EFFECT OF SUPPLEMENTARY SPRINKLER IRRIGATION ON GROWTH AND YIELD OF FRENCH BEANS (*Phaseolus vulgaris L.*) IN SEMI-ARID MUVUMBA VALLEY, RWANDA

MIZERO JULES

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2022

DECLARATION

This thesis is my original work and has not been presented for the award of a degree in any other University.

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DEDICATION

This work is dedicated to:

The Almighty God for his mercy and blessing upon me, God is my rock, my fortress, and my deliverer; He is strength, in whom I trust and the horn of my salvation, and my high tower.

My beloved brother, Gerald Nshimiyimana and my family, who pray all the time that God protects and gives me courage, strength and blesses the work of my hands.

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TABLE OF CONTENTS

LIST OF THE TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

CV: Coefficient of Variability
DRC: Democratic Republic of Congo
FAO: Food and Agriculture Organization
FAOSTAT: Food and Agriculture Organization Corporate Statistical Database
GMT: Greenwich Mean Time
ITCZ: Inter-Tropical Convergence Zone
NAEB: National Agricultural Export Development Board
NISR: National Institute of Statistics Rwanda
m.a.s.l: meter above sea level
MINAGRI: Ministry of Agriculture and Animal Resources
RAB: Rwanda Agricultural Board
REMA: Rwanda Environment Management Authority
SDGs: Sustainable Development Goals
SSIT: Small Scale Irrigation Technology
SWOT: Strengths, Weaknesses, Opportunities and Threats
USD: United States Dollars
UK: United Kingdom
UN: United Natioms

ABSTRACT

This study was conducted in semi-arid area of Muvumba valley, Nyagatare District, Eastern Province of Rwanda. This work was formulated with the aim of assessing the effect of supplementary sprinkler irrigation on growth and yield of French beans (*Phaseolus vulgaris l.)* in semi-arid Muvumba valley, Rwanda. The irrigation treatments were EM (early in the morning), EL (late in the evening) and ELE (both early in the morning and late in the evening) and each treatment was replicated three times in a randomized complete block design (RCBD) for two seasons (Dry-Wet and Wet-Dry seasons). Soil water content was monitored with gravimetric method at 0.30 m depth every time irrigation was undertaken and CROPWAT 8.0 was used to estimate the crop evapotranspiration.

The results obtained show that the treatments had significantly different effects on plant height, leaf width, leaf length, leaf area and leaf area index. Reduced water application due to evapotranspiration (ET) from 252.7 mm/dec during Dry-Wet season to 223.8 mm/dec during Wet-Dry season increased water use efficiency (WUE) during Wet-Dry season. The highest water use efficiency of French bean was 1.637 Kg/mm, irrigated early in the morning and late in the evening (ELE) during Wet-Dry season, and the lowest water use efficiency of French bean was 0.969 Kg/mm irrigated once only in the morning during Dry-Wet season.

The results obtained also show that French bean growth parameters and yield were significantly different ($p < 0.01$) and were highest in both the seasons when the crop was irrigated twice a day (ELE) than when irrigated either early in the morning (EM) or late in the evening (LE). In both seasons, the highest yield of French bean was 366.8 Kg/ha with a net income of 98,414 Rwandan Franc equivalent to 103.5 USD. This yield was obtained when the crop was irrigated twice a day (ELE) during the Wet-Dry season. The results also indicated that the Wet-Dry season (yields of total irrigation regimes) had the highest yield (1,338.7 Kg/ha) with the net income of 320,443 RWF (337 USD) than. Irrigating early in the morning and late in the evening (ELE) using supplemental sprinkler irrigation system increased WUE and yield than either irrigation in the morning only (LE) or in the evening only (EM). The study recommends that it is financially viable to irrigate twice a day because it is possible to obtain higher return as compared to irrigating in the morning or in the evening only.

Key words: Semi-arid area, French bean production, watering regimes, sprinkler irrigation, financial returns and water use efficiency.

CHAPTER ONE

INTRODUCTION

1.1. Background Information

Equitable and sustainable water management, and innovative irrigation strategies are needed for improving water services to rural development and agriculture (FAO, 2018). The 2030 Agenda for Sustainable Development Goals' success in eradicating poverty and hunger, protecting natural resources, and addressing climate change all depend on the production of food and agriculture. (Nhemachena et al., 2018). Farmers in semiarid areas aim in maximizing their production to sustain their livelihoods by using irrigation systems. When rainfall is insufficient to provide plants with the necessary moisture for proper growth and development, supplemental irrigation is used to supplement rainfed crops in order to maintain growth and increase yields (Oweis et al., 2018). It is a very effective technique with significant promise for boosting agricultural output and enhancing incomes in dry rainfed areas (Oweis and Hachum, 2006). Irrigation boosts food production in semi-arid and arid regions of the world, helping to feed the world's expanding population. Therefore, with irrigation efficient use of uncommon methods of water application becomes an important contributor to the attainment of higher productivity and optimum use of water (Al-Ghobari and Dewidar, 2018). This study focused on French bean production in a low rainfall area using sprinkler irrigation to supplement rains (Vaissière et al., 2014).

A big challenge facing Sub-Saharan Africa today regarding food deficiency and water scarcity is due to a number of factors. Among these there is increased water withdrawals and climate change (Green, 2019). Water shortage is one of the most important factor threatening agriculture in Rwanda. Muvumba catchment where this study was carried out is one of the upriver parts of the Nile basin that experience scarcity of water. The river flows through Nyagatare, Gicumbi and Gatsibo Districts in the Kagera sub-basin (Aboniyo et al., 2017). In Muvumba valley, irrigation is destined to make an impact in the future as the area plays a significant function in boosting food output. Irrigation in the valley has potential of improving crop production and extending the actual growing period of crop during dry seasons in this part of Rwanda. The horticulture industry in

Rwanda earned USD 6.1 million in 2015, a rise of 41.3% compared with what was earned in 2014. Currently, the Government of Rwanda is concentrating on supporting French beans and peas, chili pepper, mini leek, African eggplants, mushrooms (FAO, 2016). French bean is also known as garden, green, string, or snap bean (*Phaseolus Vulgaris L.)*; are among the greatest leading vegetables in providing to humans worldwide vitamins, minerals, proteins and dietary fiber (Myers et al., 2019 and Munywoki et al., 2016). Globally, the total production go above 17 million tons, with China, Indonesia, Turkey, India and Egypt being amongst the biggest producers (Ngelenzi et al., 2016). In Eastern Africa, Kenya is leading while Rwanda is the second (Petry et al., 2015; Wangui et al., 2019 and FAOSTAT, 2020).

French bean production in Rwanda is steadily rising and becoming most important export vegetable crop according to the National Agricultural Export Development Board (NAEB). It is grown for fresh export and domestic market. The European Union (Belgium, France, UK, and others) is the major market for fine and extra-fine beans produced in Rwanda. The other consumer include the United State of America and Dubai. Currently, three varieties of French beans are available in Rwanda. These include Samantha, Argus, Ferali and their grades are extra-fine, fine beans and bobby (National Agricultural Export Development Board, 2020).

1.2. Problem Statement

Land and water are the two basic prerequisites for food production and the need for these two natural resources is rising more and more due to the growing population, urbanization and large-scale industrialization (Maurice et al., 2015). Water for irrigation is necessary and is influenced by its quantity and quality, and its management.

The non-irrigated agriculture is a chancy enterprise due of the great spatial and temporal unpredictability of rainfall in semiarid areas (Oweis and Hachum, 2009). In several countries, the lack of sufficient rainfall is a significant constraint to sustainable agriculture. Such is the case is the eastern region of Rwanda, which has faced several periods of drought (Jean-Fiston et al., 2014). In this region, especially in Nyagatare District crop cultivation suffers from low productivity resulting from inadequate rainfall during the dry season. Adaptation of supplementary irrigation and techniques for soil moisture conservation are necessary to address deficits of soil moisture so that land productivity and yield can be improved (Kannan et al., 2011).

Nyagatare District is classified as a semi-arid area where the potential evapotranspiration is equal to or greater than the yearly rainfall for more than two months but less than 4.5 months. Rainfall varies between 250 to 800 mm every year (Dusabumuremyi et al., 2014). This district suffers with soil erosion, river siltation, droughts, deforestation and soil degradation (Mwongera et al., 2019). Poverty and hunger are major challenges in the area because a considerable section of the region's arable land is water scarce and vulnerable to frequent dry periods (Claude, 2019 and Dusabumuremyi et al., 2014).

