UNIVERSITY FOR DEVELOPMENT STUDIES

COMPARATIVE PERFORMANCE EVALUATION OF PINEAPPLE (*ANANAS COMOSUS, VAR. MD2)* PRODUCTION UNDER DRIP IRRIGATION AND RAINFED CONDITIONS: THE CASE STUDY OF BOMARTS FARMS, GHANA

ENOCK ASANTE OSEI

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BY

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(BSc. Agricultural Engineering)

(UDS/MID/0008/20)

A THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING, SCHOOL OF ENGINEERING, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN IRRIGATION AND DRAINAGE ENGINEERING

AUGUST, 2022

DECLARATION

DECLARATION BY CANDIDATE

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for a degree in this university or elsewhere. The work of others, which served as sources of information for this study, has been duly acknowledged in the form of references.

Enock Asante Osei		27/04/2023
(UDS/MID/0008/20)	Signature	Date

DECLARATION BY SUPERVISORS

I hereby declare that the preparation and presentation of the thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies.

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ABSTRACT

Pineapple (*Ananas comosus*) is by far the most important crop within the horticultural subsector of the Ghanaian economy. Studies have revealed that most large-scale commercial farms in Ghana produce under rainfed conditions despite the current climate variability with uncertain rainfall pattern. Whereas several studies have been conducted on pineapple profitability, post-harvest handling among others, water management and irrigation practices in the cultivation of pineapple has not been adequately researched and thus, poorly understood. This study was conducted to assess the performance of pineapple production under drip irrigation and rainfed conditions in the Coastal Savannah of Ghana. A non-experimental case study research design was adopted in the study. The crop water requirement of pineapple was estimated at 516.8 mm for 13 months growth period, and the irrigation requirement was 123.8 mm. In evaluating of the performance of the drip irrigation system used on the study site, the ratings were assigned according to ASAE (1999). The emitter flow variation and coefficient of variation were 59.3 % and 0.16 %, respectively, with rating indication of poor performance. The coefficient of variation, and the uniformity coefficient were 86.8 % and 79.7 % respectively, which were rated as 'very good'. Based on these and other related parameters, the performance of the drip system on selected site was unsatisfactory. Fresh fruit yield from rainfed and irrigated fields were 32.483 t/ha and 32.640 t/ha, compared to average yield in Ghana being 60 t/ha. There was no significant difference between fruits produced under irrigated and rainfed conditions. The brix values for pineapple from irrigated field was 12.8 ºBx on day of harvest; 15.6 ºBx on 7th day after harvesting; and 19.8 on 14th day after harvesting, compared to the brix for rainfed production which was 13 ºBx on day of harvest; 16 ºBx on 7th day after harvest; and 21 ºBx on 14th day after harvest. The difference in brix values for both fields was not significant. The cost of production for irrigated pineapple over 3-year period – 2019, 2020 and 2021 was estimated at Gh₵ 16,688.00, Gh₵ 11,233.00 and Gh₵ 11,593.00 per hectare, respectively. However, the cost of rainfed production was quite low and estimated at Gh₵ 11,315.00, Gh₵ 7,760.00, Gh₵ 8,070.00 per hectare for the same three years. Conclusions are that in Ghana, pineapple can do well, and produce the desired yield under rainfed conditions if farmers adopt good agronomic practices, without the need for irrigation system which comes with high capital investment that most farmers cannot afford. Researchers, students and agricultural extension officers can infer from this study as it serves as a seminal work on water management in pineapple production in Ghana.

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DEDICATION

I dedicate this work to my father, Mr. Patrick Freeman Osei.

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LIST OF ACRONYMS AND ABBREVIATIONS

ASABE	American Society of Agricultural and Biological Engineers
CAM	Crussulacean Acid Metabolism
CROPWAT	Crop Water Assessment Tool
CU	Coefficient of Uniformity
CV	Coefienct of Variation
CWR	Crop Water Requirement
DU	Distribution Uniformity
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
EU	Emission Uniformity
FAO	Food and Agricultural Organisation of the United Nations
GEPA	Ghana Export Promotion Authority
Global GAP	Global Good Agricultural Practices
GMet	Ghana Meteorological Agency
ISO	International Standards Organisation
k_c	Crop Coefficient
UC	Uniformity Coefficient

CHAPTER ONE

INTRODUCTION

1.1 Background

Pineapple (*Ananas comosus*), a native plant to Central and South America with the tropics and subtropics being production hotspots, is the third most important tropical fruit in the world, after banana and citrus (Hossain, 2016). Pineapple is considered an important fruit crop with worldwide popularity, due to its rich vitamin (A, C, and E) content (Williams *et al*., 2017a). Due to its anticipated potential to increase impoverished growers' financial welfare by giving chances for international markets, the production of pineapple has gotten a lot of attention.

Presently, pineapples are grown in roughly 90 different nations and areas around the world. Around 400,000 hectares of land are used to grow pineapples worldwide, mostly in Africa, Asia, and America (Li *et al*., 2022). However, the major producers, according to FAO (2023) report are Philippines, China, Coasta Rica, Honduras, Ecuador, Columbia, Cote D'Ivoire and Ghana. The world's largest producer and exporter of pineapple is Costa Rica which accounts for about 70 % of pineapple exports to the world market (FAO, 2023). The Philippines is the world's second-largest pineapple exporter, with China being its main export location. Mainly, the variety produced in the Philippines is MD2 which has proved suitable for the Chinese market. While the Philippines exported 42 % of its pineapples to China, Japan and the Republic of Korea imported 32 % and 14 % of its pineapples, respectively during the first eight months of 2022. In 2022, shipments from

Ecuador, the top exporter of pineapples from South America rose by 9.4 % to a little over 110000 tonnes, filling in supply gaps around the world. Statistics on trade flows by destination show that for the first nine months of 2022, Ecuador exported to the European Union at a rate of about 50 %, Chile at a rate of about 26 %, and the United States at a rate of about 8 %. Throughout China's tropical and subtropical regions, the pineapple industry played significant roles in the development of local economies. The majority of pineapples are marketed as fresh fruit in China. Fresh pineapple fruit trade has grown by 14 % annually over the last 15 years (Shu *et al*., 2019). Africa’s leading pineapple producer and exporter according to FAO (2023) is Cote D’Ivoire which has an average export volume of 33000 tonnes. Pineapples from Côte d'Ivoire were mostly shipped to Belgium and France, who together received around 75 % of all exports from the country.

Studies by Danielou and Ravry (2005) on pineapple production in Ghana showed that there was a rapid annual growth in production from 1994 to 2004, setting the pace as Ghana’s first horticultural export product, which made a great contribution to the total GDP of the country (William *et al*., 2017b). It was also asserted by Agyare (2010) that pineapple is by far the most important crop within the horticultural subsector of the Ghanaian economy, since it has maintained its status as the key exportable horticultural crop since 2013 (ISSER, 2015). The predominant varieties usually cultivated in Africa and Ghana are Smooth Cayenne, Sugarloaf, and MD2. The development of the MD2 variety changed European pineapple preference, and this led to rapid market changes and reduction in international demand for Smooth Cayenne (Kleemann, 2016). Pineapple is an essential raw material for local processing industries, and for local consumption. Large and medium commercial farms account for about 70 % of production, with the remaining quantity produced by smallholders cultivating between 1 and 10 acres. In Ghana, the production of pineapple is predominant in the Eastern, Greater Accra, Central, and Volta regions (Ninson, 2012).

Good fruit quality is attributed to growing sites having a combination of relatively cool night temperatures, sunny days, and high day temperatures (Hossain, 2016). According to Williams *et al*. (2017b), climatic conditions such as rainfall and temperature have a significant impact on pineapple production, especially in the tropics, with a suitable temperature and rainfall range of 18 to 32 °C and 1000 to 1500 mm/annum, respectively. Generally, pineapple requires a minimum monthly rainfall total of 50 to 100 mm. If the annual rainfall of an area is less than 500 mm, irrigation is required for better yield (Carr, 2012). Thus, tropical countries with enough water available for crop production are found to be most suitable for pineapple cultivation (Bartholomew *et al*., 2003; Zottorgloh, 2014).

Pineapple plants are drought-tolerant, and yet their growth can be retarded due to seasonal drought and water shortage (Hossain, 2016). According to Zottorgloh (2014), rainfall irregularity may lead to a delay in some phenological stages of the pineapple plant, thus affecting its growth and yield (Bartholomew *et al*., 2003). Pineapple farmers attach a lot of relevance to practices such as fertilizer application, forcing, amongst others while neglecting irrigation practices, with the perception that pineapple is drought-resilient. Taking into consideration the current climatic variances with its consequential uncertain seasonal rainfall distribution and imbalance in most parts of the world, the impact of long drought on pineapple plant growth, yield and quality cannot be underrated.

Generally, pineapple under irrigation produces high yield and good fruit quality (Midmore *et al*., 2012). It is therefore important for farmers to consider appropriate irrigation practices in the cultivation of pineapple (Zottorgloh, 2014). However, pineapple is sensitive to water-logging and therefore requires well-drained soil with good aeration when grown with irrigation (Midmore *et al*., 2012). A study by Ninson (2012) on pineapple production in the then Akuapim South Municipality reveals that there are no irrigation facilities for pineapple production. None of the farmers used irrigation facilities. This situation also limits the scale of production (Ninson, 2012). Though there are a lot of large-scale commercial pineapple farms (with land holding >100 ha) in the production hotspots, most of such farms cultivate under rainfed conditions. Therefore, the study sought to ascertain the performance of pineapple (MD2 variety) under drip irrigation and rainfed conditions at Bomarts Farms in the Coastal Savannah Agro-ecological zone.

1.2 Problem Statement

Currently, most of Ghana's pineapple cultivation is rainfed (Williams *et al*., 2017a). Pineapple emerged as one of Ghana’s horticultural export crops, with the production hotspots in the Eastern, Greater Accra, Central, and Volta Regions with several commercial pineapple farms that produce for exports and local purposes. Studies have revealed that most of these large-scale commercial farms produce under rainfed conditions (Ninson, 2012) despite current climate variability with uncertain rainfall pattern. Although pineapple is drought-tolerant and can withstand harsh weather conditions, studies have also revealed that optimum water supply to the crop has a high potential of increasing and sustaining its yield (Patra *et al*., 2015). However, these studies are scanty and were not conducted under local conditions. Over 70 % of studies on pineapple in Ghana focused on the production efficiency of pineapple (Idris *et al*., 2013; Ahwireng, 2014; Ofori-Appiah, 2018) and financial profitability of the value chain (Kleemann and Abdulai, 2013; Annor, 2017) with only a few studies conducted looking at the agricultural practices necessary for successful production (Aboagye, 2002; Carr, 2012; Gerchie, 2014). At the global level, the effect of potassium concentration (Soares *et al*., 2005); chemical composition (Bartolomé *et al*., 1995); fruit translucency (Chen and Paull, 2001) among others have been considered in several studies. Postharvest technology has also been assessed extensively (Reyes *et al*., 2004; Soares *et al*., 2005; Wijeratnam *et al*., 2005). However, water management and irrigation practices in the cultivation of pineapple has not been adequately researched and thus, poorly understood. There is scanty information comparing pineapple production under drip and rainfall, and its effect on fruit yield and quality (storability and sugar content) in Ghana. Thus, there is a knowledge gap in a comparative study of pineapple production under rainfed conditions and irrigation. This study sought to comparatively evaluate the performance of pineapple (MD2 variety) under drip irrigation and rainfed conditions at Bomarts Farms in the Coastal Savannah ecological zone in Ghana.

1.3 Justification

As discussed earlier, there are few studies that compare the production of pineapple under rainfall and irrigation conditions in Ghana. Thus, the actual pros and cons of adopting the irrigation system for the pineapple crop in our local condition has not been established. Farmers continue to cultivate pineapple under uncertain rainfall, since there are few existing documents that can offer technical advice. This study produces information which can be useful to the pineapple sub-sector and for potential increase in yields and fruit quality. It also fills the literature gap on the subject matter, thereby adding to the body of existing knowledge on pineapple production in Ghana and the world at large.

1.4 Objectives of the Study

1.4.1 Main Objective

The main objective of the study was to conduct a comparative performance evaluation of pineapple (*Ananas comosus var., MD2)* production under drip irrigation and rainfed conditions using Bomarts Farms in the Coastal Savannah zone of Ghana as a case study.

1.4.2 Specific Objectives

The specific objectives of the study were to;

1. Determine the Crop Water Requirement of pineapple (*Ananas comosus var., MD2)* in Ghana's Coastal Savannah Agro-ecological zone.

2. Assess the performance of the existing drip irrigation system at Bomarts Farms for meeting Crop Water Requirement of pineapple.

3. Compare the yield and quality (sugar content, storability) of pineapple (var., MD2) under drip irrigation and rainfed conditions.

4. Analyze the cost-benefits of producing pineapple under drip irrigation and rainfed conditions.

1.5 Research Questions

1. What is the crop water requirement of pineapple in the study area?
2. What is the technical performance level of the drip irrigation system at Bomarts farms?
3. What is the yield and quality (sugar content, storability) of pineapple produced under drip irrigation rainfed conditions?
4. What is the cost involved in producing under drip irrigation and rainfed conditions and the related returns?

1.6 Organization of the Thesis

The study is made up of five chapters; Introduction, Literature Review, Materials and Methods, Results and Discussion, and Conclusion and Recommendation, respectively. In the chapter one, which is captioned as “Introduction”, Background to the Study, Problem Statement, Justification, Objectives of the Study, Research Questions, and Organization of the Thesis are captured. Chapter two presents a synthesized review of extant literature relevant to the study. Chapter three presents the various materials and methods used in the study. The Study Area, Local Climate and Soil Characteristics of the Study Area, Materials and Equipment for the Study, Measurements and Relevant Calculations, The FAO CROPWAT

Software and its required input data and several others are presented in the chapter three of this thesis. Chapter four deals with the results and discussions of the study findings. In chapter five, the study findings are summarized, and conclusions are drawn. Based on the findings of the study, policy recommendations and recommendations for further study are made.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin, Botany and Varieties of Pineapple

Several studies have expounded on the antiquity of the pineapple (*Ananas comosus*) fruit (e.g., Rohrbach *et al*., 2002; Lobo and Siddiq, 2017), leading to detailed documentation of its origin, and botany. According to Bartholomew *et al*. (2003), pineapple was always part of the diet of Native Americans in the lowland tropics. In addition to the fresh fruit, the ancient Americans used pineapple for medicinal purposes such as an abortifacient, emmenagogue, amoebicide, and vermifuge. This is because of its unique protease bromelain (Bartholomew *et al*., 2003).

Pineapple is a monocotyledonous herbaceous perennial which belongs to the family Bromeliaceae and genus *Ananas* thus, *Ananas Comosus* L. Merr. is the specie name. Pineapple plants' flowers produce multiple fruits (Wali, 2019). Morphologically, the roots, peduncle, stem, leaves, amongst others distinguish it from other tropical fruits. As a gametophyte, it is self-incompatible with pollen tube growth being slowed in the upper third of the style. Pineapple is non-climacteric; thus, it should be harvested at the consumer's preferred level of ripeness (Paull *et al*., 2017). Based on the cultivar, weight of the fruit varies from 0.8 to 15 kg. with an adult plant being 1 to 2 m wide and 1 to 2 m high, within the overall shape of a spinning top (Rohrbach *et al*., 2002; Chan *et al*., 2002).

Commercially propagated for its nutritious fruit, pineapple is the only species in the Bromeliad family that is widely grown for its fruit (Paull *et al*., 2017). It is considered as the third most important tropical fruit, after banana and citrus, in terms of global production (Lobo and Siddiq, 2017). The exceptional aroma and flavor, appealing appearance, and important nutritional makeup (vitamins, minerals, fibre) make it the consumer's preferred choice of tropical fruit.

Although there are six well-known varieties at the international level; MD2, Smooth Cayenne, Sugarloaf, Red Spanish, Abacaxi, and Queen, the widely-spread and accepted fresh fruit variety for the export market is the MD2 hybrid (Paull *et al*., 2017). The second preferred cultivar for canning is ‘Singapore Spanish’ also known as ‘Singapore Canning’ (Chan *et al*., 2002).

