

The county government should invest in agricultural education to improve the knowledge and skills of the pixie farmers. By providing training and investing in skill development for the farmers, maximum output would be realized. Also, through knowledge of the best agricultural practices, the labour productivity of the farmers will be increased and hence higher technical efficiency.

With manure contributing to increased pixie productivity, the farmers should be encouraged to practice organic farming practices. This is attributed to the reason that manure acts as a natural fertilizer. Farmers should ensure the regular and appropriate application of manure to help maintain soil health and boost pixie yields. Much focus needs to be placed on the timing and the method of application to help ensure the trees produce the pixie fruits to their optimum level. Integrating manure with other organic or inorganic inputs could further enhance effectiveness in the output.

Application of fertilizer was also found a crucial determinant towards increased pixie productivity. The county government should invest in agricultural extension services which will help educate them on the best use of fertilizer, timing of application, and the application method. To make the fertilizer affordable to the pixie farmers, subsidies and incentives for fertilizer use should be provided.

5.4.2 The effects of socio-economic characteristics on technical efficiency in pixie production

With pixie farmers having other sources of income found to have had higher technical efficiency, there is a need for pixie farmers to diversify into other income-generating activities and use the income earned from those activities to re-invest in agricultural activities. There is need for promotion of policies which encourage farmers too have diversified income sources. Through these, adoption of efficiency-enhancing technologies in pixie farming is possible.

Efforts should be made to improve the accessibility and quality of extension services, particularly in rural areas. This is attributed to the role of extension staff in the dissemination of knowledge to the farmers on the best practices to adopt in pixie farming. Farmers need to be educated on the best utilization of the production inputs to benefit from increased pixie productivity, which will result to higher efficiency levels. The national and county government should prioritize in making investment in agricultural extension systems to offer tailored advice to the farmers.

The most efficient age for farming was between 31-40 years. The farmers in this age group have information on the best practices to adopt in agriculture. They are more likely to adopt the new technologies as opposed to the older farmers who are more receptive to the changes in technologies. There is need for development of programs which target young farmers with training on adoption and expansion of sustainable agricultural technologies. The study, therefore, recommends young farmers to engage in agricultural activities. The perception of agriculture being a dirty profession among the youth should be eradicated. This can be achieved by educating them on the role of agriculture as the bedrock of the economy.

The farming households should have access to basic education. In addition, adult literacy programs and informal education on farm management can also help boost the efficiency of farmers with lower education levels. With basic education, the farmers have the basic knowledge on the best practices to adopt in pixie farming.

With pixie farmers who had credit access having a higher efficiency as compared to those who lacked credit access, the majority of the respondents lacked formal access to credit. Only 45.81% of the respondents had formal access to credit. The lack of access to formal credit could be an indicator of resource constraints, with the farmers who lacked credit access finding it a challenge to have access to the production inputs used in pixie production. The adoption of sustainable agricultural technologies is a challenge, since adoption of such technologies is costly. The financial institutions providing credit facilities to the farmers should harmonize the credit repayment and offer flexible loan products suitable to the pixie farmers. The County government, in collaboration with the credit institutions, should also come up with measures to help ensure that they help inculcate and improve the savings culture among the pixie farmers. The savings could enable them to acquire credit from lending institutions as they can act as collateral for loans obtained.

5.4.3 The effect of adoption of sustainable agricultural technologies on technical efficiency in pixie production

With the adoption of irrigation found to have contributed to higher technical efficiency in pixie production, the farmers should be encouraged on the need for adoption. The county government should focus on making investments in irrigation agriculture through constructing irrigation systems such as pipelines, dams, and reservoirs. Through this, access to reliable water sources for irrigation agriculture will be expanded in the water-scarce areas. The pixie farmers need also to be educated on efficient irrigation practices.

IPM adoption contributed to higher technical efficiency. It is one of the good agricultural practices adopted in agriculture. With IPM adoption, overreliance on chemical pesticides is reduced. The adoption of IPM is crucial to reducing the presence of chemicals in the pixie fruits. This is due to the reason that it is an organic pest control method. The pixie farmers should be encouraged to use different IPM techniques such as cultural and physical control methods.

Agricultural programs should offer education and training on soil conservation practices, such as mulching, cover cropping, and terracing. Also, investments in water harvesting should be made a priority. The non-adopters of the soil and water management techniques need to be educated on the importance of adopting them, given the higher technical efficiency realized by the adopters.

5.5 Areas for further research

There exist various ways in which the research can be extended. The study was only focused on technical efficiency in pixie farming in Makueni County. This was only one aspect of efficiency. Therefore, a study on allocative efficiency would provide a greater perception of efficiency studies. In addition, a study on both technical and allocative efficiency could be conducted, thus focusing on the economic efficiency in pixie farming.