In Matimba and Musheri sectors of Nyagatare District, an irrigation facility stands tall above crops especially for vegetables production (French beans) during drought period. In Rwanda, specifically in Nyagatare District, constraints facing the production of French beans comprise abiotic (flooding /excessive rain, drought, stress from heat and cold, and insufficient soil fertility) and biotic (pests and diseases, field and post-harvest). All these decrease the yield in smallholder production systems. The challenge is increased by improper agronomic practices as a effect of a scarce investigation, expansion system and absence of experienced workers (Dusabumuremyi et al., 2014). In order to produce French beans with the potential for high returns on investment, a high input crop like labor-intensive crop is needed, specifically for land preparation, planting, and weed management, well-drained soils rich in organic matter, at temperatures of 18 to 30 °C harvesting, and postharvest handling. In addition, the crop requires large amounts of fertilizer and pesticides (Fulano et al., 2021). This study seeks to address the water deficiencies in agriculture at Nyagatare district (Muvumba valley). It addresses inequitable water distribution between water users, insufficient water for irrigation to fulfill the need for crop water requirement and poor distribution of water to crops. This shall shed a light on what needs to be done to develop irrigation for better yield of French beans.

1.3. Justification of the Study

The necessity for the developed world to reduce labor inputs, keep energy costs down, and reduce water waste while preserving operational reliability is what drives modern technical advancements. In the context of irrigation, the word "modern technology" refers to sprinkler and trickle irrigation systems used on farms, sprinkler irrigation technology as used on approximately five percent of irrigated land throughout the world. This provides the mobility and ease of use needed for optimal operation, regardless of the changing topographic circumstances and soil conditions. (Kay, 2001).

The major resource in modern technology is water. Water is leading restricting factor to agriculturalists, in arid and semi-arid areas (Abdel-Mawgoud, 2006). Water shortage limits agricultural development and calls for financial and efficient water use. Irrigation therefore becomes a crucial agricultural technique for the production of food, pasture, and fiber in these areas (Koech and Langat, 2018). With the increase in food requirement in the world, there is necessity for investigation to increase the stress tolerance of plants and to improve well management techniques to maintain food production high in spite of restricted accessibility of water and land (Akıncı and Lösel, 2012). The production of French beans under irrigated conditions is a possible remedy.

French bean requires 15-25 ^{0}C temperature for optimum growth and pod yield (Tineke, 2003; Mal and Thirumdasu, 2015). French beans can be grown in all types of soils but they prefer well drained fertile loamy soils and they grow better in soils having pH 6.0 to 7.5 (Tineke, 2003; Malesu et al., 2010 and Rajinder, 2016). The French bean significance is owing to their great nutritious value together with protein and energy contents. In numerous nations, rising crop production is one of the best significant goals of agricultural policy (Menge et al., 2014). In Rwanda, green beans were developed by rural societies. They provide large quantities of calories as they are the main source of proteins and micronutrients. There is need for significant research efforts to improve water use and increase yield, consumption, and market qualities of French beans in Rwanda. For ensuring sustainable food production for the Rwandan rural livelihoods, this research seeks to solve problems connected to water use efficiency, weather changes and food insecurity in Rwanda. Use of supplementary sprinkler irrigation for the production of French beans can contribute towards the realization of SDGs in particular goals number 1, 2, 3, 6, 8, 13, 14 and 15 in the semi-arid Muvumba valley area in Rwanda. Therefore there is need to undertake research on the impact of supplementary sprinkler irrigation on the production of French beans in Muvumba valley.

1.4. Objectives

1.4.1. Overall objective

To assess the effect of supplementary irrigation for increased French beans production in the semi-arid area of Rwanda.

1.4.2. Specific objectives

1. To assess the effect of different sprinkler irrigation watering regimes on yield of French beans,
2. To determine water use efficiency of French beans production under different sprinkler irrigation watering regimes,
3. To evaluate the costs and benefits of growing French beans under different sprinkler irrigation watering regimes.

1.5. Hypotheses

The study is based on the following hypotheses:

1. The growth and yield of French beans is not affected by different sprinkler irrigation watering regimes,
2. Water use efficiency in French beans production is not influenced by different sprinkler irrigation watering regimes,
3. There are benefits accrued by growing French beans under irrigated conditions.

CHAPTER TWO

LITERATURE REVIEW

2.1. National Water Balance in Rwanda

Rwanda's water potential at the national and watershed levels reveals that the country receives an average of 28 billion m^3 of precipitation per year, which covers all of its water resources (precipitation, overflow, surface water bodies, and groundwater). Runoff water generates around 4.3 km^3 of water, evaporation loss is 9.5 km^3 of water, transpiration of all vegetation is 5.3 km^3 of water and penetration into the groundwater system is 4.3 km^3 of water. Noting of the large accessible storage of water in Rwanda, the irrigation improvement is not limited on the national scale by water availability (Malesu et al., 2010). The estimation of the present water use of any catchment is centered on water accessibility and discharge from boreholes or springs; the ability of piped water supply systems production. This is related to the rainwater harvesting, ability of irrigation ponds and swamps; the diverse annually supply of surface irrigation or groundwater resources and the different capacities of irrigation water projected from dam sites in the Eastern and Western areas (Aboniyo et al., 2017).

2.2. Irrigation Water Sources in Rwanda

Rwanda is located on the great East African Plateau between the Nile and Congo rivers (Nyandwi et al., 2016). The Congo river basin has 33 % of the countrywide area and obtains 10 % of the total nationwide waters. The Nile basins has 67 % of the countrywide area draining 90% of Rwanda water (Aboniyo et al., 2017, Bizuhoraho et al., 2018). The two drainage basins are subdivided into ten watersheds where Muvumba valley is located which are Akagera, Akanyaru, Kivu, Mukungwa, Mulindi, Muvumba, Mwogo, Nyabarongo amont, Nyabarongo aval and Rusizi (Nyandwi et al., 2016). The inventory displayed that Rwanda has 860 marshlands covering 10% of the country surface area (278,536 ha), 101 lakes (Kivu, Bulera, Ruhondo, Muhazi, Cyohoha, Sake, Kilimbi, Mirayi, Rumira, Kidogo, Mugesera, Nasho, Mpanga, Ihema, Mihindi, Rwampanga, and Bisoke are among the 17 largest lakes) covering a total surface of 149,48 ha and 861 rivers (In the Nile Basin, the important rivers are the Akagera, Akanyaru, Base, Kagitumba, Mukungwa, Muvumba, Nyabarongo, and Ruvubu; in the Congo Basin, the key rivers are the Koko, Rubyiro, Ruhwa, Rusizi, and Sebeya) totaling 6462 km in length (Aboniyo et al., 2017). Rwanda is divided into nine catchments, in which the Nile Basin contains seven catchments and the two remaining catchments localized in Congo Basin. The Muvumba catchment (1565 Km^2) is belong to the most upstream parts of the Nile Basin and the Mediterranean Sea is the final outflow. It is locate in the Kagera sub-basin and covers of Nyagatare, Gicumbi and Gatsibo Districts (Bizuhoraho et al., 2018 and Aboniyo et al., 2017).

2.3. Irrigation in Rwanda

Rwanda has a surface area of 26,338km^2 (Nabahungu and Visser, 2011). This land locked country (Okereke and Tyldesley, 2011) is situated in the tropical belt with Longitude 28°52'E to 30°55'E and Latitude 1°51'S to 2°51'S (Asumadu-Sarkodie, 2015) and it is landlocked. Rwanda is bordered by Burundi in the south, Uganda in the north, Tanzania in the east, the Democratic Republic of the Congo (DRC) in the west, and the Democratic Republic of the Congo (DRC) in the west (Okereke and Tyldesley, 2011, Rutagarama, 2015). The Rwandan population in 2012 was 10, 515, 973, having a 415 resident per square kilometer population density. Nyagatare district has a population density of 242 inhabitants/km^2 (NISR, 2014).

The low altitudes of Rwanda are situated in eastern and southern provinces while the high altitudes are situated in northern and western provinces (Ntwali et al., 2016). Rwanda with its nearness to the Equator, likes a tropical climate controlled by hilly topography differing from 900 to 4507 m and prolonging from East to West (Muhire et al., 2015 and Mikova et al., 2015). The greatest totals annual rainfall located in the western part and the high elevated north-western part (>1200 mm) diminishing towards the eastern plateau (<900 mm) of Rwanda (Safari, 2012).