2.2 Overview of Pineapple Production

Pineapple is considered as a tropical fruit that is very well appreciated all over the world and has high economic importance (Cahyono *et al*., 2016), accompanied by excellent organoleptic qualities. Being cultivated purposely for its fruit (Carr, 2012), it is the only source of bromelain, an enzyme used by pharmaceutical industries (Cahyono *et al*., 2016). Pineapple has other uses such as being used for meat tenderizing, as an ingredient for foods, it is used in the brewery and for medicinal purposes. Its leaves and stems can also serve as a source of fibre for paper and cloth-making, whereas animals can feed on its waste. The tropical fruit is well suited because it is a homogeneous high-value crop, compared to other crops like coffee where a lot of different varieties and quality grades prevail (Kleemann, 2016). Cultivated pineapple (*Ananas comosus L.*) crop has an adaptation system of photosynthetic carbon fixation that allows it to be highly productive in limited water availability conditions (Cushman, 2005). Therefore, tropical countries are most suitable for pineapple plantations, mainly in the regions with low water availability. With over five (5) commercially cultivated varieties, the smooth Cayenne cultivar is extensively cultivated in many tropical countries: Hawaii, Philippines, Australia, South Africa, Puerto Rico, Kenya, Mexico, Cuba.

In Indonesia and Thailand, a large area is demarcated for the Smooth Cayenne variety which is purposely grown for processing industries. However, Costa Rica, Columbia, Honduras, and the Philippines grow MD2 on a large scale. In many other parts of the world, particularly the tropics and subtropics, small-scale farmers grow the Smooth Cayenne for the local fresh fruit market and export. Brazil is known as a major producer of pineapple, and the Perola variety is the main cultivar cultivated there, purposely for the local market. Brazil also grows cultivars such as the MD2, Smooth Cayenne, BRS Imperial, and many more (Viana *et al*., 2013). Coastal tablelands of Paraı´ba state are traditionally used for growing pineapple and sugarcane. Thailand's scale of production is like that of Ghana, with over 90 % of production coming from small-scale farmers (Bartholomew *et al*., 2003) with land holdings ranging from 1 to 5 hectares (hereafter ha). Contrarily, Indonesia and the Philippines have almost all their production coming from large-scale farmers (Carr, 2012)

A decade ago, Brazil was the leading producer of pineapple (60,000 ha for 2.49 million tonnes), followed by Thailand, the Philippines, and Costa Rica who produced 2.28 million tonnes from 90,000 ha, 2.21 million tonnes from 58,000 ha, and 1.67 million tonnes from 33,000 ha respectively (Carr, 2012). Currently, Costa Rica is the leading world producer, which exported 2,247,096 tonnes in 2021 and

2,194,490 tonnes in 2022 according to the FAO (2023) statistical compendium on major tropical fruits.

From 2018 to 2022, according to the FAO (2023), Asia produced an average of 638,440.8 tonnes of pineapple with the Philippines and China leading production at mean volumes of 542,176 tonnes and 39,492 tonnes (2018 to 2022), respectively. Africa produced an average of 75,485 tonnes from 2018 to 2022. The top producers were Cote D'Ivoire and Ghana with mean production volumes of 29,655.2 tonnes and 10,322 tonnes from 2018 to 2022, respectively (FAO, 2023). In Central America and the Caribbean, the average production from 2018 to 2022 was 2,380,350 tonnes, with the leading producers being Costa Rica and Honduras who produced an average of 2,195,526 tonnes and 70,862 tonnes, respectively as shown in Table 2.1. South America's average production for 2018 to 2022 was about 107,813.6 tonnes, with Ecuador and Columbia leading in production at average volumes of 92,762.8 tonnes and 8,527.4 tonnes from 2018 to 2022, respectively as indicated in Table 2.1. Whilst Asia leads pineapple production at the continental level, Costa Rica is presently the world's leading producer and exporter of pineapple. The USA accounted for 42.6 % of Costa Rica's total pineapple exports. Other expert destinations were the Netherlands (7.7 %), Spain (7 %) and Italy (6.3 %) (GEPA, 2022).

Table 2.1: Leading World Pineapple Exporters at Continental and Country Levels (in tonnes)

Country	2018	2019	2020	2021	2022	Average
			tonnes			
Asia	489461	756713	683690	619996	642344	638440.8
Philippines	391982	631486	594726	536719	555967	542176
China	37899	57337	47738	30308	24178	39492
CA & Caribbean	2523364	2398191	2209454	2425358	2345384	2380350
Costa Rica	2308339	2197992	2029713	2247096	2194490	2195526
Honduras	71449	78360	62593	72984	68924	70862
South America	100694	103123	96472	114359	124420	107813.6
Ecuador	80750	89002	84267	100197	109598	92762.8
Columbia	15549	8922	5822	6627	5717	8527.4
Africa	71964	75143	79020	76093	75205	75485
Cote D'Ivoire	30469	32064	26063	30917	28763	29655.2
Ghana	20036	18957	8214	2466	1937	10322

(Source: FAO, 2021, 2023)

Costa Rica, Côte D'Ivoire, Ecuador, and Ghana are the top 4 countries that export pineapple to Europe, with a total market share of 69.2 % (GEPA, 2019). According to GEPA (2020), 79 % of pineapple export from Ghana ends up in Europe. However, seven percent (7 %) of France's pineapple import was from Ghana, with Costa Rica supplying about 43 % whilst Cote D'Ivoire and Ecuador supplied 11 % and 8.5 %, respectively to the French market (GEPA, 2019).

2.3 Ghana's Pineapple Production Sub-Sector

It is reported that the introduction of pineapple in Ghana is traceable to the arrival of the Portuguese on the west coast of Africa in 1548. In the account of Pinto (1990), it is revealed that production in Ghana began in Samsam, a community in the Greater Accra Region. The pineapple industry in most countries in sub-Saharan

Africa was started and developed by multinational companies such as Compagnie Fruitière, Dole, Del Monte, etc. However, this is not the case for Ghana's pineapple industry which was kick-started by small-scale local farmers (Danielou and Ravry, 2005) under the sponsorship of government developmental projects to diversify, dilate and augment the country's export portfolio. This was further to ameliorate the livelihoods of farmers who lost their cocoa farms in the 1980s due to bushfires and blight.

From the late 1970s to the mid-1980s, there was a decline in Ghana's economic growth because of high inflation rates, high public debt, etc. Consequently, employment numbers, agricultural growth, exports, and production volumes were stifled, and this widened and entrenched the poverty gap of the country (Achaw, 2010). Whilst the prices of main export commodities such as cocoa and gold at the world market plunged, the then government implemented Structural Adjustment Programmes (SAPs) in the 1980s. Thus, diversification programs that introduced commodities like timber, aluminum, and non-traditional export (NTE) crops (e.g., pineapple and papaya) were incorporated into the export portfolio (ISSER, 2003). This led to rapid growth in the NTE products sub-sector from the mid-1980s and during this period, pineapple production in Ghana intensified and retained a higher share in export to Europe.

In the diversification of Ghana's export portfolio to ensure that decline in economic performance is forestalled, other non-traditional crops such as citrus, mango, and papaya were commercialized and are beneficent. However, they are not at par with the pineapple industry's contribution to Ghana's economy, in terms of revenue generation from export and employment (Achaw, 2010). Ghana started exporting pineapples to Europe in the 1980s, and this gained much momentum after 2000. However, the sub-sector was affected when Costa Rica released the MD2 variety in 1996. From 2004 to 2007, there was a decline in Ghana's export volumes which greatly affected small-scale farmers who primarily constituted the sub-sector (Fairtrade Foundation, 2009). The MD2 variety had extensive research support and strong marketing campaigns from multinational organizations, such as Dole and Del Monte.

In 2001, high levels of residual ethephon, far above the maximum acceptable EU residual levels, were detected in some sampled pineapples exported from Ghana to Europe (Gogoe, 2004). Since then, Ghana has not been able to retain its share of pineapple export to Europe. For producers who would like to export to Europe, which has been Ghana's pineapple export destination, a certification known as the GLOBALGAP became necessary. Due to the high cost involved in Good Agricultural Practice (hereafter GAP) compliance, most farmers, according to Achaw (2010) were not certified and this discouraged many. However, in 2008 the government together with the World Bank contributed an amount of US$2 million for the industry for MD2 plantlets to be made available to farmers and Ghana could export about 42,000 tonnes of MD2 pineapple. Figure 1 shows the trend in Ghana's production volume for export from 2008 to 2021.

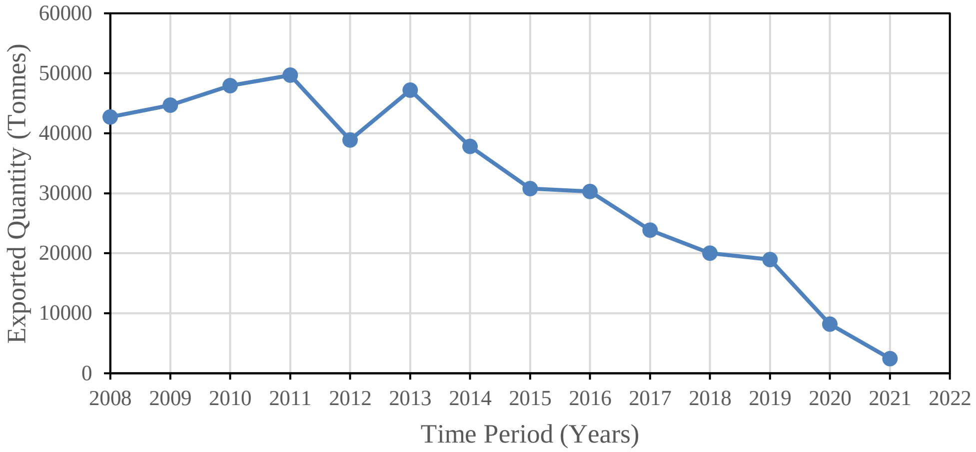

Figure 2.1: Trend in Ghana's Gross Pineapple Export

(Source: FAO, 2021, 2023)

In Ghana, the pineapple subsector is known to be the most developed and well-structured horticultural sector. The production hotspots are the Greater Accra, Central, Eastern, and Volta regions where the subsector mainly constitutes smallholder farmers and a few other private-owned large-scale farms who usually produce for export to parts of Europe, and in most instances, contract small-holder farmers to produce per their specifications (Fold and Gough, 2008). In 2018 and 2019, pineapple export from Ghana to France was worth US$ 2,105,398 and, US$ 1,894,091 and US$ 343,000 worth of pineapple were exported to Germany in 2018 and 2019, respectively. Pineapple export to Belgium and Italy was worth US$ 3,414,594 and US$ 2,007,534 and US$ 49,817 and US$ 242,147 for 2018 and 2019, respectively (GEPA, 2019).

Ideally, pineapple stays on the field for about 11 to 18 months after planting, and this depends on the soil physicochemical properties, water availability, just to name a few. Mostly, the cost of production is influenced by other factors such as the variety, and the production scale, aside from the type of production method adopted, either organic or inorganic (Williams *et al*., 2017a).

The main cause of the structural changes in the subsector is the switch from the Smooth Cayenne to the MD2 variety. Of late, the Smooth Cayenne variety is processed into fresh or dried cuts for export, and it is preferable for juice making. MD2 is more vulnerable to blights and pest attacks than the Smooth Cayenne variety. Thus, in the early days of its introduction in Ghana, costs for MD2 suckers constituted about 70 % of production cost. Currently, MD2 suckers are not as expensive as they used to be (GEPA, 2019).

2.4 Environmental Factors for Sustainable Pineapple Production

Pineapple thrives very well in tropical and subtropical regions with a climate that ranges from the mild coastal zone to about 1000 metres a.m.s.l altitude, on the condition that the milieu is devoid of frost. Thus, pineapple is commercially cultivated in a humid and warm climate, with latitudes ranging from 30°N and 33°S in the Northern and Southern Hemisphere (Cahyono *et al*., 2016). Studies have shown that the most favourable range of temperature for pineapple cultivation is from 18 to 35 °C, and best fruit development in terms of yield and quality can be achieved with environmental temperature from 22 to 32 °C and relative humidity should be more than 70 % (Midmore *et al*., 2012).

Generally, saturated soils do not support pineapple production and growth. Studies have proved that the plant is well-suited for well-drained soils that have a good supply of oxygen. Such soils are sandy and intermediate textured soils, with a satisfactory acidic level of 4.5 to 5.5 (Reinhardt *et al.*, 2017). A well-prepared soil devoid of fragipans is necessary for good growth and establishment of the pineapple root system, according to Reinhardt *et al.* (2017), and that if the soil is supplied with organic matter and protected with mulch, it aids in the fast development of the crop. For Reinhardt *et al.* (2017), an adequate supply of nutrients to the pineapple crop is necessary but it should correspond with the growth stage of the plant, whilst weeds are also handled by an integrative management approach (mechanical, chemical, and cultural). Reinhardt *et al.* (2017) suggested that covering the soil with locally-available biomass can be adopted to minimize the occurrence of soil erosion and loss in organic matter.

2.5 Approaches to Crop Water Requirement Estimation

Crop water requirement (CWR) depends on climate, and irrigation scheduling is usually dependent on ETc. To have a reliable CWR estimate, it is necessary to adopt the right tools and/or approaches, for enhanced water productivity (Guerra *et al.*, 2015). Since the FAO 56 reports a wide range of Kc values (Guerra *et al.*, 2015) asserted that using the FAO-56 method could be an oversimplification of what is needed.

In estimating reference evapotranspiration, a lot of climatic parameters are required and this includes relative humidity, air temperature, sunshine hours, solar radiation and wind speed. Unfortunately, there are few weather stations in many regions where such datasets of these climatic variables can be sourced (Feng *et al.*, 2021). Thus, many researchers have developed empirical models which require fewer weather data. A typical example is the Hargreaves model which requires only temperature data. For any method chosen, it is important to consider the data available, and the accuracy of the model (Feng *et al*., 2021).

Scholars have had excellent outcomes by using different Artificial Neural Network (ANN) algorithms to model the reference evapotranspiration under climatic assumptions. Landeras *et al*. (2008) and Khoob (2008) estimated reference evapotranspiration without the use of daily light. With five meteorological datasets, Mattar (2018) developed eight ETo estimation models with Gene Expression Programming (GEP) intelligent algorithm, with the outcomes closely related to FAO-56 PM estimation. Simply put, GEP is more accurate than Hargreaves and Samani models, Irmak, TURC and Irmark models for ETo estimation. Also, Feng *et al*. (2021) used just the maximum temperature, minimum temperature and relative humidity to predict ETo. In testing the model, Feng *et al*. (2021) realized that the K-Near Neighbour (KNN) algorithm's accuracy is not satisfactory. With few variations such as normalization, using different weights and Kc values, the model gave a good output closer to that of FAO-56 output.

Crop evapotranspiration (ETc) is a necessary input needed to calculate or estimate CWR. Researchers have used several approaches to accurately estimate it; using weighing lysimeters, Bowen ratio and the Eddy correlation method (Elnashar *et al*., 2021). These methods are reliable options for determining evapotranspiration at an accurate level for a homogeneous area. However, for large areas, it has practical limitations because of the number of sites to consider in providing point values of evapotranspiration for a given area. Also, such evapotranspiration estimation approaches are difficult to extend to produce maps at high accuracy, over a large area (Elnashar *et al.*, 2021). Typically, ETc values are a product of crop coefficients (k_c) and weather-based reference evapotranspiration (ETo), and this approach is flawed for several reasons, in that ETo is exclusively a function of weather parameters.

According to Elnashar *et al*. (2021), k_c values for a similar crop were significantly different among locations because of variations in climate, crop growth stages, soil properties, crop variety, irrigation method and regime, and crop management practices. The soil moisture stress level is not considered. Elnashar *et al*. (2021) asserts that ETc values obtained from this approach relative to using the lysimeter are accurate if it is well done, since it has an error margin of ±20 %. However, the accuracy of this approach relies on climatic data, which are mostly unreliable in most parts of the world. Thus, scholars have resorted to remote sensory data for ETc estimation over large areas.

With excellent spatial mapping results, the estimation of ETc with a remote-sensed dataset has become suitable in water resources optimization (Fisher *et al*., 2017). A myriad of remote sensing models for ETo estimation have been developed from satellite images; Surface Energy Balance System (SEBS), the Surface Energy Balance Algorithms for Land Model (SEBAL), Mapping Evapotranspiration at High Resolution with Internalized Calibration (METRIC). The Atmosphere-Land Exchange Inverse (ALEXI) and, operational Simplified Surface Energy Balance (SSEBop) (Bastiaanssen *et al*., 1998; Allen *et al*., 2007; Anderson *et al*., 2007; Senay, 2018). The SEBAL model has proven effective with the least number of inputs. As a result, according to Elnashar *et al*. (2021), it has a lot of promise for use in less developed nations where water management policies are often lacking and ground.