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Appendix 1. Definition and measurement of variables

Variable	Definition	Measurement
Output	Pixie output harvested per production season	Kilograms/Ha
	SOCIO-ECONOMIC FARMER CHARACTERISTICS	
Gender	The gender of the household head. It was expected to have an impact on technical efficiency as households led by men are expected to be more efficient in comparison to those led by female as they are mostly entitled to household chores; hence less time will be allocated to agricultural activities. In addition, most of the societies still have in place the traditional land tenure system which restricts women from owning land title deeds. Thus, credit access becomes a challenge from formal financial institutions due to a lack of security for the credit.	Dummy variable
Age	Number of years of the farmers. The age in efficiency studies is an indicator of the experience of the farmers. Farmers who are aged and have been exposed to farming activities for a long are expected to be more efficient than those farmers who are young and have not been exposed to farming for long. On the other hand, age may have a negative influence on efficiency as young farmers are more likely to adopt new technologies in comparison to aged farmers.	Years

Education level	The highest level of education attained by a pixie farmer. Education level is expected to have a positive impact on technical efficiency. With more exposure to education, the farmers are equipped with more knowledge and skills, which they will use to help increase pixie output. The education level will also lead to an exposure of the farmers to the sustainable agricultural technologies available.	Years of schooling
Credit	The amount of credit received by a farmer in a season. Access to credit will be expected to have a positive impact on technical efficiency. Credit will enable the farmers to purchase all the necessary production inputs and farm equipment, which as a result will help in the enhancement of efficiency.	Kenya Shillings
Non-farm income	Income from other sources other than farm activities. It is expected to have a negative impact on technical efficiency. This is because the farmer diverts his/her attention to other activities and as a result, less time invested in agriculture.	Dummy variable
Extension service	Involvement frequency of farmers in knowledge programs. Exposure of the farmers to extension services will be expected to have a positive impact on technical efficiency since the farmers will be more exposed to the required knowledge on	Number of visits

	farming activities and technological breakthroughs towards increased pixie productivity.	
	PRODUCTION INPUTS	
Quality of seedlings	Refers to the quality of the pixie seedlings used by the farmer during the planting stage. It will be a dummy variable as the seedlings will either be sourced from certified seedling companies or uncertified seedling companies. Obtaining the pixie seedlings from certified seedling companies is expected to have a positive impact on technical efficiency as through certification, high-quality seedlings adaptable to climatic conditions and prone to pests and diseases will be availed.	Source of seedlings
Amount of manure	Refers to the organic matter that is applied as an organic fertilizer in pixie production. The application of organic manure in the soil increases the soil nutrients. This, is expected to cause increased pixie output. In addition, it will help in the reduction of the yield gap by ensuring that maximum output is realized.	Wheelbarrow(s) per tree
Fertilizer	Comprises of the different types of fertilizers used for pixie production by the farmers in the study area. It is expected to cause increased pixie output. However, in the long term, without proper soil management, it may have adverse effects.	Kilograms

Total labour force	Includes both the family and hired labour force used in the farming of pixie up to the point of harvesting. With the pixie trees being prone to attack by pests and diseases, enough labour force is crucial to the realization of maximum pixie output.	Man days
Chemical pesticides	The quantity and different types of chemicals used in the spraying of the pixie from the flowering stage up to the point they are ready for marketing	Application frequency
	SUSTAINABLE AGRICULTURAL TECHNOLOGIES	
Irrigation	Irrigation entails the application of water to plants and trees in a controlled manner to aid in their growth and development. It is mainly conducted in regions that experience insufficient rainfall to help ensure optimum yield. Irrigation use in pixie farming is a sustainable measure towards increased productivity. This reduces fruits from falling off the trees.	Dummy variable
Integrated Pest Management	It is a sustainable agricultural technology that purposes to reduce chemical pesticide use; thus, reduction of environmental pollution. There are various IPM techniques such as: physical control, cultural practices, and biological control. With IPM strategies, the overreliance on chemical	Dummy variable

	pesticides is reduced. This makes it a sustainable approach to pixie farming.	
Soil & Water Management	The soil and water management techniques entail the conservation practices and technologies employed in agriculture to reduce the harsh environmental impacts. Soil conservation techniques include terracing and the planting of cover crops. They help in the prevention of soil erosion. With the prevention of soil erosion, soil fertility is maintained. Different water management techniques such as mulching and rainwater harvesting aim at the efficient use of water to realize optimum output.	Dummy variable

Appendix 11. Questionnaire

CONSENT STATEMENT

I am a postgraduate student from Maasai Mara University conducting research on the technical efficiency in pixie production in Makueni County. The study intends to obtain information from Nzaui and Makueni sub-county pixie farmers. I have obtained the permit to collect data from NACOSTI (a government agency on research). The information obtained will purposively be used for academic purposes and kept confidential.