The north-south oscillating migration of the Inter- Tropical Convergence Zone (ITCZ) of trade winds associated with two rainy seasons are experienced in Rwanda. The long rainy season starts when the ITCZ moves to the North from March to May and the short rainy season start when the ITCZ returns to the South between October and December. January to February marks the beginning of the short dry season, whereas June to September marks the beginning of the long dry season (Asumadu-Sarkodie, 2015 & Safari, 2012). According to the Rwanda National Water Supply Masterplan (2016); the total annual rainfall is 27.505 billion m^3 while the total renewable water resources per annum is 6.826 billion m^3 with a groundwater recharge of 4.554 billion m^3 and less than 1000 m^3 with available fresh water (per capita) which is less than the average 4000 m^3 for Africa.

Irrigation was started in Rwanda in 1945 in Karongi District after the famine of Ruzagayura that occurred in 1943–1944 (Malesu et al., 2010). According to the Irrigation Master Plan for Rwanda, the country's 589,711 ha of land, which includes 219,797 ha of marshland, 153,534 ha of hillside domains, 179,954 ha of river and lake pumping domains, and 36,432 ha of groundwater resources, has the potential to be irrigated and used for modern agriculture. Rwanda has developed about 30,000 ha of its potential irrigated area- including around 26,000 ha of marshland and 3,000ha of hillside land (MINAGRI, 2014). The hillside, swamp and small-scale irrigation systems are the three categories developed in Rwanda and pressurized irrigation system represents hillside irrigation. Sprinkler and drip irrigation systems are mainly localized to the irrigation systems used in the hillside schemes. Gravity stream diversions and valley dams are utilized as improved surface irrigation systems in marshlands (swamps) to supply canal networks for flooding basins planted with rice (MINAGRI, 2013).

2.4. French Beans (*Phaseolus vulgaris L.)* Production

To humans worldwide, French bean *(Phaseolus vulgaris L.)* is among the essential vegetables in providing minerals, vitamins, proteins and dietary fiber. Its successful production in the tropics is reserved by biotic and abiotic stresses as the crop is mainly grown in open fields (Ngelenzi et al., 2016). Normally, since it is the most consumed bean in the world, it is commonly well recognized as green beans French beans, ‘common beans’ and it is also known as ‘snap beans’ owing to the sounding created when the pod of green is broken (Sermet et al., 2006 and Wangui et al., 2019). French bean originated in central and South America and It is used as vegetables when pods are immature and tender as well as seeds are also used as pulse. French beans are widely grown in

North and Central America, Eastern Africa, Eastern Asia, South and Western Europe, and South and Eastern Asia (Rahman et al., 2018).

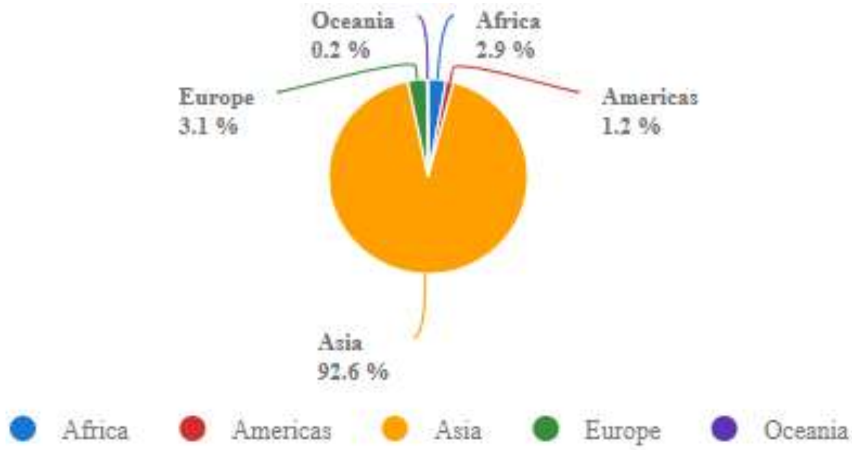

Figure 2.1: World production of French beans
Source: (FAOSTAT, 2020)

Green bean total worldwide-cultivated area (Figure 2.1) in 2018 was 1,567,394 hectares, produced 24,752,675 tons. The highest continent of green beans (French bean) production was Asia with 22,923,896 tons in 1,329,006 ha, followed by Europe with 758,576 tons in 104,150 ha, Africa had 722,022 tons in 78,131 ha, America had 297,468 tons in 48,059 ha and the lowest continent was Oceania with 50,713 tons in 8,048 ha (FAOSTAT, 2020). The top ten countries in green bean production were China (19,897,100 tons), Indonesia (939,598 tons), India (715,141 tons), Turkey (580,949 tons), Thailand (315,293 tons), Egypt (284,299 tons), Italy (163,824 tons), Marocco (148,392 tons), Spain (138,925 tons), and lastly 134,860 tons produced by Bangladesh in 2018. In Eastern African, Kenya produced 34,211 tons in 3,234 ha, Rwanda produced 7,597 tons in 901 ha, United Republic of Tanzania produced 4,492 tons in 874 ha and South Sudan produced 1015 tons in 232 ha (FAOSTAT, 2020).

2.5. Water Requirement of French Beans

The total growing period of French been (green beans) is 75-90 days, (Brouwer and Heibloem, 1986, Munuve, 2015). The length of French beans planted took 75 days where Initial stage took (L_{ini}): 15 days, development stage (L_{dev}): 25 days, mid stage (L_{mid}): 25 days, Late stage (L_{late}): 10 days (Allan et al., 1998, Doorenbos and Pruitt, 1977, Savva and Frenken, 2002). The French bean crop coefficients at initial stage was 0.5, development stage 0.75, at the mid season 1.105 and at Late season stage 0.9 (Lado et al., 2017). Depending on climatic condition and the variety, French beans water requirement range between 300 to 500 mm (FAO, 2022). Crop water requirement of French beans varies with the development stages: 35 mm /week/plant from planting days up to ten days post emergence, 50 mm /week/ plant from ten days after emergence until flowering stage and lastly 35mm /week/plant at podding stage of French bean (Kalawa, 2017).

The ratio of crop evapotranspiration (ETc) to reference evapotranspiration (ETo) is known as the crop coefficient (Kc). (Allan et al., 1998 and Silva et al., 2017). Crop evapotranspiration (ETc) is the quantity of water that plants lose through evaporation when they are cultivated in wide fields, under perfect soil water conditions, and at full production under the relevant meteorological circumstances. These plants are disease-free, fertilized, and have reached full production. The reference evapotranspiration (ETo) is parameter of climatic and can be calculated from weather data. At a precise position and season of the year, it expresses the evaporating power of the atmosphere and does not deliberate the characteristics of crops and factors of the soil. Maximum French beans height (h) is 0.5 m, maximum root depth varies from 0.5-0.7 m, depletion fraction is 0.45, yield response factor is 1.15 (Doorenbos and Pruitt, 1977 and Allan et al., 1998). Yield response factor denoted (Ky) is a factor that defines the decrease in relative yield according to the decrease in crop evapotranspiration (ETc) affected by scarcity of soil water and Ky of French beans is (0.2, 1.1, 0.75, 0.2) for initial stage, development stage, flowering, harvesting stage and for total growing period is 1.15 (Savva and Frenken, 2002 and Allan et al., 1998).

2.6. French Beans Water Use Efficiency

In agriculture, the term efficiency refers to the relationship between output and input that is calculated as a proportion (output/input) or as the slope of the functional relationship between output and input (Sadras et al., 2014). The ratio of net benefits from different agricultural systems, such as crops, forests, fisheries, livestock, and aquaculture, to the amount of water required to create those advantages is known as water productivity (Molden et al., 2010). The economic value of produce per unit volume of water, or the physical mass of production, are additional terms for it (Molden, 1997; Cook et al., 2006 and Santosh, 2016). Physiologists of crop initially well-defined water use efficiency (WUE) as crop yield and carbon assimilated per unit of transpiration (Viets, 1962 and Molden et al., 2010). The experts in irrigation have used this term to define how successfully water is supplied to crops and to show the quantity of water wasted (Molden et al., 2010). In agriculture, "water use efficiency" is the ratio of the amount of organic matter a plant produces to the amount of water it required to produce it (De Wit, 1958; International Water Management Institute, 2008 and Nair et al., 2013).

The two indicators of the return on the water used by the crop are water productivity and water use efficiency (WUE). The greatest limitation to production is water, in areas with limited resources of water and for assessing the performance of agricultural production systems, WUE is the main criterion (Oweis and Hachum, 2012). In arid and semi-arid areas, rising water use efficiency (WUE) connected with the crops production is the only way to improve agricultural production where there is no or little expectation for development of water resources (Webber et al., 2006).