2.6 Crop Water Requirement of Pineapple

Crop Water Requirement (CWR) is the quantity of water that commensurate to the water lost from a cultivated field by evapotranspiration, which is expressed as ET_c in mm/day (Mebrahtu *et al*., 2021). It depends on conditions such as climate, crop type, and area, soil physical properties, growing seasons (FAO, 2009). The main parameters which affect CWR values are Crop Coefficient (Kc), and potential evapotranspiration (ET_o). The simultaneous loss of water from a cropped soil surface and plant stomatal pores by evaporation and transpiration respectively is known as evapotranspiration. It constitutes a major part in the water cycle, and it is a basic factor for irrigation scheduling (Feng *et al*., 2021).

Climate variability and change affect the hydrologic cycle, which is constituted by relevant phenomena such as evapotranspiration (Rezaei *et al*., 2016). According to Chowdhury *et al*. (2015), an increase in temperature results in a rise in evapotranspiration, and this can be attributed to the widening of stomatal pores of plant leaves during high temperatures, allowing for the rapid loss of water vapour (Urban *et al*., 2017; Onyutha, 2020). Scholars (Rotich and Mulungu, 2017; Salman *et al*., 2020) asserted that there might be consequent effects on CWR and water availability to crops when there is a rise in temperature, evapotranspiration, and variable rainfall patterns. Prolonged dry conditions or drought might occur with low or inadequate precipitation, and a rise in temperature, which may consequently affect CWR (Onyutha, 2020).

There have been many experimentally-proven approaches and methods developed to estimate or determine CWR. The Blaney-Criddle method is the oldest and yet simplest, and the FAO Penman-Monteith is the recent and accurate method of determining CWR, thus it is suggested as the suitable method to determine reference evapotranspiration with climate data (Ewaid *et al*., 2019; Feng *et al*., 2021). Also, the FAO has developed a decision-support tool called CROPWAT for irrigation scheduling and management, which is mostly used to estimate reference evapotranspiration (ETo) and CWR. It incorporates the process involved in determining reference evapotranspiration and CWR, allowing for the modelling of crop water use in varying conditions (climatic, crop, and edaphic). It aids in adopting suitable irrigation schedules and practices, and rightly assessing crop production under irrigation or rainfed conditions (Gabr, 2021).

CROPWAT aids in estimating crop evapotranspiration (ET_c), agricultural water requirements, and irrigation scheduling. Every crop has a peculiar water requirement, with the same weather conditions. With ineffective irrigation design and scheduling, and judicious use of water, especially in arid areas, CWR estimation is relevant (Rowshon *et al*., 2014; Xu *et al*., 2021). A fair idea about the crop water needs will aid in the proper planning of the irrigation regime and management (Mebrahtu *et al*., 2021).

According to Carr (2012), water lost from the soil and crop surfaces is the major component of evapotranspiration in the daytime, in a fully matured pineapple crop. At the vegetative stage, pineapple uses about 3.5 mm of water in a day, and a total of about 1421 mm for 270 to 330 days (de Azevedo *et al*., 2007). The monthly water requirement of pineapple is in the range of 50 to 100 mm (Carr, 2012).

Pineapple is adaptive to areas with low rainfall, and this is quite different from most commercial crops. With a special photosynthetic feature facilitated by Crassulacean Acid Metabolism (CAM), the plant takes in carbon dioxide (CO_2) at night. The small-sized and few stomatal pores on the abaxial surface of pineapple leaves which open during the night, and mid-afternoon but close in the daytime, results in the use of about 60 to 80 % of CO_2 at night (Carr, 2012).

Plants with CAM survive prolonged drought periods because their leaf tissues can keep water, and counteract the reverse flow of water from its storage tissues into the planting medium. This special feature aids the plant to conserve water, especially when grown in arid areas (Carr, 2012). CAM plants' water-use efficiency is six times higher than C3 plants and thrice higher than C4 plants. Scholarly reports reveal that pineapple uses a disproportionate quantity of water during the night, whilst some also argue that evapotranspiration in the plant occurs during the daytime (Carr, 2012). Carr (2012) reported an average pineapple water requirement of 4 mm/day, irrespective of the plant’s growth stages, with a crop coefficient (k_c, maintained at 0.88, relatively higher than what Allen *et al*. (1998) recommended for the various stages; the initial stage, $k_c = 0.50$; mid-season, $k_c = 0.30$; end-season, $k_c = 0.30$. The underlying assumption was that 50 % of the ground surface is covered with black plastic mulch.

2.7 Pineapple Production in Rainfed or Irrigation Conditions

Advancement in the application of irrigation water provides an important management tool that allows farmers to grow high-yield varieties, apply appropriate plant nutrient amounts, practice integrated pest control, and other inputs to create suitable conditions for crop yield increment (Guerra *et al*., 2017). The application of water by a sprinkler is identified as an appropriate method of irrigating pineapple plants since uniform application might be achieved (de Azevedo *et al*., 2007). According to de Azevedo *et al*. (2007), irrigating pineapple plant should be carried out in the plant's phenological growth stage of the actual crop growth (planting to flower induction) to forestall the occurrence of water stress. In the view of de Azevedo *et al*. (2007), the sugar level greatly increases in a fruit when water is applied during the flowering stage till harvesting, which also catalyzes fruit spoilage.

Rainfall irregularity produces a delay in some phenological stages of the pineapple plants, resulting in a reduction of the production of the fruit (Zottorgloh, 2014). Although most of the pineapple crop has been grown in a rainfed system, appropriate irrigation practice needs to be incorporated into its production system. The morpho-physiological mechanism of pineapple plants allows them to use the water more efficiently, resulting in a transpiration rate ranging from 0.3 to 0.5 mm per leaf square centimetre per hour (Py, 1965). However, water limitation in any phenological phase results in low crop productivity even for those areas where the use of supplementary irrigation has not been applied appropriately. The optimal yearly precipitation varies from 1000 to 1500 mm, evenly spread all year, for rainfed pineapple crop growth (Peiris and Wickrama, 2015). Supplementary irrigation is only necessary in regions where seasonal rainfall amount falls below a certain threshold and also poorly distributed with long period drought. Evenly distributed rainfall or irrigation of 600 mm per year is adequate for maximum growth (Evans *et al*., 2002).

On the other hand, over irrigation has not led to significant increases in crop productivity but rather bring about water logging condition which affect the physiological development of the crop. The lack of information on the actual crop water requirements therefore results in either under or over irrigation of the crop.

Herbicides that are broadcasted over the farm area get washed off on the plastic by rain and/or irrigation water from sprinklers and concentrated in areas that are open and uncovered between the sheets of plastic (Dusek *et al*., 2010). Drip irrigation is used where the water supply is restricted, the cost of labour is high and cultivation techniques are advanced. Micro-jets can also be used, as any of the overhead sprinkler systems, depending on local circumstances. For example, rain-guns and booms attached to hose-reels are used to irrigate pineapples in Indonesia, Ghana, South Africa, and Thailand as revealed by Carr (2012).

Studies in Hawaii have shown that sprinkler system is good for establishing newly-planted pineapple suckers in the dry season (2012). Whilst drip irrigation may be from planting to just before harvest, sprinkler (overhead) irrigation should not be used throughout the growing stages but from planting to the onset of the open petal to control fruit disease infestation (Carr, 2012).

2.8 Overview of Drip Irrigation

Drip irrigation is a micro-irrigation approach with the main principle of supplying the needed amount of water to plants around the plant root zone, without necessarily wetting an entire land area. This method of irrigation ensures high water use efficiency, since a dense root system is developed by plants within the wetted area (Singh, 2012). With its high prospects to increase yields at the minimum application of water, agrochemicals and labour in some cases, the drip irrigation method has gained much attention in recent times. Drip irrigation method has proven to be suitable for vegetable, orchard and plantation crops (Singh, 2012). Thus, in most developed parts of the world such as Hawaii, large-scale plantations usually adopt drip irrigation methods together with the use of plastic mulch on beds or ridges to forestall the volatilization of pesticides and other chemicals supplied to the pineapple plant (Carr, 2012). Often, a bed of a given length has two rows of pineapple plants. A drip line is to a bed/ridge, placed beneath the mulch, at the centre of the two rows. In such an instance, an emitter caters for two plants (Carr, 2012). With such a practice, the drip system is to supplement rainfall, and this has become a common practice even with some large-scale farms in Ghana.

2.9 Hydraulics of Drip Irrigation System

The hydraulic function of trickle/drip irrigation system is evaluated by distribution uniformity, which is assessed with the indicators; emission uniformity, coefficient of uniformity, coefficient of variation and manufacturing variation coefficient (Solomon, 1979; Wu and Gitlin, 1983; Wu, 1997).

The metrics for the hydraulic performance of trickle irrigation system are helpful for system design and operation (Kumar and Singh, 2007). Wu and Gitlin (1974) developed a simple mathematical formula for estimating pressure drops along the span of a drip line, whereas Keller and Karmeli (1974) concocted an exponential equation for the emitter properties. Watters and Keller (1978) supposed that the drip tubes were hydraulically smooth, hence the Darcy-Weisbach formula was used to calculate the friction-induced head loss in trickling irrigation system. Kang and Nishiyama (1994) derived a polynomial equation for the intake outflow and inlet pressure head, which they utilized to build the trickle irrigation system. Singh (1999) specified and defined driplines, laterals, micro-pipes, micro-sprayers, emitters, venturi systems, media filters, and other formalized specs and features. He also elaborated on the various operation and maintenance phases starting from design through to field assessment of a micro-irrigation setup per the Bureau of Indian Standards. For laterals with varying diameters, geometries, lengths, quantities of outlets, and discharges. Shete (2005) presented explanations for variable f-values (Darcy-Weisbach). The f-values for laterals with diameters ranging from 12 to 25 mm were documented for quantities of outlets ranging from 1 to 500.

Gerrish *et al*. (1996) used the finite element approach and the virtual emitter system to enhance the design of large micro-irrigation systems without neglecting tiny pressure loss owing to different networks. The fluid movement in a micro-irrigation setup was characterized using a second order partial differential equation. The equation was solved using Galerkin's version of the finite element approach, which demanded fewer computation time and memory utilization whilst including inputs from all minor system components and retaining correctness. Dandy and Hassanli (1996) provided a similar non-linear formula for the best construction and operation of drip irrigation systems on undulating ground. Their study was focused on splitting sub-units inside a farm, while assessing alternative shift patterns and the related pipeline and pump diameters to discover the lowest price option, which was an advance over earlier models. Based on economic parameters and emission uniformity, Reddy *et al*. (2000) developed a drip irrigation system. At different nodes of the pipelines, the Newton Raphson approach was utilized to work out and compute pressure heads using a different form of the Darcy-Weisbach's and Bernoulli's equations. The pipeline system was designed with the life span method in mind. DRIPCAD, a computer program, was created to solve formulas and identify the most cost-effective pipe diameters depending on emission uniformity and total yearly expense. They estimated a total yearly cost savings of up to 29 % as compared to standards in which emission uniformity was the single consideration in the design process. Dhole *et al*. (2010) conducted experiments to determine drip emitter coefficients for several kinds of drippers. The drip emitter coefficients Kd and x (in the emitters discharge formula, Q = KdHx) of eight distinct brands of emitters from four manufacturers, Jain Irrigation, Netafim Irrigation, EPC Irrigation, and Jivanbindu Irrigation were evaluated in laboratory research using ISO and ASABE specifications. The evaluation was done with 20 drippers of each kind put on a lateral pipe at varied pressures ranging from 6 to 11 m of water column. The results of the trials were analyzed to determine the influence of pressure on emitter outflow and to calculate emitter coefficients. The drip emitter's constant 'x' ranged from 0.056 to 0.54, according to the researchers. According to ISO and ASABE guidelines, EPC Irrigation, Jain Irrigation, and Netafim Irrigation emitters were categorized as 'A' and 'good.' Jivanbindu Irrigation's emitters were assigned to the 'Average' and 'B' categories.

2.9 Performance Indicators of Drip Irrigation System

Scholars have used various techniques and methods to evaluate the performance of drip irrigation systems. The mostly employed performance indicator has been the Uniformity Coefficient, which is underpinned by scholarly works by Christiansen (1942), Wilcox and Swailes (1947), Hart *et al*. (1979), Burt *et al*. (1997), Ascough and Kiker (2002) and many others.

According to Solomon (1979), the performance of drip irrigation systems is determined by the emission uniformity across the network. The unit-to-unit fluctuation among emitters is a big component impacting uniformity. The degree of unit-to-unit variation that may be expected depends on the layout of an emitter, the materials used to make it, and the maintenance and care rendered throughout the production process (Leo, 2004).

Investigating the effect of water quality on distribution uniformity of drip systems, Capra and Scicolone (1998) asserted that sampling 16 emitters is adequate to assess the uniformity distribution of a drip irrigation system. These samples are selected at different points on laterals in relation to the point of water entry (Bajpai, 2014).

Gontia *et al*. (1998) published the findings of an experimental investigation that measured uniformity at various levels of emitter blockage. They suggested that for hydraulic assessment of a system with blocked emitters, absolute uniformity should be used as an indicator. Mofoke *et al*. (2004) designed, constructed and evaluated the hydraulic performance of a low-cost constant-pressure drip system with a continual flow of water. Results of the system's evaluation revealed that high Application Efficiencies in the order of 95 %, 96 %, 96 %, and 98 % under continuous discharges of 9 %, 13 %, 17 %, and 21 % drops/min respectively. The corresponding Irrigation Efficiencies were 94.0 %, 90.1 %, 91.0 %, and 88 %. Measured Distribution Uniformity for the four treatments were 90.0, 91.4, 93, and 97 %, while the Adequacy of Irrigation were 92.0 %, 93.1 %, 94.0 %, and 98 % for the four treatments in the same order. Such high values of measured performance parameters indicate an excellent exploit of the continuous-flow system. For applicability and conceptual goodness, performance measures have been understood in different ways to account for one aspect or the other, or in applicability to one or the other irrigation strategy (Burt *et al*., 1997).

Aside from how thoroughly the given water is being used, it's also crucial to consider how evenly the water is delivered to the plant (or the soil, for a pre-irrigation). A non-uniform water supply will not only deny areas of the crop of required water, but it can also over irrigate portions of a field, resulting in poor drainage, plant damage, soil salinity, and chemical transmission to the water table (Solomon, 1984). The term "Distribution Uniformity," or "DU," refers to the consistency at which irrigation water is supplied over a field's various sections

(Burt *et al.*, 1997). Moreover, expressing DU simply in terms of infiltration depth after watering, as is often done, excludes both fluids collected by the canopy and evaporation that affects crop transpiration, both of which are percentages of the disseminated water but never add to infiltration depth. Incorporating certain proportions into light sprinkling usage, for instance, might greatly increase the estimation of actual DU compared to a DU computed from soil moisture assessments after the event (Burt *et al.*, 1997). Furthermore, field techniques of analyzing sprinkler pattern overlap nearly often employ catch cans well above canopies and quantify intercepted, as well as penetrated, and depths. As a result, for the purposes of quantifying DU, the term ‘accumulated water’ is used to encompass canopy interception, infiltration, and transpiration decrease while irrigating. The proportion of any estimate of the least accumulated depths in the distribution to the average thickness gathered is commonly described as DU. In principle, a uniformity ratio might be described by means of a measurement of the distribution's greatest values. According to Burt *et al*. (1997), no numeric number can properly depict the variance in application depth throughout the field area without a sense of it. A description is as good as the other if specific assertions about the real form of the cumulative public water function are made. Despite this, the shortest depths have typically been chosen to represent homogeneity due to the significance of appropriate irrigation to agricultural production.