Part 1. Background information on farmers' characteristics

1. What is your gender?

    Male ( )   Female ( )

2. Kindly specify your age bracket

    10-20 ( )   21-30 ( )   31-40 ( )   41-50 ( )   51 years and above ( )

3. Kindly indicate your marital status

    Single ( )   Married ( )   Divorced ( )   Widowed ( )

4. What level of education have you attained?

    None ( )   Primary ( )   Secondary ( )   University ( )   Other ( )

5. What is your religion?

    Christianity ( )   Islamic ( )   Pagan ( )   Other ( )

6. What is your main occupation?

    Farmer ( )   Teacher ( )   Business person ( )   Other ( )

7. How many years have you been into farming pixie fruits?

Less than 5 yrs ( ) 6-10 yrs ( ) 11-15 yrs ( ) 16-20 yrs ( ) More than 20 yrs ( )

8. What is the household size?

………

9. Farm characteristics

Distance of the farm from home	Total area under pixie production (Ha)	Output realized (Kgs)

Part 2. Production Inputs

Labour

10. What is your source of labour in pixie production on your farm?

Family ( ) Hired ( ) Both ( )

11. If family/hired what is their number and hours worked in a day?

Source of labour	Number of workers	Hours worked per person on average in a day
Family		
Hired		

Fertilizer

12. Do you apply fertilizer in any stage of pixie farming?

Yes ( )   No ( )

13. If yes, which type of fertilizer do you apply and in what quantity per hectare?

Fertilizer	**Quantity/Ha (Kgs)**
DAP	
NPK	
Urea	
Other(s)	

14. Which method of fertilizer application do you use?

Broadcasting ( )   Foliar application ( )   Top Dressing ( )   Placement ( )

15. With regards to your opinion, are there benefits realized from fertilizer application?

Yes ( )   No ( )

16. If yes, what are the benefits?

Increased production ( )   Increased income ( )

17. If you answered no in question 12, what are the reasons for not applying fertilizer?

High cost of fertilizer ( )   Inaccessibility of the fertilizer ( )   Lack of information ( )

Quality of seedlings

18. Where do you source the pixie seedlings from?

Non-certified seedling sources ( )   Certified seedling companies ( )

19. If the seedlings are purchased, do you purchase the grafted seedlings/lemon seedlings and what is their cost?

Grafted seedlings ( )   Lemon seedlings ( )

20. If you use certified seedlings, what are the benefits of their use? (√)

Reduction of pests	
Tolerant to pests and diseases	
High yields	

Manure application

21. Do you apply manure in the pixie trees?

Yes ( ) No ( )

22. What type of manure do you apply and in what quantity?

Type	**Quantity in wheelbarrow(s)/tree**	**Frequency of application per season**
Farmyard manure		
Green manure		
Compost manure		

23. What benefits do you derive from the application of manure in the pixie trees? (√)

Increased yield	
Improved soils' water holding capacity	
Proper drainage	

Chemical pesticides

24. Do you apply chemical pesticides in any stage of pixie farming?

Yes ( )   No ( )

25. If yes, what is the frequency of spraying?

Pesticides	**Frequency of application per production season**
Insecticides	
Fungicides	
Herbicides	

26. Are there any challenges involved in accessing the chemical pesticides? (√)

Poor infrastructure	
High costs of chemical pesticides	
Other(s)	

Part 3. Extension provision

27. Have you ever received any extension services on pixie production?

Yes ( )   No ( )

28. If yes, what is the frequency with which the extension officers disseminate knowledge?

Weekly ( )   Monthly ( )   Quarterly ( )   Yearly ( )

29. Were the extension services beneficial toward increased production?

Yes ( )   No ( )

30. If yes, how were they beneficial? (√)

Increased output through education on proper farm practices	
Identification of high-quality seedlings	
Education on correct pesticide use	
Education on proper fertilizer application	

Part 4. Credit access

31. Do you have any formal access to credit?

Yes ( ) No ( )

32. If yes, have you received credit over the last three years?

Yes ( ) No ( )

33. Source of credit, amount, and motive for obtaining the credit

Source of credit	**Amount of credit**	**Credit motive**

Part 5. Sustainable agricultural technologies

34. Do you practice irrigation in pixie farming?

Yes ( ) No ( )

35. If yes, what are the benefits realized from it? (√)

High yields	

High-quality fruits	
Lengthening of the growing season	

36. Are there any challenges in practicing irrigation agriculture? (√)

Water scarcity	
Poor water infrastructure	
High cost of irrigation equipment	
Inadequate credit	

37. Do you use natural pest control mechanisms in pixie farming?

Yes ( ) No ( )

38. If yes, what methods do you use?

Method	**Whether used (√)**
Commercial biopesticides	
Cultural practices	
Physical control	
Plant extracts	

39. What are the benefits realized from the use of natural pest control mechanisms in pixie farming? (√)

Cost-effective	
Safe and non-toxic	
Reduction of environmental contamination	
Reduction of chemical usage	

40. What are the challenges faced by the use of natural pest control mechanisms? (√)

Lack of professional education	
A lot of resources are needed	
It takes longer to see the results	

41. Do you use soil and water management techniques on your farm?

Yes ( ) No ( )

42. If your answer to the above question is yes, which techniques have you adopted?

Technique(s) adopted	Tick where appropriate (√)
Mulching	
Semi-circular bunds	
Cover crops	
Water harvesting	
Terracing	

Thank you.

Appendix 111: Geographical location of Makueni County