Drought-adaptation mechanisms in French beans consist of minimum a deep root systems with a suitable architecture that increases soil moisture and French beans has a greater capacity to extract water from the depths of the soil. There is also increased water use efficiency (WUE) in the plant for photosynthesis, development and growth, and increased transfer of photosynthetic to seed via efficient mobilization. Under drought, WUE contributes to increase yield and is linked with physiological processes of the plant such as root characteristics, leaf gas exchange, stomatal conductance and osmotic adjustment (Najeeb and Hameed, 2015).

Study conducted by Gupta et al., (2017), showed that irrigation regimes increases the growth rate which increases the rate of photosynthesis resulting in higher yield of broad bean (Vicia faba). In addition, a study conducted by Abdel-Mawgoud, (2006) reported that vegetative growth parameters (height of plant, number of leaves) and yield (fresh and dry weight) components replied positively to improve the levels of irrigation. Irrigation significantly increase the leaf area index and leaf area of French bean (Kalaydjieva, et al., 2015). A study on irrigation frequency, yield and water productivity of French beans done by Abebe et al., (2020) shown that the higher the water use efficiency, the lower the quantity of irrigation water received. De Pascale et al., (2011) showed that in order to maximize WUE and improving irrigation techniques, it is essential to maintain water and to promote maximal crop growth by increasing French bean production per applied unit of water and lowering the amount of water loss (i.e., increasing the quantity of water used by the crop per unit of water applied).

2.7. Methods of Irrigation

Irrigation is the process of applying water to the soil to supply the crop's water needs. Water through canals, pipes, ditches or even natural streams is pumped or flows from reservoirs, aquifers, rivers, or lakes by gravity. To suit the crops' water needs, numerous irrigation techniques have been created over time in various locations. There are three basic types of irrigation: surface, sprinkler, and drip/micro. Water is applied to the land by gravity for surface irrigation. Water is applied to soil using a sprinkler irrigation system that can be stationary or mobile. Micro irrigation wets a small portion of the soil surface in a field by dripping, bubbling, or spraying little amounts of water frequently. Sub irrigation is a minor and fourth component of irrigation where the water table is retained or increased up close to the plant root zone using subterranean drains or ditches to disperse the water (Bjorneberg, 2013). A number of factors must be considered prior choosing a particular system of irrigation. These comprise resources of water, slope, soils, weather, cropntype to be grown, capital and labor cost, type of irrigation technology and suitability to farmers, requirements of energy, water use efficiencies, as well as socioeconomic, health and environmental aspects (Andreas and Karen, 2002).

2.8. Types of Irrigation Systems

There are four major categories of irrigation systems: sub-surface irrigation systems, localized irrigation systems, and sprinkler irrigation systems. These categories are based on the way that water is applied to the land surface irrigation systems.

1. Surface irrigation systems: by an overland water flow regime, they apply water to the land. They are furrow, border strip and basin irrigation systems (border, check basin and furrow) irrigations systems (Andreas and Karen, 2002). Surface irrigation systems can be developed with minimal capital investment and need not require complicated and

expensive equipment. Labor requirements for surface irrigation tend to be higher than for the pressurized types, but the labor still need not be high unless maximum efficiencies are sought. However, when water supplies are short, irrigators have developed highly skilled practices, which achieve high efficiencies. Generally, energy costs are substantially lower, but inefficiency may very well reverse this factor. On the negative side, surface irrigation systems are typically less efficient in applying water than either sprinkle or trickle systems. Since many are situated on lower lands with tighter soils, surface systems tend to be more affected by waterlogging and salinity problems. The need to use the field surface as a conveyance and distribution facility requires that fields be well graded. Land leveling costs are high, so the surface irrigation practice tends to be limited to land already having small, even slopes (Walker, 2003).

2. Sub-surface irrigation system: in order to effect groundwater flow to the root zone, it depends on the increasing or decreasing of the water table and they are drainage flow systems (Andreas and Karen, 2002). The advantages of sub-surface irrigation are this system saves water and minimizes water loss, it allows crops to improve yield and grow uniformly and it is not labor-intensive. The disadvantage of sub-surface irrigation are that maintaining and setting up this system is expensive. Tractors, and other machines easily damage this irrigation system as can cause pipes and drippers blockage (Ramiz, 2020).

3. Localized irrigation system: through a pipe network, the distribution of water is under low pressure, in a predetermined pattern, and applied as a small discharge to each plant or adjacent to it (Megersa and Abdulahi, 2015). There are three main categories of localized irrigation methods, which are drip, spray and bubbler. Drip is the only irrigation system that has been developed for the laterals to be buried in the root zone of the crop. Localized irrigation system use a pipe to distribute and deliver filtered water (and fertilizer) to a predetermined point (Andreas and Karen, 2002). As advantages, a well-designed drip irrigation system reduces water loss through deep percolation or evaporation to almost zero and conditions may be less favorable for the onset of diseases including fungus. Irrigation scheduling by using drip irrigation can be managed precisely to meet crop demands, holding the promise of increased yield and quality. The disadvantage are that the initial

cost of drip irrigation systems can be higher than other systems and unexpected rainfall can affect drip systems either by flooding emitters, moving pipes, or affecting the flow of soil salt-content. There are also exposed to damage by rodents or other animals and It can be difficult to combine drip irrigation with mechanized production as tractors and other farm machinery can damage pipes, tubes or emitters (Sable et al., 2019).

4. Sprinkler irrigation systems: The broadly sprinkler irrigation systems are set systems and continuous move systems where water pressurized pipe networks are used to convey and distribute water before being sprayed onto the land (Andreas and Karen, 2002). Sprinkler Irrigation Systems involves applying water in the same way the natural rainfall does. The water is distributed through a system of pipes pumping water and using sprinklers. The method sprays water into the air and the descent is to the ground small water drops (breaks up). The size of small drops water sprayed by a sprinkler varies between 0.5 and 4.0 mm. To enable application of water uniformly, the pumping system, sprinklers and operating conditions must be well designed (Brouwer et al., 1990).

   In sprinkler irrigation, water is applied from the sprinkler nozzle, which produces a jet breaking up in thousands of drops of different diameters. The drops travel for a distance of two to fifteen meters (depending on their diameter) before reaching the soil surface (Aqeel and Rasheed, 2015 and Sai, 2009). Pumping water from a source (river, lake, canal or well) in sprinkler irrigation system and convey water through a lateral pipe system (partially underground and above ground) under considerable pressure (2–3 bar) of quick coupling light weight tubes, which can be moved over the field to the crops (M. Smith et al., 2014). The considerable investment and operational costs are major constraints of this irrigation system and the costs of high fuel and energy requirements of the pressurized irrigation system make it one of the most expensive methods used by small-scale farmers. A motorized pump with the capacity to provide sufficient pressure, the quick-coupling laterals, sprinkler risers and the pressurized pipe system are included in the costs of investment for sprinkler irrigation system. The sprinkler irrigation systems have an estimated investment costs of around US$3 000–5 000/ha and operational costs are high, around to US$800–1 000/ha per season for this high-pressure system due to the amount of fuel required (M. Smith et al., 2014). Strong winds result in a poor water distribution pattern, that why sprinkler irrigation should not normally be used when wind speeds are over 5m/sec (Doorenbos and Pruitt, 1977). A sprinkler irrigation system usually consists of a pump unit used to lift and pressurize water; tubing's include mains and sub mains and laterals used to transport water across the irrigated field, couplers, sprinkler head to apply the water within the field and other accessories such as valves, bends, plugs and risers (Aqeel and Rasheed, 2015). It tends to simulate the rainfall but in a way, that the run-off and deep percolation losses are avoided and irrigation is given under controlled conditions up to the root depth. It is adequate at the required time, to apply the required quantity of water (Ramanjaneyulu et al., 2018)**.**

2.8.1. Advantages of Sprinkler Irrigation System

Through the sprinkler systems, insecticides, fungicides and weedicides can also be inserted in a way like to the application of fertilizer and numerous amendments of soluble soil, such as gypsum, sulphuric acid, limes and soluble resins can be practical. By adding more lateral lines and sprinklers at predetermined arrangement, the sprinkler irrigation system can be acceptable changed so that the whole field can be covered with a fine mist of water in the time of freezing temperatures during post rainy season, therefore crops can be used from frost safety. Most of the yields of crops are down due to high air temperatures from the period of flowering to the period fruiting. Blossom drop of beans cause by a temperatures above 35°C and for several days, loss of grapes up to 50 % cause by a temperatures in excess of 38°C. When sprinkler irrigation system functioned at low application rates will bring down the ambient air temperatures and leaf temperature by 5°C or more thus crop losses can be decreased and quality of fruit maintained. This method of irrigation can be used for wide variety of crops except for paddy and jute. The saving of water is up to 30-50% as compared to surface methods of irrigation. This method of irrigation does not require any particular skill. It is well suited for supplemental irrigation in the event of dry spell at critical stages (Ramanjaneyulu et al., 2018).