According to Ascough and Kiker (2002), the uniformity of a system's distribution does have an impact on crop production and the application efficiency of the system. Imbalance in distribution results in higher environmental and financial expenses. Extra water used to compensate for inefficient irrigation uniformity might drain nutrients from soil (Ascough and Kiker, 2002). It will raise pumping and fertilizer expenses, as well as having potential ecological effects if excessive surface overflow and groundwater recharge are polluted with chemicals (Solomon, 1984). The uniformity of an irrigation system's distribution is determined by both hardware features and management decisions (Pereira, 1999). Various elements unique to each irrigation system will impact the uniformity of distribution of different forms of irrigation. Soil absorption features have the greatest impact on surface irrigation. The quality of sprinkler sets and the pressure fluctuation within the system have an impact on overhead irrigation. It is also impacted by the wind's intensity and direction (Burt *et al*., 1997). These aspects of an irrigation system must be maintained properly to achieve appropriate distribution uniformity. This will guarantee that water resources are used efficiently (Ascough and Kiker, 2002).

2.9.1 Coefficient of Uniformity

Uniformity refers to the capacity of drip irrigation system emitters to deliver water evenly throughout the whole field. In practice, uniformity is impossible to achieve without flaws. As a result, non-uniformities emerge during irrigation because of under and over-irrigation. As a result, homogeneity is critical in the choosing, design, and management of irrigation systems. Christiansen in 1942 developed the Uniformity Coefficient (CU) being among the first parameters for expressing uniformity. The most generally recognized and utilized criterion for defining uniformity is Christiansen's CU criteria (Zoldoske *et al*., 1994). This coefficient is calculated using catch-can data, with the assumption that all catch-cans reflect the same area. It is calculated by dividing the absolute deviation from the mean by the average. The CU can be written as (Bralts and Kesner, 1983):

$$CU = \left(1 - \frac{\sum_n \left|D_s - \underline{D}\right|}{\sum_n D_s}\right) * 100\ \% \ \ldots\ldots\ldots\ldots\ldots\ldots \ (2.1)$$

where:

CU: Uniformity coefficient (%)

D_s: depth of application in catch can,

$\underline{D}$: Mean depth of application in catch cans

n : Number of catch cans.

2.9.2 Emission Uniformity

Distribution uniformity is another name for emission uniformity. It is a relative indicator of the variation among emitters in an irrigation unit, represented as a percentage. It determines how evenly water is applied throughout the field during irrigation. The emission uniformity is used to characterize the uniformity of micro-irrigation systems and is given by Keller and Karmeli (1974):

$$EU = \left(1 - 1.27\frac{CV_M}{\sqrt{n}}\right)\left(\frac{Q_{lq}}{Q_{avg}}\right) \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots \ (2.2)$$

where:

EU: Emission uniformity (%)

CV_M: Manufacturers’ coefficient of variation for emitters (%),

n: Number of emitters per plant,

Q_{lq}: Average low-quarter emitter discharge (l/h),

Q_{avg}: Total average of emitter discharges (l/h) with similar pressure-discharge association for all emitters.

The various terms in Equation 2.2 factors in system pressure variation and emitter variation, and the equation is preferably accepted due to its simplistic nature (Ascough and Kiker, 2002). Unfortunately, low-quarter averages do not always merge ways, and their appropriate form does not in itself mirror the clarity of the preceding calculations (Clement *et al*., 1997).

In a drip irrigation system, the field emission uniformity, EU, indicates the homogeneity of discharge from all emitters. It may be deduced out of the formula given by Keller and Karmeli (1974).

$$EU = \frac{Q_{min}}{Q_{av}} \times 100\ \% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.3)$$

where:

EU: – Field Emission Uniformity (%),

Q_{min}: Average discharge of the emitters on a quarter of the area receiving, the least amount in the tested subunit (l/h)

Q_{av}: Mean flow rate of emitter at constant temperature (l/h).

High water application uniformity is one major advantage of a well-designed drip irrigation system relative to the other irrigation methods (Pitts *et al*., 1986). Poor water application uniformity can lead to low yields of crops. Application uniformity depends on several factors such as emitter manufacturing variation, hydraulic variance in irrigation units caused by land slope, emitter clogging, sensitiveness of emitter to temperature and pressure variations, and, in-pipe head losses (Mizyed and Kruse, 1989; Rodríguez-Sinobas *et al*., 1999). However, variation in the net on-field water application mostly depends on both the hydraulic and manufacturing variances. According to Gil *et al*. (2008), at a given working pressure, emitter flow variation in non-compensating driplines is a result of the emitter manufacturing variation. According to Senyigit *et al*. (2012) temperature variations do not affect flow rate variations in emitters, but rather variations are a result of physical problems. The terrible problem is when emitters are clogged by biological and particulate materials, leading to poor field application uniformity (James, 1993).

2.9.3 Emitter Flow Variation

For a set of specified circumstances, the emitter flow variation (Q_{var}) characterizes the variance in emitter output rates across the entire drip irrigation system. It can be derived out of the formula given by Bralts and Kesner (1983).

$$Q_{var} = \frac{(Q_{max} - Q_{min})}{Q_{max}} \times 100\ \% \quad \text{...} \quad (2.4)$$

where:

Q_{var}: Emitter flow variation along the lateral line (%)

Q_{min}: Minimum measured emitter (drip hole) flow rate along the lateral line (l/h)

Q_{max}: Maximum measured emitter (drip hole) flow rate along the lateral line (l/h)

Hydraulic pressure variance, temperature changes along the laterals, manufacturer's variation coefficient, and emitter clogging all influence the discharge of emitters down a lateral line. If the turbulence emitter is chosen and clogging can be managed using filtering systems, the emitter flow variation will be affected just by hydraulic pressure change and the manufacturer's variation coefficient of the specified emitters.

2.9.4 Coefficient of Variation

The Coefficient of Variation (CV) is a measurement of the non-uniformity of the discharge in emitters because of manufacturing variances. It specifies the material quality employed in the production of emission devices. Any CV larger than 0 in drip design indicates that the plant will get a different amount of water due to new emitters' inability to discharge the same flows at the same pressure. The formula for calculating the coefficient of variation, CV, is as follows:

$$Cv = \frac{s}{q} \times 100\ \% \qquad (2.5)$$

where:

CV: Coefficient of variation (%)

S: standard deviation of individual observations (l/h)

q: mean of individual discharge values (l/h)

2.10 Quality of Pineapple Fruit

Fruits weighing more than 1.5 kg are categorized under group A; fruits with weight between 1 and 1.5 kg are grouped under category B; and fruits weighing less than 1 kg are classified as C (Medina and García, 2005). For pineapple fruit, measure of maturity is done based on yellow skin coloration and fruit “eye” flatness. Consumers mostly prefer pineapple fruit with a good shape and size, with flat “eyes”, with greenish crown leaves, and medium erect length (Medina and García, 2005). However, in recent times, consumers do not just take into consideration the morphological properties of the fruit in terms of making any purchasing decision. Aside from the physical properties, other factors are considered, which includes sweetness, colour, aroma, size, fruit uniformity, and brand name, or country of origin. High skin coloration does not always indicate a fruit’s sweetness (Medina and García, 2005).

For large scale export purposes, pineapples are sorted based on the degree of skin colour, weight (size), absence of disease and defects, and uniformness of these properties prior to packing. Some of these properties include firmness, flatness of eyes, nice shape, well-cured peduncle. Also, crown size plays a crucial role in pineapple grading. Ideally, a ratio of the crown to fruit length of 0.33:1.5 is for higher grades (Paull and Chen, 2014).

Usually, after flowering, it takes about 110 days for the fruit to be mature. When half of the peels change colour to yellow, there occurs a change in the chemical composition of the fruit. Basically, carotenes, chlorophyll, anthocyanins and xanthophylls are the major pigments contained in pineapple. The presence of these substances in the fruit aids in peel colour changes from green to yellow, and this external change in colour is a necessary factor in consumer preference (Medina and García, 2005). This is because most consumers judge fruit quality by the aroma and skin coloration (Paull and Chen, 2014). At the maturation phase, the chlorophyll pigment evanesces and the overall pulp carotenes heighten, whilst peel carotene content reduces. Studies have shown that both pulp and peel carotene content increase during senescence (Dull, 1971). These variations in fruit coloration and chemical composition reveal the four phases of fruit development. The sure evidence at the maturation phase is when the basal peel colour changes from green to yellow.

Pineapple fruit is referred to as non-climacteric, in that after harvesting, it does not continue to sweeten or ripen (Medina and García, 2005), thus, at the very moment it is matured according to consumer preference, it can be harvested. Yet, the end use of the fruit mostly determines its right time to be harvested. Fruits produced for the export market should be harvested when the fruit is completely matured but still green, whilst pineapples cultivated for domestic purposes are mostly harvested mature but not fully ripened (Medina and García, 2005).

Basically, the composition of pineapple has been investigated based on its edible part. Research has shown that pineapple contains little above 80 % moisture, and total solids of 13 to 19 %, which are basically glucose, sucrose, and fructose. The main content of the total solids is carbohydrates representing about 85 % whilst 2 to 3 % are fibre. Citric acid is the main organic acid found in pineapple. Pineapple pulp has less amounts of ash, lipids (0.1 %) and nitrogenous compounds. About 30 % of the nitrogenous content is true protein. The main minerals contained in fresh pineapple are Calcium, Potassium, Chlorine, Sodium and Phosphorus. The recommended sugar-to-acid ratio in pineapple is 0.9 to 1.3 (Paull and Chen, 2014).

A minimum soluble solids content of 12 % and a maximum 1 % acidic content ensures consumers accept the fruit makeup, together with the uniform texture and size, absence of sunburn cracks, rotting, endogenous brown spot, bruises, internal breakdown, pest-induced damages. Soluble solids should be in the range of 11 and 18 %, titratable acidity known as citric acid content of about 0.5 to 1.6 %, ascorbic acid from 20 to 65 mg/100 g of fresh weight, and a value along a given range depends on the maturity stage and the cultivar (Paull and Chen, 2014).

2.11 Storage of Pineapple

Studies have revealed that storage temperatures of 7 to 12 °C are suitable for storing pineapples for a period of 14 to 20 days if the fruit is at the colour break phase (Paull 1993). Since a higher relative humidity greatly minimizes water loss, a relative humidity of 85 to 95 % is recommended for fruit storage. Fully ripe fruit can be stored at 7.2 °C (45 °F) for close to 10 days, and at a temperature of 0 to 4 °C (32 to 39 °F) for weeks, However, once the fruit is removed, it fails to continue ripening, and thus shows grave chilling injury. According to Dull (1971), fruit which is quarter yellow at harvest can stay one more week during storage, with every 6 °C (11 °F) fall in storage temperature. According to Paull and Chen (2014), the highest pineapple shelf-life when held at 7 °C (45 °F) should be about 4 weeks which is accompanied with severe chilling injury-induced internal browning within 2 to 3 days when removed.

2.12 Agricultural Production – An Outlook on Cost and Benefit

According to Kinney and Raiborn (2011), every production process comes with some form of cost; labour, material and or operating cost. At least in every service provision, labour and operation costs cannot be avoided, as compared to material cost which might not come to play (Kinney and Raiborn, 2011). Cost involves the fiscal, and the valuated measure of non-fiscal inputs needed to realize a specific objective being it the production of goods, and the provision of services (Kinney and Raiborn, 2011). Record taking by a corporation on various costs incurred can enhance their efficiency by making informed-decisions about their expenditure. Cost incurred in production is not static since it is subject to spatiotemporal variations. For this reason, a specified timeframe will help firms to appropriately identify, utilize cost behaviour information to be informed about the future extent a cost should be considered for undertaking certain activities. A right comprehension and interpretation of cost behaviour is helpful in making reasonable estimates of the total costs for an activity. The main categories of costs involved in production are variable and fixed costs (Kinney and Raiborn, 2011).

Basically, the cost involved in running a farm business can be categorized as Fixed Costs (FC) and Variable Costs (VC), and these when summed together gives the overall cost incurred in production. The costs incurred are variable cost, operating cost, fixed cost, and benefits are sales-generated revenue, and water and labor saving when an irrigation system is adopted (Baranchuluun *et al*., 2014). In Akbar *et al*. (2001), the initial (equipment and installation costs) and operating costs are higher in the case of sprinkler irrigation system compared to that of surface irrigation, although better financial outcomes could be realized from sprinkler irrigation system because of increased yield and saving of water. In the same vein, drip irrigation may have much capital cost, and better returns on investment.

Initial investment cost usually incurred in crop production comes from equipment and infrastructure. Fixed cost is always incurred, and this is expressed as depreciation, interest, rent and taxes. Depreciation is usually accounted using the straight-line method (Kinney and Raiborn, 2011). The day-to-day operations of a farm dictates the operating costs, and in the irrigated production, irrigation regime, fuel used, and the size of land irrigated will determine the operating cost. Amongst the various variable costs including costs of inputs (seeds/planting materials, fertilizer, weedicide, pesticide etc.), cost of labour stands out as a necessary variable cost component since it cuts across land preparation, planting, irrigation, harvesting, and machinery maintenance.

Economies of size has been found to be a useful concept since a farmer can lower production costs by increasing production (Duffy, 2009). As the farm size increases, the average cost per unit of production decreases. This is possible because the farmer can produce more with the same level of fixed costs. Also, economies of size come to play when a farm can obtain volume discounts for inputs such as seed or fertilizer.

The cost involved in the production, and the revenue accrued from the sales of produce determines the profitability of an agribusiness. Gross revenue accrued from agricultural production can be estimated as the product of quantity produced and the unit price of each produce (Fausti and Wang, 2018).

2.13 Previous Research on Pineapple

Scholars have investigated the production of pineapple extensively, and have touched on its pre-harvest conditioning as well as the post-harvest handling (Paull and Chen, 2014; Paull *et al*., 2017). Paul and Chen (2014) reveal that a few cultivars of pineapple have translucent flesh, and the sugar to acid ratio varies seasonally, with fruit having too little acid during the warm season. Longer shipping periods continue to cause chilling injury, despite the fact that newer low acid clones typically contain higher ascorbic acids and less chilling harm. In relation to the water needs of pineapple, de Azevedo *et al*. (2007) researched on the crop water requirement of pineapple under a sprinkler system in Brazil. In their study, the crop evapotranspiration (ET_c) was calculated with the Bowen ratio-energy balance whilst the reference evapotranspiration (ET_o) was estimated by the Penman-Monteith method. It was found that at the early stages of vegetative growth and fruit harvest, ETc is lower, and in the middle of the productive cycle, it is higher. Hanafi *et al*. (2010) also assessed the water requirement of pineapple at the different growth stages in Beach Ridges Interspersed with Swales (BRIS) soils. Pineapple suckers were planted in lysimeters constructed with oil drums and filled with BRIS soil. The readings were taken to calculate the ET_c and depth of irrigation water applied was calculated accordingly. In Hanafi *et al.* (2010)'s study, 2.43 mm/day of irrigation water was discovered to be the highest CWR in the early stages of the plant. Later stages of development, such as stage 2, midstage 3, and ripening stage 4, required less irrigation water (about 1.55 mm/day). Carr (2012) did an in-depth review on the water relations and irrigation requirements of pineapple. In his study, he talked about the various parts of the crop; the vegetative growth, flowering, fruiting, the root complex, the Crassulacean Acid Metabolism (CAM), and many others. In Carr's (2012) opinion, many questions remain regarding the real water consumption of pineapples, crop coefficient (k_c), and the relative amounts of water loss (transpiration) and carbon uptake (net photosynthesis), both during the day and at night, given various water regimes. Cahyono *et al*. (2016) assessed the water balance of pineapple to determine the crop water requirement of the fruit in Indonesia. They found out that for the months of June through to October, the water needs for small pineapple plants, medium plants, and large plants are 164.6 mm, 31.2 mm, and 12.5 mm, respectively. In August, when the water balance is at its lowest, pineapple plants require heavy watering (Cahyono *et al*., 2016). Amidst the numerous studies conducted on pineapple cultivation in Ghana, there are rare studies on the crop water requirement of pineapple. Though Williams *et al*. (2017b) assessed the impact of climate variability on pineapple production in Ghana, they considered the effect of temperature and rainfall on growth and yield in one district from four hotspot regions each. They did not estimate the crop water requirement of pineapple.

Drip irrigation system, proven to be an efficient method of water application in crop production amongst the other methods, has most of its performance reports based on theory because of trials conducted in hydraulic laboratories. Although there are several studies which have assessed the hydraulic performance of drip systems, these studies are scanty in Ghana, as it relates to the evaluation of drip irrigation systems from field conditions, especially on some tropical fruits such as pineapple. Thus, indicators that account for variations in discharge and pressure due to the state of the drippers and the hydrodynamic features of the flows along drip lines are not well accounted for (Van der Kooij *et al*., 2013). Darimani *et al*. (2021) assessed the field performance of a self-designed small-scale drip irrigation systemin Ghana's Upper West Region, and this might not fully represent the actual farmers' field conditions.