2.8.2. Disadvantages of Sprinkler Irrigation System

The effectiveness of uniform sprinkling reduces by wind interference and to reduce this disadvantage, due to reflection in the original design of the system, wind conditions should be known. Ripening soft fruit can be damaged due to spray; operating sprinkler during flowering period may affect pollination and fruit set. Compared to surface irrigation methods, the sprinkler irrigation method usually requires the higher initial investment except where for gravity irrigation, extensive land leveling is necessar. Since sprinkler operates with a water pressure of 1.0 to more than 10 kg/cm^2 gauge pressure, energy requirements are usually high. In hot wind areas, fine textured soil that has a slow infiltration rate cannot be irrigated efficiently. It means that it is not appropriate in soils with low infiltration rates. After irrigation, portable pipes may pose a problem on fine textured soils with poor drainage. More water is decreasing by evaporation through sprinkler irrigation method than with surface irrigation method and it varies from 2 to 5 % of the water used. Sprinkling irrigation on orchards has unique problems. The sprinklers may interfere with the uniform distribution of water the time they are used under a tree, hanging branches and Where sprinklers are positioned above the trees, losses due to evaporation increase (Ramanjaneyulu et al., 2018).

2.8.3. Types of Sprinkler Irrigation Systems

Depending on the rate of precipitation, there are different sprinkler irrigation systems, including high volume sprinklers, medium volume sprinklers, and low volume sprinklers; rotating sprinkler and perforated pipe systems (based on application of water); they are permanent systems, semi-permanent, semi-portable, and portable (based on portability). There are different sprinkler systems based on movement, including center-pivot sprinkler systems, linear move systems, traveler sprinkler systems, and hand, tow, side, and gun types. There are different sprinkler systems based on movement, including center-pivot sprinkler systems, linear move systems, traveler sprinkler systems, and hand, tow, side, and gun types (Ramanjaneyulu et al., 2018). Rotating (portable) sprinkler irrigation systems have been used during the study because not only there were installed in the marshland by the Government of Rwanda but also there are existing in wide sort of dimensions and cover relatively large areas of the different plots used to spray the uniform water to the crop (French beans) root zone around their axis in 3600 degrees.

2.9. Supplemental Irrigation

Supplemental irrigation involves adding small amounts of water to crops that are largely rainfed in order to increase and stabilize yields when rainfall is insufficient to provide enough moisture for normal plant growth. It is an effective approach to lessen the detrimental effects of soil moisture stress on the yield of crops cultivated with rain during dry spells. Especially during critical agricultural growth stages, supplemental irrigation can boost crop output and water productivity (Nangia et al., 2018; Oweis et al., 2018). It is an operational reaction to improve the soil moisture stress on the yield during dry periods and it is recommended for field crops in regions with an annual rainfall between of 300–600mm. The objective of supplementary irrigation is not only to maximize yield per unit area but also to increase water productivity (Hessari et al., 2016). The permanent optimal irrigation regime can be ensured through supplementary irrigation to satisfy full crop water requirements in environments where there is naturally insufficient contributions of water by rainfall or groundwater. In order to maximize production per unit of applied water rather than per unit of farmed surface area, supplementary irrigation must be used sparingly because of its restricted capacity. By lowering the amount of unirrigated surface in arid and semi-arid regions, supplementary irrigation aims to improve water use efficiency and overall farm productivity. The different purposes of supplementary irrigation are (Angelo and Francesca, 1996):

a) In environments where water scarcity is occasional and their duration is short, supplementary irrigation can optimize yield;

b) To enhance the use of water efficiency of limited available resources (natural and irrigation water). Supplementary irrigation can be considered a dry farming technique since it aims at using limited water resources; for instance in exceptionally dry years supplementary irrigation can be used to prevent complete yield loss.

2.10. Irrigation Watering Regimes

Several studied have been conducted on irrigation watering regimes. (Kassab et al., 2005) indicated that the the growth, yield, and oil content of sesame plants are affected by the irrigation water regimes (Kruashvili et al., 2016) reported that the one of the current problems in agriculture is the efficient use of water resources, which primarily entails choosing the best irrigation regime parameters to produce a consistent and long-lasting crop while maintaining the ecological balance. Wale and Girmay, 2019 also stated that a farm manager's ability to meet a crop's water needs, prevent yield loss from water stress, maximize irrigation water use efficiency, and minimize the risk of nitrate leaching all depend on their ability to time irrigation water applications correctly. In order to maximize crop production per unit of water and support irrigated agriculture, the irrigation watering regime was chosen for this study with the goals of determining the ideal irrigation time, scheduling when to irrigate the French beans, and determining how much water to apply in sprinkler irrigation system.

2.11. The CROPWAT Model

The software program CROPWAT (version 8) is an intriguing and cutting-edge instrument for managing agricultural water use. The application uses Penman–Monteith method (Karuku et al., 2014). It is a Windows computer program used to determine the amount of irrigation and water that crops need based on information about the soil, climate, and crops. The software provides both the scheduling of irrigation for various management scenarios and the estimation of scheme water supply for various crop combinations. Furthermore, CROPWAT 8.0 can assess farmers' irrigation practices and forecast crop yield in both rainfed and irrigated areas. A representative station from the CLIMWAT database can be used if the local meteorological data that CROPWAT needs are not available. Similar to this, CROPWAT can use standard soil and crop property values in the absence of local soil and crop data. When employing different user-defined options for water supply and irrigation management settings, climate data input can accommodate daily, decadal, or monthly values and turns them into a daily soil-water balance to produce appropriate irrigation schedules. According to the user-defined cropping pattern, which may contain up to 20 crops, the scheme's water supply is determined. There are no GIS features in CROPWAT, which is location-based (FAO, 2022).

CHAPTER TREE

MATERIALS AND METHODS

3.1. Description of Study Area

The study was conducted in Muvumba valley (Latitude $01^0$4’28.11”S and Longitude $30^0$23’51.45”E) across Musheli Sector at Mushorerwa Village-Mushorerwa Cell in Nyagatare District of Eastern Province of Rwanda. The area is bounded by Uganda in the north, by Tanzania in the east, in the south by the Rwandan district of Gatsibo and in the west by the Rwandan district of Gicumbi (*Catchment Plans | Rwanda Water Portal*, 2018). The catchment of Muvumba which is part of the Nile Basin is situated between latitude of 01° 27' 59.70" and 01° 03'27.35" South; longitudes: 30° 21' 29.65" and 30° 13' 27.64" East. The altitude generally varies between 1,250 m.a.s.l and 1,600 m.a.s.l (Ukurikiyeyezu, 2018). The Nyagatare district (Fig 3.1) is situated in the north Eastern corner of Rwanda which is semi- arid. There is lack of water resources in the district (Green, 2019). Nyagatare district covers an area of 1,920.11 Km^2; characterized by low hills dominated by granite rocks and average altitude of 1513.5 m.a.s.l. The temperature is characterized by hot seasons with average temperature ranging from 25.3°C to 27.7°C, with annual rainfall, estimated to be 827 mm (Bizuhoraho, 2018).

The Nyagatare District (Figure 3.1) features four distinct climatic seasons that last three months each: long rainy season, short rainy season, long dry season, and short dry season. The long rainy season lasts from March to May, the short rainy season lasts from September to November, the long dry season begins in June and ends in August, and the short dry season begins in December and ends in February (Muhire et al., 2015 and Green, 2019). Through its final outflow into the Mediterranean Sea, the catchment of Muvumba is part of the most upstream parts of the Nile Basin. It is collected the districts of Gatsibo (1 582 km^2), Gicumbi (830 km^2) and Nyagatare (1 920 km^2) and located in the Kagera sub-basin (Aboniyo et al., 2017). The river of Muvumba flows by the Mutara Rangeland in the District of Nyagatare in northeastern Rwanda and it is a atributary of the Kagera river that belongs to the Nile upper headwaters and open grasslands and savannah woodlands cover most of Nyagatare District (Umuntunundi et al., 2017).

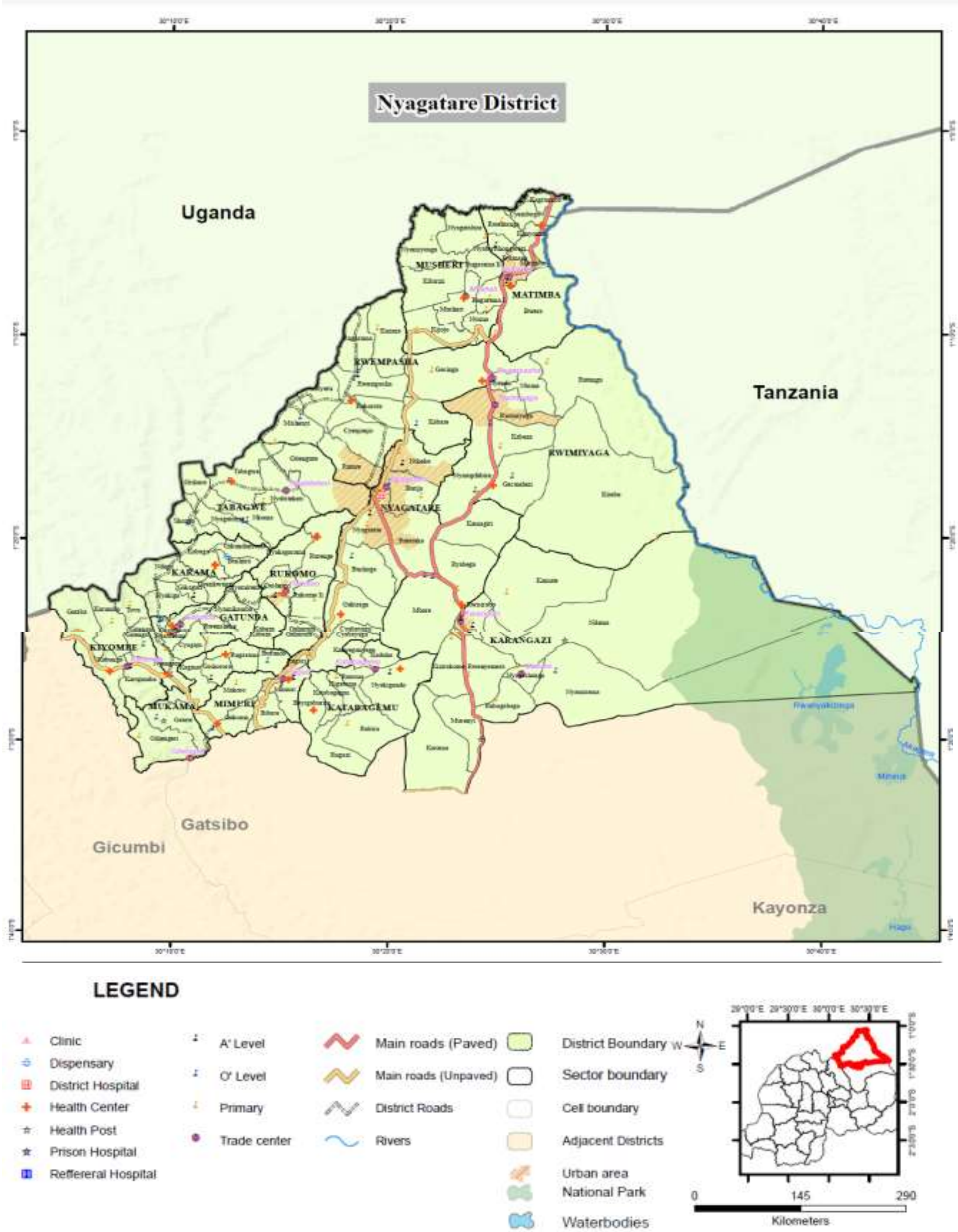

Figure 3.1: Nyagatare District (Source:(NISR, 2014))

The classification of this area is semi-arid, categorized by low rainfall distribution of 827 mm per annum and high temperatures. The major soil type in Nyagatare district is Arenosol (Loamy Sand) which has low organic matter content and is rich in mineral nutrients. The area is characterized by afforested savanna vegetation (Iraguha et al., 2015).

This zone is generally characterized by a gently sloping landscape that varies from 2 to 3 % and has hills that are intersected by large valleys. The irrigation development of the valley covers an area of 900 hectares. It is designed to allow the cultivation of different seasonal crops in 3 seasons per year. To manage the drought that affects the area, crops are irrigated by four (4) different irrigation systems such as 200 ha for sprinkler, 90 ha for drip, 90 ha for gravity and 520 ha for center pivot (Ntirenganya, 2017). These technologies benefit 1,083 farmers of whom 364 are women organized in cooperative and water users' association (WUA).

WUA has a water use license with important responsibilities of water distribution between the water users, repairing and maintenance of irrigation infrastructures, water fees collection, resolution of conflict between the water users and in general for the purpose of improvement of irrigation performance and water use efficiency giving other related facilities to farmers. Normally, the leading entry requirements in the water users' association are to have a plot of land in irrigation scheme, to pay water fees and be a farmer in irrigation scheme (Theobald and El-Sayed, 2019).

3.2 Methodology

3.2.1 Soil sampling and analysis

Before planting a composite soil samples were taken randomly to each plot in the study area and thoroughly mixed. Soil sampling, at 30 cm depth, was done using a soil auger. Sampling was done by taking 4 samples mixing throughougly covering the whole research field (1,064 m^2). A 1 kg of a composite soil sample was taken for laboratory analysis. Following the procedures of standard laboratory, soil sample was analyzed for soil chemical, and texture properties including NPK, pH and % OC (Espinoza et al., 2006; Hazelton and Murphy, 2007; Motsara and Roy, 2008; Horneck et al., 2011).

Measurement of soil pH

Weigh 50 g of air-dry soil (2 mm) into a 100 mL glass beaker, and then add 50 mL of DI water using a graduated cylinder or 50 mL volumetric flask. After complete mixing with a glass rod, allow the suspension to rest for 30 minutes while stirring it every 10 minutes. One hour later, agitate the mixture while calibrating the pH meter. Suspend the composite electrode in air (about 3 cm deep). Take a reading with one decimal place after 30 seconds. The combined electrode needs to be removed from the suspension, thoroughly washed in DI water in a different beaker, and gently blotted dry of any remaining water. Using a pH meter, the soil's pH was determined. Strongly acidic is defined as pH 5.0. Moderately to slightly acidic is defined as a pH range of 5.0 to 6.5. pH values between 6.5 and 7.5 are regarded as neutral. Strongly alkaline is defined as a pH above 8.5 and moderately alkaline as a pH between 7.5 and 8.5. (Nsengiyumva, 2021).

Measurement of Cation Exchange Capacity (CEC)

Weigh 4 g (for soil with a medium to fine texture) or 6 g into a 40-mL centrifuge tube (for coarse textured soil). Shake for five minutes with the stopper tube attached and 33 mL of 1 N sodium acetate trihydrate solution. Removed stopper from tube and centrifuged at 3000 rpm until clear liquid formed in the supernatant. The supernatant was as thoroughly decanted and discarded as practicable. As much as feasible, decanted the supernatant and discarded it. 33 mL pieces of 1 N sodium acetate trihydrate solution were used four times, discarding the supernatant liquid each time. The tube was filled with 33 mL of 95 percent ethanol, sealed, and agitated for five minutes before being uncapped, centrifuged, and having the supernatant decanted. 33 mL pieces of 95 percent ethanol were washed three times, with each wash resulting in the liquid supernatant being discarded. The third washing's supernatant liquid should have an electrical conductivity (EC) of 400 or less S/cm. To remove the adsorbed Na from the sample, extract three 33 mL portions of 1 N ammonium acetate solution. Shake for five minutes each time, then centrifuge the liquid supernatant until it is clear. The three supernatant liquids should be thoroughly decanted into a 100 mL flask. To the flask, add a 1 N solution of ammonium acetate, and thoroughly mix. a calibration curve was created after a series of acceptable Na standards were run. The samples (soil extracts) were calibrated, and emission data were collected, using a Flame Photometer with a 767-nm wavelength. The calibration curve was used to compute the Na concentration. (Nsengiyumva, 2021).

CEC (meq/100g) = V/Wt*100/1000 * meq/LNa (from calibration curve) *{Equation 3.1}*

Where Wt = Weight of the soil when it is air-dried; V = Total Volume of Soil Extracted (mL); (g).