Unfortunately, most students' research dissertations on pineapple production in Ghana have focused on pineapple farm size choice (Ayagiba, 2002); farmers' livelihood (Abbey, 2005; Achaw, 2010; Gerchie, 2014); adoption of alternative production system (Badu-Gyan, 2015); production efficiency analysis (Ofori-Appiah, 2018) and many others. Thus, there is knowledge gap on the water requirement, performance of drip systems for cultivation, fruit quality, and cost involved in production under drip and rainfed conditions in Ghana.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The Coastal Savannah (CS) Agro-Ecological Zone spans about 20000 km^2 and is found in the South-East coastal plains of Ghana and encompasses the Accra and Ho-Keta plains and some parts of Winneba-Cape Coast (Owusu-Ansah, 1994). This zone lies between latitude of 4.5 °N and 6 °N, and longitude of -0°13'56" to 0°58'42" W, and it is distinguished by its relatively low rainfall of 800 mm distributed in two seasons (major and minor), and grassland savannah vegetation (Cotillon and Tappan, 2016).

Bomarts Farms Limited, established in 1985 and later incorporated in 2001 is a producer, processor and exporter of fresh and dried fruits. The company grows and processes the three most common varieties of pineapple: MD2, Smooth cayenne, and Sugarloaf as well as mangoes. With a 4,000-acre land for pineapple, and 800 acres for mango, they produce for both the local and international markets and to feed the processing factory. Bomarts Farms is both Global G. A. P and Fair Trade certified.

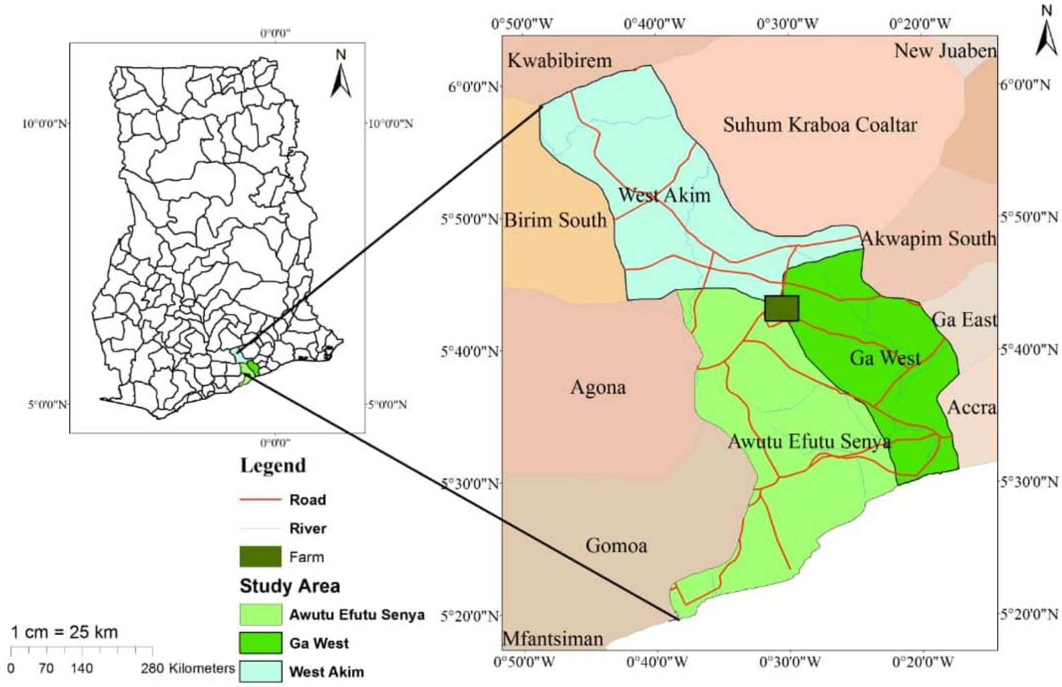

Figure 3.1: Map of Coastal Savannah Agro-ecological Zone showing Bomarts Farms

(Source: Author, 2022)

3.2 Local Climate and Soil Characteristics

The Coastal Savannah (CS) Agroecological zone is quite dry with mean annual rainfall of 800 mm (MoFA, 2016). The major rainy season runs from April to mid-July, followed by a one to two-month dry period, whereas the minor season rainfall peaks in October, with a dry period from December to March. The rainfall distribution is quite variable in relation to the beginning and end, as well as inter and intra-trends. Thus, in Ghana's Coastal Savannah (CS) Agroecological zone, rainfall and its fluctuation are a major bottleneck for rainfed agricultural production. Temperatures in the coastal savannah zone are high. The average yearly temperature is 26.5 °C. The mean temperature throughout the day is 30 °C, with monthly averages ranging from 24.5 °C in August to 28 °C in March.

Humidity is high in general (65 to 95 %), although it is lower during the warmer months, especially in January, when the northeast harmattan winds are prevailing (Teye and Owusu, 2015). Due to the soil type, texture and composition, which supports pineapple production, several large-scale pineapple farms are established in this area. The geographical area for the present study was the Ga South Municipal area, where Bomarts Farm operates. It lies in the latitude and longitude 5.5358° N and -0.48333° W, respectively. The elevation of the area ranges between 68 to 74 m above sea level.

3.4 Materials and Equipment used for the Study

1. FAO CROPWAT model 8.0 and Climwat 2.0: This is the decision support software which is used to estimate the CWR of a particular crop. It was used to estimate the CWR of pineapple with meteorological data sourced from the Ghana Meteorological Agency.

2. Catch cans, stopwatch and a measuring cylinder: These materials were used to assess the performance of the drip system. Sixteen (16) catch cans of capacity 250 ml each were used to capture water from emitters, which was measured with a calibrated plastic cup over an hour period measured by a stop clock. Four laterals and four locations on each lateral were chosen. The four (4) laterals were chosen with the help of the functions: *n*/4, *n*/2, 3*n*/4 and far end (the last lateral) where *n* is the number of laterals on the field. The various positions on the laterals were chosen with the help of the functions: l/4, l/2, 3l/4 and far end. The catch cans were arranged linearly at relevant positions on the laterals. This

measurement was replicated twice. The averages were used to determine the technical performance of the system.

3. The fruit quality was assessed by measuring the weight (g) and size (mm) of five randomly selected pineapple fruits from both drip irrigation and rainfed plot each. A digital stainless-steel measuring scale with a maximum weight bearing threshold of 10 kg and a digital Vernier calliper with an accuracy of ± 0.2 mm was used to measure the weight and size respectively.

4. A handheld refractometer was used to assess the brix of the sampled pineapple grown under rainfed and drip irrigation, whilst a hygrometer-thermometer clock was used to record the temperature and humidity of the storage space during the pineapple shelf-life assessment.

Figure 3.2: Equipment used for the study

(Source: Author, 2022)

3.5 Measurements and Relevant Calculations

3.5.1 Crop Water Requirement

i. Source of Data

Climatic data for the Coastal Savannah including minimum and maximum temperatures, humidity, wind speed and sunshine hours were sourced from the Ghana Meteorological Agency (GMet), with the monthly averages calculated. Also, long-term rainfall data (from 2010 – 2020) were obtained from GMet, and the averages for each month were computed. Altitude, latitude and longitude of the study area was recorded with a smartphone and compared with what is contained in literature. This was to help with representing the study area on the map district map. Crop parameters such as planting and harvesting dates and plant rooting depth were taken from the farm, whilst the kc values for the various growth stages were sourced from FAO manual. Soil taken from the farm is predominantly sandy loam. The corresponding soil properties such as Total Available Moisture Content (TAMC), maximum rain infiltration rate, maximum rooting depth, etc. for sandy loam were obtained from the FAO manual 56 (Allen *et al*., 1998).

ii. Pineapple Crop Parameters

The following details about the pineapple plant were required by the CROPWAT software before the model was run; planting date, harvesting date, the kc values for the four distinct growth phases, the span (in days) of each growth stage, critical water depletion, rooting depth.

Table 3.1: Pineapple Parameters for Computing CWR with FAO CROPWAT

Parameter (Unit)	Growth Stage	Value
Plant Stages duration (days)	Initial season	80
	Mid-season	90
	Late season	100
Crop coefficients, (k_c)	Initial season	0.5
	Mid-season	0.3
	Late season	0.3
Rooting depth (m)	Initial season	0.1
	Mid-season	0.2
Crop height (m)	Mid-season	0.3
Critical depletion fraction	Initial season	0.45
	Mid-season	0.25
	Late season	0.35

Source*:* FAO CLIMWAT 2.0 and Allen *et al.* (1998)

iii. Crop Water Requirement Estimation

Crop water requirement (CWR) is the quantity of water commensurate to the water lost from a cultivated field by evapotranspiration, which is expressed as ET_c in mm/day (Mebrahtu *et al.*, 2021). CWR depends on climate, and irrigation scheduling ETc are used as CWR values, and it was derived using Equation 3.1.

$$ETc = k_c \times ETo \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

where:

ET_c – Crop evapotranspiration (mm/day)

k_c – Crop coefficient (dimensionless)

ET_o – Reference evapotranspiration (mm/day)

To have a reliable CWR estimate, it is necessary to adopt the right tools and/or approaches, for enhanced water productivity (Guerra *et al*., 2015). The FAO CROPWAT 8.0 software was developed on the bases of the Penman-Monteith method, and it factors in the various procedures involved in calculating the reference evapotranspiration (ET_o) and CWR, allows for the simulation of CWR under various climate, soil and crop factors (Mebrahtu *et al*., 2021). FAO CROPWAT 8.0 software was used in this study to estimate the crop water requirement of pineapple. The model estimates the ET_o with the FAO Penman-Monteith method as presented in Equation 3.2:

$$ET_o = \frac{0.408\Delta\,(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_a - e_d)}{\Delta + \gamma(1 + 0.34U_2)} \text{......................................} \quad (3.2)$$

where:

ET_o – Reference evapotranspiration (mm/day)

R_n – Net radiation on the crop surface ($MJ/m^2/day$)

G – Soil heat flux density ($MJ/m^2/day$)

T – Air temperature at 2 m height (^oC)

U_2 – Wind speed at 2 m height (m/s)

e_a – Saturation vapour pressure (kPa), e_d = Actual vapour pressure (kPa)

e_a - e_d – saturation vapour pressure deficit (kPa)

Δ – Slope vapour pressure curve (kPa/^oC)

Y – Psychrometric constant (kPa $°C^{-1}$)

iv. Irrigation Water Requirement

Monthly rainfall was collated and the average for every month was used to estimate the effective rainfall. The USDA soil conservation method was used to run the model with the FAO CROPWAT software. The method works with reference to the condition that:

If Total Rainfall, $P_{tot} < 250$ mm, then Effective rainfall, R_{eff} will be

$$\text{Effective Rainfall, } R_{eff} = P_{tot} \times \frac{125-0.2P_{tot}}{125} \quad \text{.......................................} \ (3.3)$$

If Total Rainfall, $P_{tot} > 250$ mm, then Effective Rainfall, R_{eff} will be

$$R_{eff} = 125 + 0.1 \times P_{tot} \quad \text{..} \ (3.4)$$

v. Input Data Description

The data entered into the CROPWAT 8.0 software included the country (Ghana), climatic station (Winneba), planting date, type of crop, and soil type (sandy loam), rooting depth, percent area covered by plant and initial soil moisture and criteria of irrigation. The monthly mean climate variables were: minimum and maximum temperatures (°C), relative humidity (%), windspeed (km/day), sunshine hours (hours), and rainfall from 1989 to 2019, all were used to compute the CWR (Meteorological data are presented in Appendix I). The CROPWAT 8.0 software generated the radiation values $(\frac{\mathrm{MJ}^2}{\mathrm{m}}/\mathrm{da})$, reference evapotranspiration, ET_o (mm/day), effective rainfall (mm), and total irrigation requirements (mm/dec) for pineapple.

3.5.2 Hydraulic Flow Calculation and Performance Evaluation of the Drip System

a. Flow Variation

Emitter flow variation Q_{var} was calculated using the equation:

$$Q_{var}=\frac{100\,(Q_{max}-Q_{min})}{Q_{max}}\times 100\,\% \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.5)}$$

where:

Q_{var} – Emitter flow variation (%)

Q_{max} – maximum emitter (drip hole) flow rate (l/h)

Q_{min} – minimum emitter (drip hole) flow rate (l/h)

b. Coefficient of Variation

Coefficient of variation is the ratio of the standard deviation of flow to the mean flow for a sampled number of emitters. It is a statistical parameter expressed as in Equation 3.6 as given by Keller and Karmeli (1974).

$$\text{Coefficient of variation, } C_V = \frac{s}{\underline{q}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.6)}$$

where:

C_V – Coefficient of variation

s – standard deviation of (drip flow) emitter flow rate (l/h)

q – Mean of discharge (q) (l/h)

c. Uniformity coefficient

Uniformity Coefficient is the ability of the emitters in a drip irrigation system to distribute the water in the whole field equally, as given by Christiansen (1942) and it was calculated with equation 3.7.

$$\text{Uniformity coefficient, UC} = 100\ \% \times \left[1 - \frac{\left(\frac{1}{n}\sum_{i=1}^{n}|q_i - \bar{q}|\right)}{\bar{q}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

where:

$\bar{q}$ – Mean of discharge (q) (l/h)

q – discharge (l/h)

n – number of (drip holes) emitters to evaluate

d. Emission Uniformity

Emission uniformity is the ratio expressed as a percentage of average emitter discharge from the lower quarter (1/4th) of emitter to the average discharge of all the emitters of the drip system. The average of lowest quarter (1/4th) of emitter was selected as a practical value for minimum discharge, as recommended by the United State Soil Conservation Services for field evaluation of irrigation systems as expressed in Equation 3.8 (Bralts *et al.*, 1987).

$$\text{EU} = 1 - \left[\frac{0.8CV}{n^{0.5}}\right] \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.8)$$

where:

EU – Emission Uniformity (%)

CV – Coefficient of variation,

n – number of emitters per plant

e. Assessment of Hydraulic Performance of the Drip Irrigation System

The source of water for the farm is a dugout dam entrenched for irrigation purposes. The pump station installed on the farm is a diesel-powered centrifugal pump which abstracted water and supplied it to the laterals. The working pressure of the pump during the field study was 4.7 bar. The pump station is equipped with filters which ensures that particles in the water are filtered out before the water is released to the field. It also has a fertigation kit ensuring that fertilizer can be applied to the crops in the crops in the course of drip irrigating. The drip irrigation system used in this study had a lateral size of 16 mm of 80 m length with emitters spaced at 30 cm. The distribution of water application and discharges from emitters along the lateral were measured according to ASABE Standards (ASAE, 1999).

1. First, the entire area for the performance assessment of the drip irrigation system was determined. The length of the submain was determined as 180 m, and four drip lines, measuring 80 m each were selected.
2. Drippers for the assessment were chosen based on the use of a standard approach. The criteria for selection of the laterals and emitters are given by the function: $n/4$, $n/2$, $3n/4$, last line; $l/4$, $l/2$, $3l/4$, end where n is the number of lines, and l is the length of line. 16 emitter points were determined.
3. Catch cans were placed at each of these positions to collect water for a period of 20 minutes at a pump operating pressure of 4.7 bar. The volume of water collected in each catch can was measure with a graduated container. This was done for all the four drip lines. At each of the 16 predetermined emitter points,

two values were recorded; water collected in a catch can at a point and its adjacent point (i.e A and B).

4. The procedure was repeated and the average of the volume of the water was considered as the discharge for a position.
5. The average emitter discharge for each of the sixteen locations was then calculated.
6. The selected performance indicators were computed using the applicable equations (i.e., equations 3.5 to 3.8).