Measurement of total Nitrogen

The 0.15 mm finely milled soil sample was mixed and evenly distributed on a piece of paper until it seemed uniform. By taking 10 little parts, or 10 g, of the soil sample, we were able to collect a typical soil sample that includes between 3 and 8 mg of nitrogen. 0.5 grams of air-dry soil (0.15 mm) were weighed and put into a calibrated digestive tube measuring 250 mL. To represent data on a dry-weight basis, the moisture content of soil subsamples was determined. 10 mL of DI water were added to each tube, and the soil was carefully swabbed. Give soggy soil 30 minutes to stand. Holding the digesting tube at a 45° angle, slowly add 20 mL of 50 percent H_2SO_4 in a way that flushes out any material that has adhered to the tube neck after adding 10 mL of potassium permanganate solution. 15 minutes should pass before stirring well. After adding acid, avoid quickly swirling the digesting tube because this could produce excessive foaming. N-octyl alcohol solution was added in 2 drops. A few granules of pumice powder were added to the blank, EDTA, and sample digest tubes. A 5-cm (ID) glass funnel with the stem removed should be inserted into the tube neck right away after 2.5 g of reduced iron has been added through a long-stemmed funnel. Then, give it a whirl. At this time, excessive frothing can be stopped by adding 5 mL of DI water through the 5-cm glass funnel without spinning. All night long, the tubes must remain upright. While the samples were on the cold block, they were heated for an hour at 100°C to pre-digest them. The block digester takes around 1 hour and 15 minutes to complete since it reaches 100 °C in just 15 minutes. The samples were mixed after 45 minutes.

Once the tubes have been removed from the block digester, cool. Rapid cooling may be affected by tap water. fled for the evening. Use of a long stem funnel was used to add 5 g of the catalyst mixture. Next, 25 mL of the concentrated H_2SO_4 were added to each tube, and they were stirred (more acid may be required if larger amount of soil is used). The block digester was preheated to 100°C, the funnels were removed, the block temperature was increased to 240°C, and the tubes were then repositioned on the digester. Funnels that have been arranged in a methodical manner so they can be afterwards placed inside the same digesting tube. It took 40 minutes to reach 240°C. The water should keep boiling off for a further hour at 240°C. Once the water has been emptied, raise the temperature to 380°C, and then replace the funnels. Decide on a four-hour digest time and temperature for the block digester. The tubes were removed from the block digester before being introduced and combined in a vortex with around 50 mL of DI water. Use a glass rod to dislodge any remaining solid precipitate in the tubes. Once it has cooled, add DI water to the mark at 250 mL (Nsengiyumva, 2021).

Measurement of Phosphorus

Pipette Add 10 mL of clear solution and 10 mL of ammonium-vanadomolybdate reagent to a 100 mL flask, and then re-diluent it with DI water to volume. The standard curve was created as follows: pipette 1, 2, 3, 4, and 5 mL of the standard stock solution, then follow the same procedures as for the samples. Use 10 mL of the ammonium-vanadomolybdate reagent to prepare a blank, and then proceed as you would with the samples. After 30 minutes, use the spectrophotometer to assess the absorbance of the samples, standards, and blanks at 410 nm. In order to generate a calibration curve for standards, absorbance was plotted against the respective P concentrations. To find the P content in the unidentified samples, read the calibration curve. (Nsengiyumva, 2021).

$$\mathrm{P}\ (\%) = \mathrm{ppm\ (from\ calibration\ curve)} * \frac{V_1}{W_t} * \frac{100}{V_2} * \frac{1}{10000} \qquad \textit{\{Equation 3.2\}}$$

Where: Wt is the weight of the dried plant, V1 is the total volume of the plant digest (mL), V2 is the volume of the plant digest used for measurement (mL), and (g).

Measurement of exchangeable Potassium

The majority of the total extractable K is often made up of exchangeable-K, or potassium that is stored on the surfaces or exchange sites of clay minerals. By comparing, it can be determined. (Nsengiyumva, 2021).

Exchangeable-K (ppm) = Extractable K (ppm) – Soluble K (ppm).

Measurement of Zinc

Pipette 10 mL of the 1000 ppm Zn Stock Solution into a 100 mL flask, and then add DTPA solution to dilute it to volume. This solution has a 100 ppm Zn concentration (Diluted Stock Solution). Pipette 10 mL of the volume-diluted stock solution into a 100 mL flask before adding DTPA solution to further dilute it. This solution has a 10 ppm Zn concentration (Second Diluted Stock Solution). Pipette the second diluted stock solution into 50-mL numbered flasks at a rate of 1, 2, 4, 6, 8, and 10 mL. The solution is then diluted with DTPA until the appropriate volume is reached. These solutions contain 0.2, 0.4, 0.8, 1.2, 1.6, and 2.0 ppm of Zn, respectively (Nsengiyumva, 2021).

Measurement of Organic Carbon

Estimations of organic matter and organic carbon were made using volumetric and colorimetric techniques. A pipette was used to add 10 mL of a 1 N potassium dichromate solution after 1 g of air-dry soil (0.15 mm) had been weighed into a 500 mL beaker. The suspension was then blended in the beaker after 20 mL of strong H_2SO_4 had been added. A dispenser was used to add 10 mL of concentrated H3PO4 after 200 mL of DI water was added, and the mixture was allowed to stand for 30 minutes before being given time to cool. A Teflon-coated magnetic stirring bar was affixed after 10-15 drops of diphenylamine indicator were introduced to the beaker, which was then placed on a magnetic stirrer. Two blanks were created with all the chemicals but no soil, and both of them received the same treatment as the soil suspensions. After the color of the solution changed from violet-blue to green, they were titrated with 0.5 M ferrous ammonium sulfate (Nsengiyumva, 2021).

Organic matter (%) = Total Organic Carbon (%) *1.724 *{Equation 3.3}*

Total Organic Carbon (%) = Oxidizable Organic Carbon (%)* 1.334 *{Equation 3.4}*

Oxidizable Organic Carbon (percent) is equal to 0.3*M*(Vblank - Vsample) / Wt *{Equation 3.5}*

M stands for $(NH_4)_2SO_4.FeSO_4.6H_2O$'s molarity (about 0.5 M). The blank must be titrated using a volume of $FeSO_4$, H_2O, and Vblank $(NH_4)_2SO_4$ (mL). To titrate the sample, a volume of the sample

$(NH_4)_2SO_4$, $FeSO_4$, and H_2O is required (mL). 0.3 equals $3*10^{-3}*100$, where 3 is the weight of carbon, and Wt is the air-dry soil weight (in grams).

Measurement of extractable Calcium and Magnesium

Put 50 mL of a 1 N NH4OAc solution and 10 g of air-dry, 2-mm soil in a 250 mL flask (ratio 1:5). The suspension was shaken on a reciprocating shaker at 200–300 rpm for 30 minutes to remove any debris particles. The extract was then diluted with 1 N NH4OAc solution to a level of 50 mL after being filtered using Whatman No. 1 filter paper.

Using a fallow pipette, calcium was measured. 5-10 mL of soil extract with no more than 1 meq Ca should be added to a 250 mL Erlenmeyer flask. This extract should then be diluted to 20-30 mL with DI water, and 2-3 mL of 2 N NaOH solution added. Using 0.01 N EDTA to titrate the solution, 50 mg of ammonium purpurate indicator was added, and the color of the mixture was monitored until it went from red to lavender or purple. Due to the fact that the color change does not happen quickly, EDTA (Ethylene Diaminetetraacetic Acid Solution) should be added near to the finish line, one drop every 10 seconds. Run a blank experiment every time, processing it exactly like the samples while using all the chemicals but no soil. From the measurements for all the samples, deduct the reading from the titration of the blank (Nsengiyumva, 2021).

Calculate the reading from the titration of the blank by subtracting it from the values for all of the samples. Adding a few drops of eriochrome black indicator, 20–30 mL of DI water to dilute it, and 3–5 mL of buffer solution. Titrating is carried out with 0.01 N EDTA until the red color changes to blue. To standardize the EDTA solution used in the determination of Ca and Mg, pipette 10 mL of 0.01 N calcium chloride solution, treat it as in the Ca and Ca + Mg procedures, respectively, take the reading, and calculate the EDTA normality (Nsengiyumva, 2021).

$$N_{EDTA} = \frac{10*N_{cacl_2}}{V_{EDTA}} \qquad \textit{\{Equation 3.6\}}$$

Where $NCaCl_2$ is the normality of the $CaCl_2$ solution, NEDTA is the normality of the EDTA solution, and VEDTA is the volume of EDTA solution used (mL).

$$\text{Extractable Ca or Ca + Mg (meq/L)} = 1000 * N * V_1 \, (V-B) / Wt * V_2 \qquad \textit{\{Equation 3.7\}}$$

$$\text{Extractable Mg (meq/L)} = \text{Extractable (Ca + Mg)} - \text{Extractable Ca} \qquad \textit{\{Equation 3.8\}}$$

Where V is the volume of EDTA used to titrate the sample (in milliliters), B is the volume used to titrate the blank (in milliliters), V1 is the total volume of soil extract (in milliliters), V2 is the volume of soil extract used for titration (in milliliters), N is the normality of the EDTA solution, and Wt is the weight of air-dry soil (g).