3.5.3 Yield and Fruit Quality of Pineapple

3.5.3.1 Fruit Yield

In investigating the yield of pineapple under drip irrigation and rainfed conditions, forty (40) matured fruits were sampled from a 40 m x 40 m area under each condition. The fresh weight was determined and the yields for the two fields were computed as:

$$Y_{FF} = \frac{FF}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

where,

Y_{FF} – Fresh fruit yield (t ha^{-1}),

FF – Total pineapple fresh fruit harvested (tonnes),

A – Area covered by crops used in FF sampling (ha)

3.5.3.2 Procedure for Pineapple Yield and Fruit Quality Assessment

Five (5) fully mature fruits which were yet to turn yellow from the base, with crown leaves fresh and green were randomly selected from 100 m x 100 m pineapple field under rainfed conditions and five (5) fruits from 100 m x 100 m pineapple field under drip irrigation. These fruits were subjected to the same storage conditions (temperature and relative humidity). The temperature and Relative Humidity (RH) in the storage space were recorded with a Hygrometer-thermometer clock thrice (6:00 am, 12:00 pm and 6:00 pm) in a day for a storage period of 10 day. The weight and size (diameter) of each fruit were measured with a measuring scale and a Vernier calliper respectively, prior to placement in a storage space and at two days intervals. Changes in fruit peel coloration recordings were done with eye-estimation, and graded accordingly for the storage period. The Total Suspended Solids (Brix) were determined with a refractometer. The process used is described below:

Hand refractometer is an instrument for measuring refractive index which is widely used for measuring the sugar concentration of sugarcane, syrups, jams and many others. It is easy and quick and requires only a few drops of sample liquid in the main prism and the percentage value is immediately read out. By shining a beam of light through a sample of liquid, a refractometer measures the amount of liquid that is refracted from the light path due to the constituents in the sample. The device takes the refraction angle and correlates it to an already established refractive index which then evaluates the concentration of solutions. Brix value is a specification parameter for beverages and it was obtained by conducting a Brix test. This is normally done by calibrating the refractometer using distilled water or brix solution. The Nimatic Brix refractometer flip was opened and washed with distilled water and then cleaned with a tissue paper; the calibration adjuster was adjusted to zero before dropping the sample on the slide. Few drops of the degassed sample were dropped on the slide using a dropper and the flip was covered. The reading was taken through the eyepiece under a light ray when the value became steady.

3.5.4 Cost and Returns on Pineapple Production under Drip and Rainfed Conditions

In estimating the cost needed to cultivate pineapple under drip and rainfed conditions, data were sourced from the farm records of Bomarts farms, and was standardized through an interview with other farmers in the study area. Tabular analysis was employed in estimating the different costs involved in production. The study data were drawn from 2019 to 2021 archives. This format was employed because other scholars (Singh *et al.*, 2016; Mathew *et al.*, 2017) used it in estimating the economics of farm businesses. The cost concept employed is expounded below.

Cost A_1: Total cost for hired labour, hired machinery, suckers, agrochemicals, irrigation charges, electricity charges, depreciation on implements and farm buildings.

Cost A_1:

i) Value of hired human labour
ii) Value of owned machinery labour
iii) Value of hired machinery charges
iv) Value of suckers
v) Value of insecticides and pesticides
vi) Value of fertilizer

$Cost\ A_1 \ = \ \text{Sum of variable cost}$

$Cost\ A_2 \ = \ \text{Cost } A_1 + \text{rent paid for leased in land}$

$Cost\ B_1 \ = \ \text{Cost } A_2 \ + \text{rental value of owned land}$

$Cost\ B_2 \ = \ \text{Cost } B_1 + \text{supervision charges}$

The equations below were used in estimating the returns and income in the case of production under drip irrigation and rainfed conditions;

$Gross\ Farm\ Income\ (GFI) \ = \ \text{Value of main product } + \text{Value of by} - \text{products} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ (3.10)

$Farm\ Business\ Income\ (FBI) \ = \ \text{GFI} - Cost\ A_1 \ldots\ldots\ldots.$ (3.11)

$Net\ Farm\ Income = \ \text{GFI} - \text{Total Cost} \ldots\ldots\ldots\ldots\ldots\ldots\ldots$ (3.12)

3.6 Data Analysis

Data for crop water requirement (as described in section 3.5.1) was inputted into the FAO CROPWAT model and analyzed with same. Data on discharge of drip irrigation system obtained from the field was used to compute for the drip irrigation system performance indicators with the help of Microsoft excel and mathematical formulae for the various indicators. Pineapple yield data was analyzed with SPSS version 26.0, and data on cost of production under drip and rainfed conditions were analyzed with the help of Microsoft excel.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Crop Water Requirement of Pineapple (*Ananas comosus var.* MD2)

4.1.1 Long-term Weather Data and other Parameters for CWR Estimation

Table 4.1 presents the output of CROPWAT 8.0. The average temperature from 1989 to 2019 was 23.6 °C and 31.4 °C for minimum and maximum temperatures, respectively, whilst relative humidity ranged between 88 to 93 %, with an average of 91 %. Average monthly wind speed ranges from 187 to 304 km/day, whilst average monthly sunshine hours ranged between 4.5 hours and 8.1 hours, with an average of 6.6 hours. The lowest monthly rainfall (12.0mm) was recorded in January with the highest (204 mm) rainfall recorded in June. The ET_o values for the various months of the year ranged between 3.1 to 4.4 mm/day, with an average of 3.9 mm/day. The highest and lowest ET_o values were recorded in April and August, respectively.

Table 4 g-term (1989 - 2020) Monthly Averages of Climatic Data

Mo	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day	Rain mm	Eff rain mm
Januar	23.0	32.3	88	210	6.5	18.0	3.87	12.0	11.8
Februa	24.3	33.0	89	273	7.4	20.2	4.34	27.1	25.9
March	24.5	33.0	90	261	7.1	20.5	4.37	56.4	51.3
April	24.5	32.8	90	240	7.5	21.0	4.44	99.0	83.3
May	24.1	31.9	91	226	6.9	19.3	4.03	164.0	121.0
June	23.6	30.1	92	230	5.3	16.5	3.36	204.0	137.4
July	23.0	29.0	93	274	5.2	16.5	3.19	65.1	58.3
August	22.6	28.9	93	276	4.5	16.0	3.09	22.0	21.2
Septem	23.1	30.0	92	304	5.5	17.8	3.49	45.3	42.0
Octobe	23.3	31.0	91	273	7.4	20.3	4.01	85.9	74.1
Novem	24.0	32.1	90	219	8.1	20.4	4.17	38.0	35.7
Decem	23.3	32.3	89	187	7.4	18.9	3.96	21.0	20.3
Average/Tot	**23.6**	**31.4**	**91**	**248**	**6.6**	**13.3**	**3.86**	**839.8**	**682.3**

(Source: Ghana Meteorological Agency Database, 2022)

Reference evapotranspiration is an indication of the available energy to vaporize water under enough water supply conditions. This parameter is affected by meteorological factors such as solar radiation, temperature, and windspeed amongst others. Thus, the range of ET_o values recorded in this study is attributable to the variations in atmospheric conditions (temperature, humidity, wind speed, etc.) across the various months of the year. With low values of temperature, sunshine hours, and wind speed, the consequent reference evapotranspiration was low. Conversely, high values in meteorological factors such as temperature, windspeed, solar radiation, and sunshine hours tend to produce higher reference evaporation with an increased in crop water requirement. This assertion as revealed by this study agrees with Liu *et al*. (2019) who found that sunshine and temperature are positively correlated with reference evapotranspiration. Generally, during the dry season, temperature values rise, with low relative humidity values as compared to the rainy season. The rainy season is characterized by high values of rainfall and relative humidity and low-temperature values. This might have accounted for the low values of ET_o in the rainy season, particularly in June. The RH, temperature, and solar radiation are reflected in the ET_o values across the year. The impact of climatic parameters such as temperature, humidity, etc. on ET_o reveals that ET_o is a climatic variable, since it varies across the various months of the year, especially during the two distinct seasons in the year. The ET_o output from the model agrees with the results of Mebrahtu *et al*. (2021) and Adeniran *et al*. (2010) which revealed that ET_o was high at the peak of the dry spell and low at the peak of the wet season.

4.1.2 Crop Water Requirement, Effective Rainfall, and Irrigation Requirement of Pineapple

The crop water requirement during the production period varied from 0.86 to 2.18 mm/d as presented in Table 4.2.

Table 4.2: Crop Water Requirement, Effective Rainfall, and Irrigation Requirement of Pineapple

Month	Decade	Stages	kc Coef	ET_c mm/day	ET_c mm/dec	Eff. Rain mm/dec	Irr. Req mm/dec
Dec	3	Init	0.30	1.18	13.0	5.6	3.1
Jan	1	Init	0.50	1.95	19.5	4.2	15.3
Jan	2	Init	0.50	1.94	19.4	2.9	16.5
Jan	3	Init	0.50	2.01	22.2	4.8	17.4
Feb	1	Init	0.50	2.09	20.9	6.7	14.2
Feb	2	Init	0.50	2.17	21.7	8.1	13.6
Feb	3	Init	0.50	1.74	17.4	11.1	6.3
Mar	1	Init	0.50	2.18	21.8	14.1	7.7
Mar	2	Deve	0.49	2.13	21.3	16.8	4.5
Mar	3	Deve	0.46	2.04	22.5	20.5	2.0
Apr	1	Deve	0.44	1.95	19.5	24.0	0.0
Apr	2	Deve	0.42	1.86	18.6	27.5	0.0
Apr	3	Deve	0.40	1.71	17.1	31.8	0.0
May	1	Deve	0.37	1.56	15,6	36.8	0.0
May	2	Deve	0.35	1.42	14.2	41.3	0.0
May	3	Deve	0.33	1.25	13.8	42.8	0.0
Jun	1	Deve	0.30	1.09	10.9	47.0	0.0
Jun	2	Mid	0.28	0.95	9.5	50.3	0.0
Jun	3	Mid	0.28	0.92	9.2	40.0	0.0
Jul	1	Mid	0.28	0.90	9.0	26.9	0.0
Jul	2	Mid	0.28	0.88	8.8	17.5	0.0
Jul	3	Mid	0.28	0.87	9.6	14.0	0.0
Aug	1	Mid	0.28	0.87	8.7	9.4	0.0
Aug	2	Mid	0.28	0.86	8.6	4.4	4.2
Aug	3	Mid	0.28	0.89	9.8	7.6	2.2
Sep	1	Mid	0.28	0.93	9.3	11.4	0.0
Sep	2	Late	0.29	1.00	10.0	13.5	0.0
Sep	3	Late	0.30	1.10	11.0	17.2	0.0
Oct	1	Late	0.30	1.15	11.5	23.3	0.0
Oct	2	Late	0.30	1.20	12.0	28.0	0.0
Oct	3	Late	0.30	1.22	13.4	22.6	0.0
Nov	1	Late	0.30	1.23	12.3	15.5	0.0
Nov	2	Late	0.30	1.25	12.5	10.8	1.7
Nov	3	Late	0.30	1.23	12.3	9.5	2.8
Dec	1	Late	0.30	1.21	12.1	8.3	3.8
Dec	2	Late	0.30	1.19	11.9	6.5	5.4
Dec	3	Late	0.30	1.18	5.9	2.6	3.1
Total					**516.8**	**685.2**	**123.8**

A total crop water requirement of 516.8 mm for the production period was estimated by the model. However, the net irrigation water requirement of pineapple (var. MD2) was from 0 to 17.4 mm/d with a total seasonal net water requirement of 123.8 mm, when effective rainfall is considered.

Information on when to irrigate and how much quantity of water to supply to a crop helps in irrigation management - this is a function of crop water requirement, and appropriate irrigation scheduling (Mebrahtu *et al*., 2021). The overall objective of water management in an irrigation scheme is to regulate the amount of water, and the rate of application on time to ensure that crop water needs are met without wasting the water, plant nutrients, soil, or energy. The results presented in Table 4.2 shows that pineapple requires 516.8 mm of water, effective rainfall amount of 685.2 mm, and 123.8 mm of irrigation requirement for the entire growing season.

4.2 Hydraulic Performance of Drip Irrigation System at Bomarts Farms

The emitter flow variation, coefficient of variation, uniformity coefficient, and field emission uniformity are the performance indicators used in this study, with the ASAE (1999) ratings and interpretation shown in Table 4.3. The computed values obtained from data collected from the field were 59. 3 %, 0.16 %, 86.8 %, and 79.7 % for emitter flow variation, coefficient of variation, uniformity coefficient, and field emission uniformity, respectively.

Table 4.3: Hydraulic Performance of the Drip Irrigation System at Bomarts Farms

Performance Indicators	**ASAE (1999) Rating**		**Field values and remark**	
	Range	Interpretation	Value	Remark
Emitter flow Variation	90 – 100 %	Excellent	59.3 %	Poor
	80–90 %	Good		
	70 – 80 %	Fair		
	< 70 %	Poor		
Coefficient of variation	< 0.05	Excellent	0.16	Unacceptable
	0.05 – 0.07	Good		
	0.07 – 0.11	Fair		
	0.11 – 0.15	Poor		
	> 0.15	Unacceptable		
Uniformity Coefficient	≥ 100 %	Excellent	86.8 %	Very good
	80 – 90 %	Very Good		
	70 – 80 %	Fair		
	60 – 70 %	Poor		
	< 60 %	Unacceptable		
Field Emission Uniformity	90 – 100 %	Excellent	79.7 %	Fair
	80– 90 %	Good		
	70 – 80 %	Fair		
	< 70 %	Poor		

ASAE – American Association of Agricultural Engineers

From the values presented in Table 4.3, the emitter flow variation which is 59.3 % was below the threshold, thus rated as poor per the ASAE (1999) rating. The coefficient of variation was unacceptable since the computed value from the field is 0.16. The uniformity coefficient value was 86.8 % with the interpretation that the similarity of the drip system's water distribution ability is very good within the field. The field emission uniformity value, 79.7 % shows that the performance of the emitters to uniformly discharge water to the plants is good.

The coefficient of variation quantifies the non-uniformity of the discharge in the emitters because of manufacturing variation. It defines the material quality employed in the manufacture of emitters. According to Mangrio *et al*. (2013), the coefficient of variation value greater than zero (0) of a drip irrigation system suggests that the plants being irrigated by the system will be fed with varying amounts of water because emitters failed to deliver the same flows at the same operating pressure.

Generally, two parameters, which were used by Al-Ghobari (2012) in assessing the application uniformity for surface and subsurface drip irrigation system are Uniformity Coefficient and Emission Uniformity. These parameters were also to assess the performance of the system, and the range of values obtained used in this study are in tandem with that of Al-Ghobari (2012). The rating of these parameters indicates that the drip irrigation system at use in the farm has good application uniformity. Acceptable values of performance indicators suggests that the amount of water being supplied to the pineapple plant is sufficient and possibly could meet the crop water requirement.

4.3 Weight, Yield, Storability and Brix of Pineapple under Drip Irrigation and Rainfed Conditions

4.3.1 Yield of Pineapple Cultivated under Drip Irrigation and Rainfed Conditions

The weight (g) and the corresponding fruit size (mm) of 40 matured pineapples sampled under drip irrigated and rainfed plots were analysed and the results are presented in Table 4.4.

Table 4.4: Summary Results of Sampled Fruit Weight and Size under Rainfed and Drip Irrigated Plots

Variable	Obs	Mean	Std. Dev.	Min	Max	Mean Diff	Sig (2-tailed)
Weight (g)						11.49	0.815
Drip Irr.	40	1006.4	198.78	652	1524		
Rainfed	40	995	234.06	609	1512		
Size (mm)						5.347	0.000
Drip Irr.	40	97.22	4.08	89	104		
Rainfed	40	91.875	2.32	88	97		

Obs – Observations; Std. Dev. – Standard Deviation; Diff – Difference, Sig – Significance

From the 40 sampled fruits, the mean fruit weight for fruits sampled from the irrigated field was 1006.4 g, whilst that of the fruits from the rainfed field was 995 g. Fruit weight ranged from 609 to 1524 g, with the minimum recorded weight of sampled fruits from both drip irrigation and rainfed fields being 652 g and 609 g, respectively. The maximum fruit weight was 1524 g and 1512 g from drip irrigated and rainfed fields, respectively. The difference between the mean fruit weight under both conditions is minimal (11.4 g). However, statistically, at a 95 % confidence interval, the independent samples t-test reported in Table 4.4 shows that there is no significant difference between the weight of fruit under drip irrigated and rainfed plots (p-value = 0.815).

Also, the mean fruit size of pineapple under drip irrigation was 97.23 mm, and that of rainfed pineapple size was 91.88 mm. The difference between the fruit size under both conditions is statistically significant, according to the p-value (0.000).

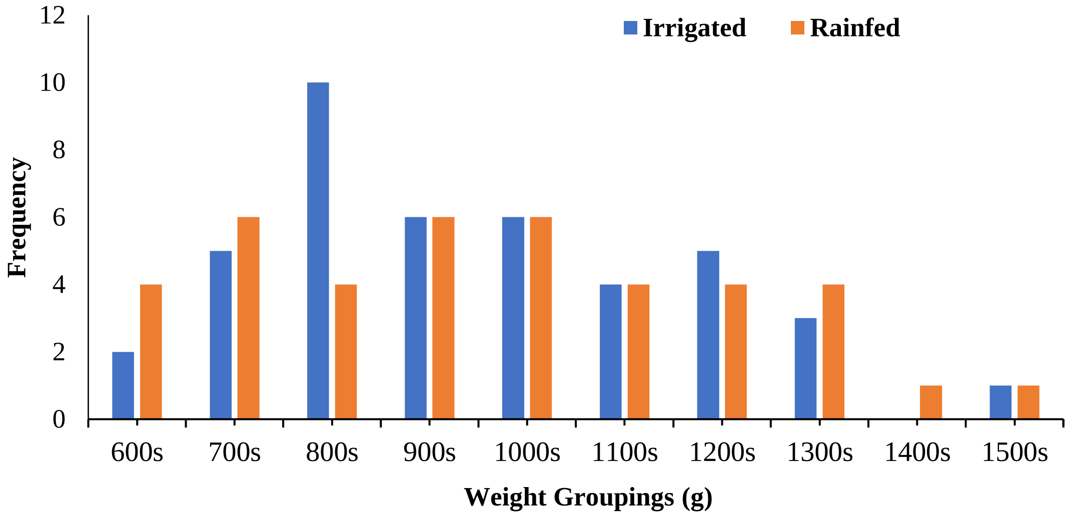

Figure 4.1: Weight Distribution of Pineapple under Drip Irrigation and Rainfed Conditions

The weight of fruit samples from the rainfed field was distributed across the weight range of 600 to 1500 g as shown in Figure 4.1. Unlike fruits from drip-irrigated fields with most fruit weight around 800 g, fruits with a weight of around 700 g appeared as many times as 900 g and 1000 g. Fruit weight was evenly distributed across the range (600 to 1500 g). This could be profitable in instances whereby the orders from customers vary in size.

The role of irrigation in plant growth and yield cannot be overemphasized as revealed by the results of this study. With the higher fruit weight recorded by fruits sampled from irrigated fields, the outcome of the study agrees with a study by Chapman *et al*. (1983) who investigated the effect of irrigation frequency on the growth and yield of pineapple. From the study, increased irrigation interval resulted in decreased leaf area and fresh fruit weight.

4.3.2. Fruit Yield under Drip Irrigation and Rainfed Conditions

The fresh fruit yield which was estimated from the cumulative weight of randomly sampled fruits shows that yield for the drip-irrigated field was higher than the rainfed field. The values obtained from drip-irrigated field and rainfed field were 32.640 t/ha and 32.483 t/ha respectively, showing a marginal difference between fruit yield. This value is less than the average industry yield of pineapple per hectare in Australia (i.e., 50.92 t/ha, 53.08 t/ha and 49.50 t/ha for control, oxygation and no irrigation respectively) as revealed by Midmore *et al.* (2012), as well as less than the national estimated per hectare yield of 60 t/ha (Kleeman, 2016). A study by Valleser (2018) showed that pineapple yield is a function of fruit weight and planting population. Yield difference for MD2 pineapple planted under drip irrigation and rainfed conditions will be attributable to agronomic practices when all the other relevant factors are constant. In a similar studies by Midmore *et al*. (2012), the yield of pineapple under irrigated field was higher than rainfed field (69.2 t/ha versus 65.9 t/ha).

4.3.2 Weight Loss in Pineapple in the Storage

Figures 4.2 and 4.3 present pineapple weight loss for 14 days under ambient conditions (28 – 31 °C and 60 – 75 % RH).

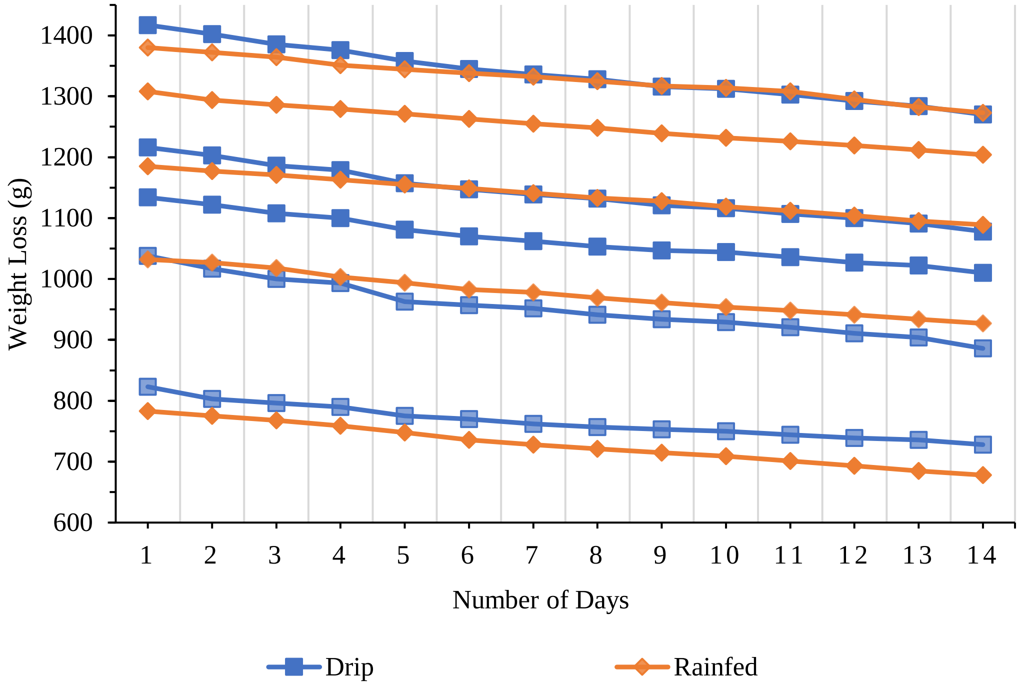

Figure 4.2: Weight loss of pineapple fruit cultivated under drip irrigation and rainfed conditions over 14 days

Significant effects were seen in total weight loss of pineapple grown under drip irrigation during storage. Total weight loss was generally higher in fruits from drip-irrigated fields during the entire period of storage (Figure 4.2). The weight loss in the first seven days of the storage period for pineapple grown on drip-irrigated field was higher than in the following seven days. This trend was different from fruits cultivated under rainfed (Figure 4.3) conditions, which had lower values of weight loss throughout the storage period. However, the common effect across both drip-irrigated fields and rainfed fields is that the highest weight loss was seen in bigger fruits, as expected. Matin *et al*. (1993) also established that crop weight loss is heavily influenced by maturity stage and storage conditions.

4.3.3 Brix Content over the Storage Period

The Brix was observed in three different days during the storage; the day of harvest which also marks the beginning of the storage of the pineapple, seven (7) days after harvesting, and fourteen (14) days after harvesting as presented in Table 4.5.

Table 4.5: Brix of pineapple grown under drip irrigation and rainfed conditions

	Brix, ⁰Bx		
Test days	Day of harvest	7th day	14th day
Drip Irrigated	12.8	15.6	19.8
Rainfed	13	16	21

On the day of harvest, the Brix for pineapple grown under drip irrigation was 12.8 ⁰Bx as against 13 ⁰Bx for pineapple cultivated under rainfed conditions. After seven days, the values increased to 15.6 ⁰Bx and 16 ⁰Bx for drip irrigated and rainfed cultivated pineapple, respectively. In the first week after harvest, the Brix values were in customers' mostly preferred range of values. However, after the first week, brix values were very high; 19.8 ⁰Bx and 21 ⁰Bx for drip and rainfed conditions, respectively. Although pineapple is a non-climacteric fruit which means its sugar content does not increase dramatically after harvesting, the common trend of increase in Total Soluble Solids (TSS) content, whilst the fruit changes color from dark green to yellow has been observed in this study, and several other studies (Wijesinghe and Sarananda, 2002; Yapo *et al*., 2011). A study by Wijesinghe and Sarananda (2002), the TSS for 'Mauritius' pineapple variety was observed to be 14.73 %, whilst the pineapple shell was 100 % dark green. However, whilst 20 % of the shell turned yellow, the TSS was observed as 17.32 %, which was the same trend observed in this study. Although physicochemical changes in fruit quality may be caused by different maturity and ripening stages of fruit (Kumara and Hettige, 2020), that might not be the case in the variation of the Brix of pineapple cultivated under drip irrigation and rainfed conditions. This is because the sampled pineapple from both conditions reached the same maturity stage before harvesting. However, other agronomic factors related to the different conditions of cultivation might have resulted in the variation in Brix values for pineapple under drip irrigation and rainfed conditions.

4.4 Cost and Return on Production under Drip and Rainfed Conditions

Table 4.6 and 4.7 present the financial breakdown in terms of cost and returns in rainfed pineapple production and drip irrigation, respectively. The cost and returns were estimated across a three-year period with data sourced from Bomarts Farms, the study site.

For production under rainfed condition (Table 4.6), the total variable cost for the first, second and third years were Gh₵ 6,415.00, Gh₵ 4,060.00 and Gh₵ 4,370.00. The total fixed cost for the first year was Gh₵ 2,700.00, the second year was Gh₵ 1,500.00 and the third year was Gh₵ 1,500.00. The gross incomes for the three years were Gh₵ 9,000.00, Gh₵ 10,000.00, and Gh₵ 11500.00 for the first, second and third years, respectively.

Table 4.6: Per hectare cost and return on pineapple production under rainfed conditions

Cost categorisation	**Cost across the years (Gh₵)**			**Total (Gh₵)**
	I	II	III	
Variable Cost				
Hired labour	1370	1370	1400	4140
Manures and fertilizer	950	1000	1150	3100
Herbicide	425	450	500	1375
Fungicide	150	170	200	520
Carbide	500	520	550	1570
Plastic mulch	520	550	570	1640
Planting material (sucker)	2500	-	-	2500
Total	**6415**	**4060**	**4370**	**14845**
Fixed Cost				
Rental value of owned land	600	-	-	600
Rent paid for a leased land	600	-	-	600
Depreciation	1500	1500	1500	4500
Total	**2700**	**1500**	**1500**	**5700**
Cost A1	6415	4060	4370	14845
Cost A2	7015	4660	4970	16645
Cost B1	7615	5260	5570	18445
Cost B2	8615	6260	6570	21445
Total	**11315**	**7760**	**8070**	**27145**
Gross farm income (GFI)	9000	10000	11500	30500
Farm business income	2585	5940	7130	15655
Net farm income	-2315	2240	3430	3355

Source: Adapted from Farm records (2019-2021)

The variable cost for the first year is higher than the second and third years because of the need to buy planting materials (suckers) in the case of beginning production. However, in the subsequent years, there is no need of buying planting materials, and this cuts the down the cost of production. In a study by Mathew *et al*. (2017), the initial cost of cultivating pineapple in India was also higher than the following years they considered in their study. This is attributed to the high labour intensity needed for the commencement of a pineapple farm. The high variable cost in the first year (Gh₵ 6,415.00**)** reflected also in the total cost of production in the first year (Gh₵ 11,315.00). To an extent, this affected the net farm income. Thus, in such a farm operation, the farmer runs at a loss of Gh₵ 2,315.00 in the first year of production. However, in the second and third years, a profit of Gh₵ 2,240.00 and Gh₵ 3430.00 are made respectively. This result is consistent with that of Singh *et al*. (2016) who found that large scale pineapple farmers in India incur loss in their first year of production, and make some profit in the subsequent years. In a study by Mathew *et al*. (2017), although farmers did not incur loss, the return on investment in the first year was smaller than the second and third years.

The total variable cost for cultivating under drip irrigation across all the years were higher than that of producing under rainfed conditions as shown in Table 4.7; Gh₵ 7,955.00 for the first year, Gh₵ 5,700.00 for the second year, and Gh₵ 6,060.00 for the third year. The total fixed costs for the first, second and third years were Gh₵ 4,533.00, Gh₵ 3,333.00, and Gh₵ 3,333.00. This cost category was also higher than that of the rainfed production.

Table 4.7: Per hectare cost and return on pineapple production under drip conditions

Cost categorization	Cost across the years (Gh₡)			Total (Gh₡)
	I	II	III	
Variable Cost				
Hire labour	1110	1110	1140	3360
Manures and Fertilizer	950	1000	1150	3100
Herbicide	425	450	500	1375
Fungicide	150	170	200	520
Carbide	500	520	550	1570
Plastic Mulch	520	550	570	1640
Planting material (sucker)	2500	-	-	2500
Fuel and Repair	1800	1900	1950	5600
Total	**7955**	**5700**	**6060**	**19715**
Fixed Cost				
Rental value of owned land	600	-	-	600
Rent paid for a leased land	600	-	-	600
Depreciation	3333	3333	3333	9999
Total	**4533**	**3333**	**3333**	**11199**
Cost A1	7955	5700	6060	19715
Cost A2	8555	6300	6660	21515
Cost B1	9155	6900	7260	23315
Cost B2	10155	7900	8260	26315
Total cost	**14688**	**11233**	**11593**	**37514**
Gross farm income (GFI)	10500	12000	13500	36000
Farm business income	2545	6300	7440	16285
Net farm income	-4188	1367	1907	-1514

Source: Adapted from farm records (2019-2021)

The gross incomes across the three years were Gh₵ 10,500.00, Gh₵ 12,000.00 and Gh₵ 13,500.00 for the first, second and third years respectively. This is also higher than the gross income accrued for pineapple production under rainfed conditions. The initial investment cost, coupled with the operation and maintenance cost of the irrigation system led to the high variable and fixed costs. Although the gross farm incomes across all the years were higher than that of the rainfed production, there was an incurrence of loss of Gh₵ 4,188.00 in the first year of production. In the second and third years, a profit of Gh₵ 1,367.00 and Gh₵ 1,907.00, respectively were made. Relatively, the profit made in the second and third years of producing under rainfed conditions is better than that of producing under drip irrigation. It is not surprising that most large-scale farms still operate all their fields under rainfed conditions, whilst some also have some part of the field under drip irrigation and other parts under rainfed. For the drip system, "*when there is drought you can water, and then you can also reduce labour cost, you use less water even when there are no rains.* Those are things we looked at before investing in the drip because the drip irrigation is quite expensive (Asherow, 2020, personal communication). This implies that large scale farms do employ irrigation in pineapple production to cater for drought effect on phenological growth stages of pineapple. According to Baranchuluun *et al*. (2014), the benefits of adopting an irrigation system for crop production include yield increase, and a decrease in labour, as well as its related costs. Yield increase is not always assured since the technical know-how and proper maintenance of the system play key role in increased crop yield.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and Conclusion

The incorporation of irrigation practices to crop production has proven worthwhile in most studies, and this has led to the dissemination and adoption of different systems of irrigation in production of high-value crops. In any case, several factors should be considered prior to the adoption of an irrigation system. Amongst such factors are crop characteristics, microclimate and edaphic features of the location of the farm, and scale of production. Unlike other crops mostly supplemented with some form of irrigation, pineapple farmers in Ghana produce mainly under rainfed conditions. Considering the unreliable trend in rainfall pattern, and its impact on agricultural production, the study sought to ascertain the performance of pineapple under drip irrigation and rainfed conditions in the Coastal Savannah agroecological zone of Ghana.

The study revealed that:

1. A total of 516.8 mm of water is required for the production of pineapple from December through to the following year December.
2. The emitter flow variation, coefficient of variation, uniformity coefficient and field emission uniformity were 59.3 %, 0.16 %, 86.8 % and 79.7 %, respectively.
3. There was no significant difference between weight of fruit from irrigated and rainfed fields. The yield for fresh fruit for irrigated field was 0.2516 t/ha, which is higher than that of rainfed production which was 0.24875

t/ha. The Brix values for fruits from rainfed production were higher than those produced under drip irrigation.

4. The overall cost of production for drip irrigated and rainfed plots across the three-year period considered in the study were Gh₵ 14,688.00, Gh₵ 11,233.00 and Gh₵ 11,593.00 and Gh₵ 11,315.00, Gh₵ 7,760.00, Gh₵ 8,070.00, respectively. The total net income across the three (3) years (2019, 2020 and 2021) for rainfed production was Gh₵ 3,355.00. However, there was a loss incurred (Gh₵ 1,514.00) at the end of the third year of production under drip irrigation. The production under rainfed has shown to be more profitable than that under drip irrigation in this study, considering a shorter period of three years. However, some profit could be realised for drip irrigation in the long-term.

The bimodal rainfall pattern in the production hotspot in Ghana takes care of the need to incorporate irrigation to the production of pineapple, coupled with the crassulacean acid metabolism of the pineapple plant. Due to this metabolism, pineapple plants close their stomata in the daytime and take up carbon dioxide during the night where evapotranspiration is low. This makes the pineapple plant water efficient, compared to other crops.

The state of the irrigation system on the study site, particularly as it relates to the drip lines was poor, which reflected in the low grading of some performance indicators. This further affected the individual weight of fruits under drip irrigation which were not significantly different from that of rainfed production. The yield margin for irrigated production and rainfed production was not wide. Thus, poor management of irrigation system in pineapple production will lead to low yields. Considering the crop water requirement and the prevailing weather conditions in the Coastal Savannah agroecological zone, farmers can realize better yield without necessarily incorporating irrigation systems.

5.2. Recommendations

5.2.1. Policy Recommendations

Based on the findings of the study, it is recommended that:

1. The Ghana Export and Promotion Authority (GEPA) should liaise with the Ministry of Food and Agriculture (MoFA) to organise regular training for pineapple farmers to expose them to GLOBALGAP in the subsector.
2. Large scale farms should consider setting up research divisions in their companies and liaise with academic and research institutions to close the gap between the practice and academia, and make informed decisions emerging from scientific studies.
3. Farmers and investors should understand the phenology of pineapple production, and thus cultivate them successfully under rainfed conditions, avoiding the need for irrigation.
4. MoFA should organise regular workshops for extension officers, and at the district levels, officers should be assigned to specific crops cultivated in the district. By this, officers can be responsible and farmers will know which officers to approach.
5. Farmers and investors should seek the know-how of agricultural experts to help them understand the various options and the consequent implications.

5.2.2. Recommendations for Further Research

The following recommendations are being made for further research:

1. A study to determine the critical need for water in growth stages of pineapple and for increase yield.
2. A study to determine the crop coefficients (kc) of pineapple for all the major growth stages.

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APPENDICES

Appendix I: Method for Collecting Data for Hydraulic Performance Assessment of a Drip Irrigation System

Drip irrigation system having a lateral size of 16 mm of 80 m length with emitters at 30 cm apart was used for the study of hydraulic performance.

The distribution of water application and discharges from emitters along the lateral were measured using ASABE Standards.

7. Firstly, the entire area for the performance assessment of the drip irrigation system was determined. The length of the submain was determined as 180 m, and four drip lines, measuring 80 m each were selected.
8. Drippers for the assessment were chosen based on the use of a standard approach. The criteria for selection of the laterals and emitters are given by the equation: n/4, n/2, 3n/4, last line; l/4, l/2, 3l/4, end where n is the number of lines, and l is the length of line. 16 emitter points were determined.
9. A catch can was placed at each of these positions to collect water for a period of 20 minutes at a pump operating pressure of 4.7 bar. The volume of water collected in each catch can was determined with a graduated container. This was done for all the four drip lines. At each of the 16 predetermined emitter points, two values were recorded; water collected in a catch can at a point and its adjacent point (i.e A and B) as shown in table 1.
10. The procedure was repeated and the average of the volume of the water was considered as the discharge for a position.

11. The emitter discharge for each of the sixteen (16) locations were then calculated as the average discharge.
12. The emission uniformity was computed using the applicable equation.

Appen Discharge of Drip Irrigation System Measured at Bomarts Farms as at January, 2022.

Locatio	eral	Lateral location on the submain							
		l/4		l/2		3l/4		Far end	
		ml	l/h	ml	l/h	ml	l/h	ml	l/h
n/4		215	0.646	225	0.676	150	0.450	175	0.526
		218	0.655	230	0.691	200	0.601	190	0.571
	g	**216.5**	**0.650**	**227.5**	**0.683**	**175**	**0.526**	**182.5**	**0.549**
n/2		220	0.661	175	0.526	215	0.646	180	0.541
		178	0.535	250	0.751	175	0.526	200	0.601
	g	**199**	**0.598**	**212.5**	**0.638**	**195**	**0.586**	**190**	**0.571**
3n/4		200	0.601	190	0.571	165	0.495	165	0.495
		180	0.541	212	0.637	150	0.450	185	0.556
	g	**190**	**0.571**	**201**	**0.604**	**157.5**	**0.473**	**175**	**0.526**
Far end		190	0.571	215	0.646	100	0.300	175	0.526
	B	175	0.526	200	0.601	85	0.255	160	0.480
	Avg	**182.5**	**0.549**	**207.5**	**0.623**	**92.5**	**0.278**	**167.5**	**0.503**

Field data, 2022

Weight and Size of Pineapple from Irrigated field

Weight (g)	652	762	762	765	791	822	832	853	860	873	881	886	889	890	892	932	940	940	947
Size (mm)	89	96	95	97	93	95	92	98	90	92	93	92	91	93	95	99.9	98	96	92

Weight and Size of Pineapple from Irrigated Field

Weight (g)	958	1026	1027	1045	1067	1080	1094	1146	1164	1167	1186	1200	1214	1230	1243	1294	1346	1364	1524
Size (mm)	96	101	98	100	102	100	98	104	103	101	101	99	98	101	101	103	100	102	102

Appen Table 4 1: Weight and Corresponding Size of Pineapple Fruits from Drip Irrigated and Rainfed Fields

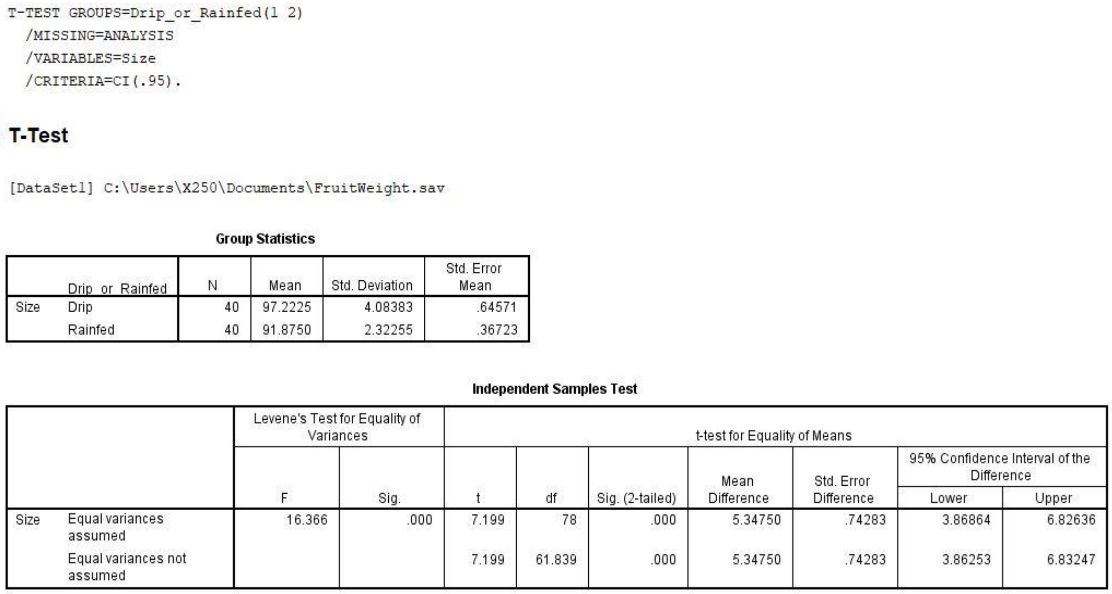
Weight and Size of Pineapple from Rainfed Field

Weight (g)	609	[illegible]	624	696	713	721	721	752	770	772	830	863	863	882	924	925	925	929	940	994
Size (mm)	88	[illegible]	91	90	92	90	89	90	89	90	95	94	90	97	94	93	92	90	89	90

Weight and Size of Pineapple from Rainfed Field

Weight (g)	1015	1009	1024	1036	1038	1040	1105	1134	1157	1101	1212	1219	1306	1208	1310	1314	1218	1342	1423	1512
Size (mm)	94	89	90	95	94	90	90	93	95	92	90	90	96	95	94	93	92	93	94	93

Appendix IV: Independent Samples t-test Output for Size and Weight of Pineapple



```
T-TEST GROUPS=Drip_or_Rainfed(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=Size
  /CRITERIA=CI(.95).
```

T-Test

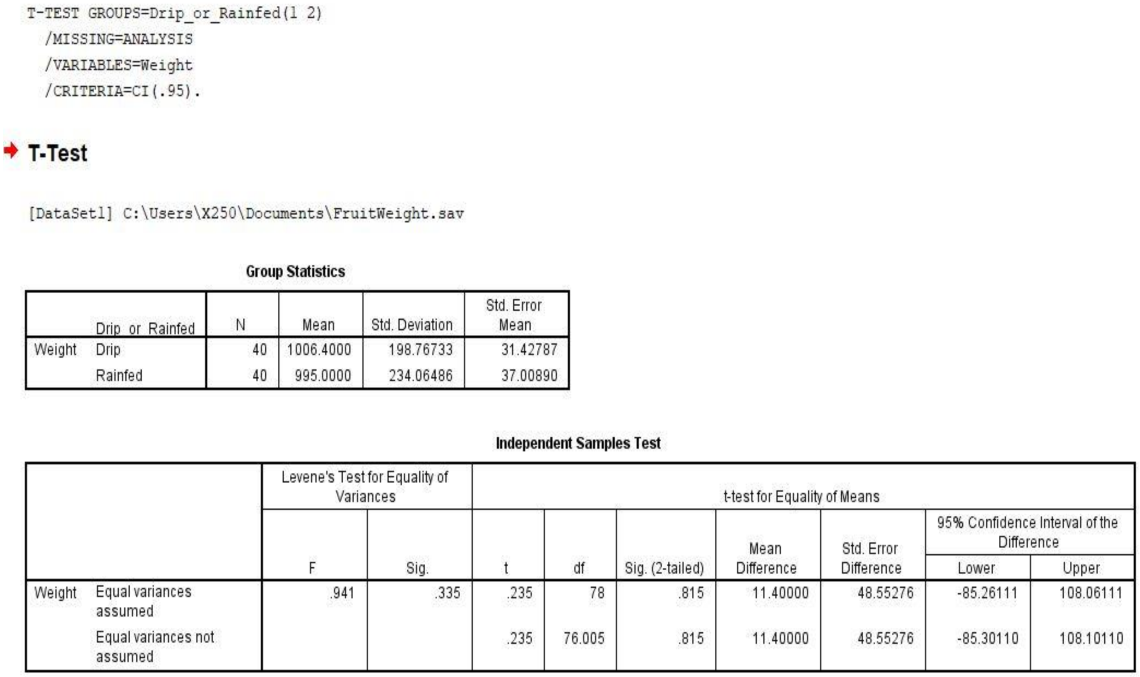
```
[DataSet1] C:\Users\X250\Documents\FruitWeight.sav
```

Group Statistics

	Drip_or_Rainfed	N	Mean	Std. Deviation	Std. Error Mean
Size	Drip	40	97.2225	4.08383	.64571
	Rainfed	40	91.8750	2.32255	.36723

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Size	Equal variances assumed	16.366	.000	7.199	78	.000	5.34750	.74283	3.86864	6.82636
	Equal variances not assumed			7.199	61.839	.000	5.34750	.74283	3.86253	6.83247



```
T-TEST GROUPS=Drip_or_Rainfed(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=Weight
  /CRITERIA=CI(.95).
```

T-Test

```
[DataSet1] C:\Users\X250\Documents\FruitWeight.sav
```

Group Statistics

	Drip_or_Rainfed	N	Mean	Std. Deviation	Std. Error Mean
Weight	Drip	40	1006.4000	198.76733	31.42787
	Rainfed	40	995.0000	234.06486	37.00890

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Weight	Equal variances assumed	.941	.335	.235	78	.815	11.40000	48.55276	-85.26111	108.06111
	Equal variances not assumed			.235	76.005	.815	11.40000	48.55276	-85.30110	108.10110

Appendix V.a: Measurement of Performance of Drip System on the Field

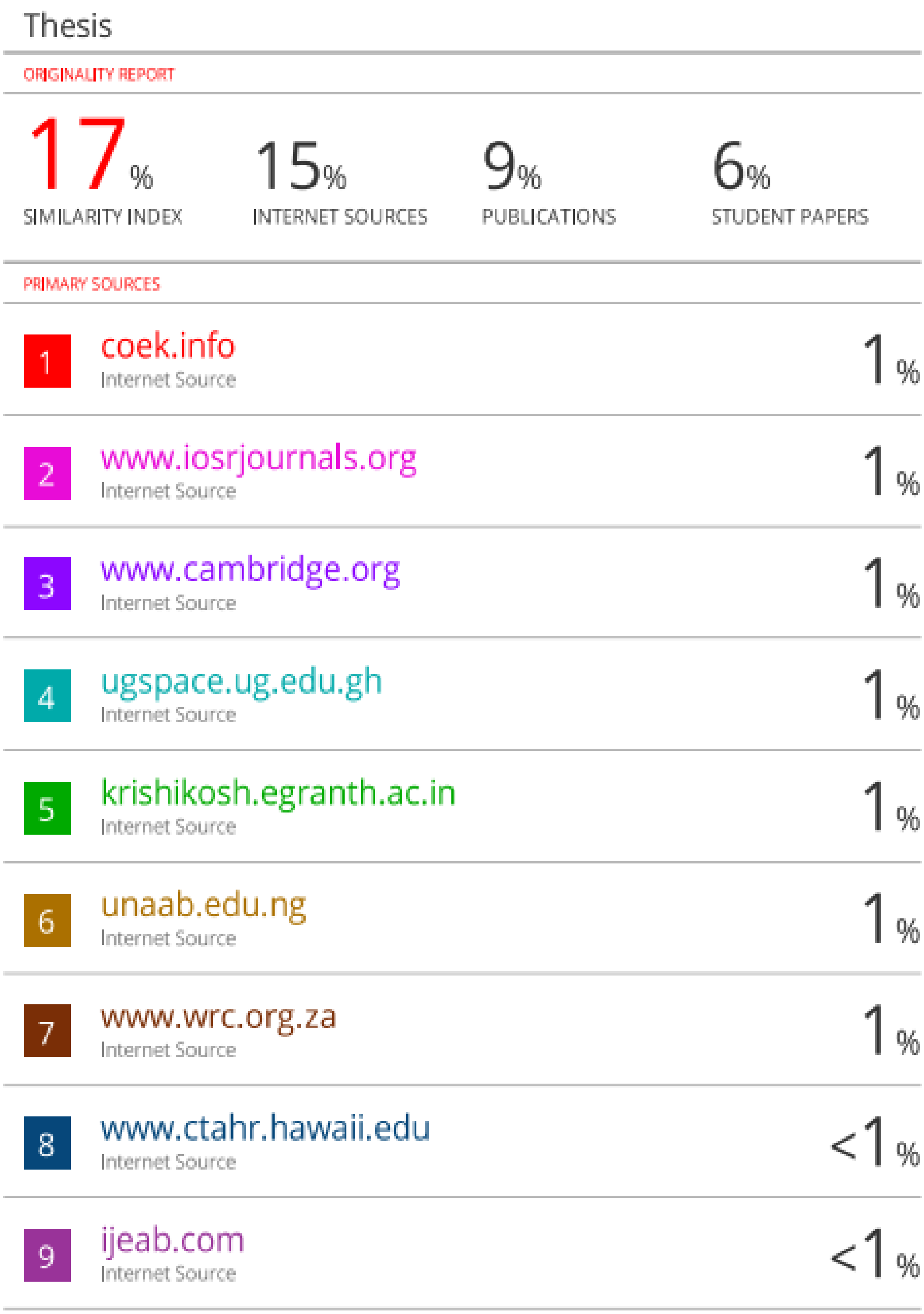
Appendix V.b: Determination of Shelf-life of Pineapple

Appendix V.c: Determination of Shelf-life of Pineapple

Appendix V.d Determination of Fruit Weight and Yield

Appendix V.e: Determination of Fresh Fruit Yield on the Field

Appendix V.f: Drip System Layout at the Farm prior to the Determination of the Hydraulic Performance of the System.



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