Determination of Particle Size Distribution

In a 600 mL beaker, 40 g of air-dry, 2-mm soil were weighed. A watch glass was placed on top of the beaker, which contained 60 mL of the dispersing solution, and it was left overnight. The next day, transfer the contents of the beaker quantitatively into a cup for stirring soil, and then partially fill the cup with water. The suspension was vigorously agitated for three minutes with the special stirrer. Shake the suspension all night if there is no stirrer present. It took a minute for the stirring paddle to stand after being washed and put in a cup. Transferred the suspension in a 1-L calibrated cylinder (hydrometer jar) on a quantitative basis, and then filled it with water (Nsengiyumva, 2021).

The determination of Blank was performed by adding water to a 60 mL dispersion solution in a 1-L hydrometer jar. Mix completely, place a hydrometer there, and then read it. Rb (Reading Blank). The blank reading needs to be recalculated if the temperature differs by more than 2°C from 20°C. The hydrometer jar was filled with a carefully mixed solution, the paddle was taken out, and the hydrometer was immediately inserted to measure the amount of silt and clay. 40 seconds after withdrawing the paddle, take a hydrometer reading and, if necessary, thin off any foam with one drop of methyl alcohol. Reading and RSC are provided (Reading Silt plus Clay). Clay content was calculated by combining a suspension with a paddle in the hydrometer jar, removing the paddle, letting the solution sit for four hours, putting the hydrometer in, and reading the hydrometer, RC

(Reading Silt plus Clay). By quantitatively pouring suspension through a 50-m filter, the determination of sand was completed after the necessary values for clay and silt were taken. The sieve should be cleaned until clear water can pass through it. Using a 50 mL beaker with a known weight, transfer the sand there quantitatively, letting it settle and decanting any extra water. An overnight 105°C drying of a sand-filled beaker was followed by cooling in a desiccator and reweighing (Nsengiyumva, 2021).

$$[\mathrm{Sil} + \mathrm{Clay}]\ (\%\ \mathrm{w/w}) = (\mathrm{R_{sc}} - \mathrm{R_b}) * \frac{100}{\mathrm{Oven{-}Dry\ (g)}} \quad \textit{\{Equation 3.9\}}$$

$$\mathrm{Clay}\ (\%\ \mathrm{w/w}) = (R_c - R_b)\frac{100}{\mathrm{Oven{-}Dry\ (g)}} \quad \textit{\{Equation 3.10\}}$$

$$\mathrm{Silt}\ (\%\ \mathrm{w/w}) = [\mathrm{Silt} + \mathrm{Clay}(\%\mathrm{w/w})] - \mathrm{Clay}\ (\%\ \mathrm{w/w}) \quad \textit{\{Equation 3.11\}}$$

$$\mathrm{Sand}\ (\%\ \mathrm{w/w}) = \mathrm{Sand\ weight\ (g)} * \frac{100}{\mathrm{Oven{-}Dry\ (g)}} \quad \textit{\{Equation 3.12\}}$$

$$\mathrm{Sand\ weight} = [\mathrm{Beaker} + \mathrm{Sand\ (g)}] - [\mathrm{Beaker\ (g)}] \quad \textit{\{Equation 3.13\}}$$

All mechanical analysis results were presented as oven-dry soil (drying for 24 hours at 105°C), where the silt, clay, and sand content should add up to 100%. The magnitude of the deviation from 100 serves as a measure of precision. After calculating the amounts of sand, silt, and clay in the soil, the USDA textural triangle was used to categorize it.

Soils bulk density

The determination of soil bulk density (undisturbed samples) was done using the standard core method (FAO, 2020). Bulk density (g/cm^3) was determined by calculating the weight of oven-dried soil (mass) at 105^{o}C divided by the soil volume, equivalent to the volume of the core ring.
The health and compaction of the soil were assessed using bulk density. Infiltration, rooting depth/restriction, available water capacity, soil porosity, plant nutrient availability, and soil microbial activity are just a few of the crucial soil processes and productivity that are impacted. The less pore space there is for water to pass through, roots to develop through and penetrate, and seedling germination, generally speaking. Because of the shallow roots and poor plant growth caused by compacted and high bulk density soils, crop yield will be affected. This will also reduce the quantity of vegetative cover that can be employed to stop soil erosion (Emnz, 2019). The clod

method was used to measure the bulk density of the soil. A meticulous collection of soil clods from a soil profile was made. weighed the clod carefully while tying and holding it with a fine copper wire. The clod was submerged in the molten wax and left to dry for 30 minutes in the open air. More melted wax can be applied to the clod to increase its water resistance. Weighing in air was done on the coated clod and wire (Wta). Employing a balance that could accept a clod suspended from the balance beam by a thin copper wire, the volume of the clod was calculated while it was submerged in water (Wtw). The weighted or water displaced volume, which is equivalent to the change in weighted volume, made up the volume of the clod (Wta - Wtw). If a graduated cylinder with half full of water was the only available container, you could estimate the change in water volume by completely immersing the clod in it (V). Determine the soil sample's moisture content on a separate sample, and then calculate the soil's oven-dry weight (Wt), or break the clod and collect a sample to ascertain the soil sample's moisture content (Nsengiyumva, 2021).

$$\mathrm{BD}\ (g/cm^3) = \frac{\mathrm{W_t}}{\mathrm{Wt_a - Wt_w}} \qquad \textit{\{Equation 3.14\}}$$

$$BD\ (g/cm^3) = \frac{\mathrm{W_t}}{\mathrm{V}} \qquad \textit{\{Equation 3.15\}}$$

Wt represents the weight in grams of the oven-dried solid particles in the clod, Wta-Wtw represents the weight in grams or cubic centimeters of water that the clod has displaced, and V represents the change in volume of water in the graduated cylinder (cm^3).

Soils moisture content

Soil moisture represents the content of water within a soil. It was monitored in the root zone of French beans using gravimetric water content and volumetric water content (FAO, 2020). This was useful in making decisions concerning irrigation depths and frequencies. Soil was collected using an auger at the depth of 0-30 cm. The collected soil was dried using an oven at 105 °C for 24 hours.

$$\theta d = \frac{Wt - wd}{Wd} * 100 \qquad \{\text{Equation 3.16}\}$$

Where θd: gravimetric water content (%); Wt: Weight of field moist soil (g); Wd: Oven dried weight soil

$$\theta v = \frac{\theta d * \rho s}{\rho w} * 100 \qquad \{\text{Equation 3.17}\}$$

Where θv: Volumetric water content (%); ρs: Soil bulk density (g/cm^3) ρw: density of water (g/cm^3)

The obtained results of analyzed soil properties are presented Table 3.1.

Table 3.1: Soil chemical and physical properties of the study area

Soil properties	Value obtained	Category
Soil pH	5.8 pH Value	Moderately acidic
Total Nitrogen	0.08 %	Low
Available phosphorous (Av. P)	24.1 ppm	Medium
Exchangeable potassium (K)	0.28 meq/100g	Low
Calcium (exch.)	8,2 $mmol^+/kg$	Very low
Extractable magnesium (Mg)	3,5 $mmol^+/kg$	Low
Zinc	2,8 mg/kg	Adequate
Copper	0,5 mg/kg	Low
Cation Exchange Capacity(CEC)	4,3 $mmol^+/kg$	Very low
C:N	21%	High
Organic Carbon (O.C)	1.68%	Moderate
Organic Matter (OM)	2.9%	Moderate
Clay	10%	
Silt	8%	
Sand	82%	
Textural Class	Loamy sand (30cm)	

3.2.2 Water sampling and analysis

Before planting, water taken from the study area for supplementary sprinkler irrigation was examined for its irrigation suitability to verify if the water from Muvumba river pumped should be used for irrigation purpose to produce French beans. The water for irrigation was analysed for Na^+, SAR, EC, pH, Ca^{2+}, Mg^{2+} and K^+ (Park et al., 2014 and Guset User, 2017).

Measurement of water pH

Once the pH meter has been calibrated and a 50 mL sample of water has been collected in a 100 mL flask, place the combination electrode in the sample of water (about 3-cm deep). The reading was taken after 30 seconds. After being thoroughly rinsed with DI water in a different beaker, the combined electrode was removed from the sample and properly dried with a tissue (Nsengiyumva, 2021).

Measurement of Electric Conductivity

The cleaned and dried conductivity cell was added to a 100 mL glass beaker, which was then filled with 75 mL of water. read the article. The display will need some time to stabilize before the reading. A tissue was used to gently dry the excess water after the conductivity cell had been removed from the glass beaker and thoroughly rinsed with DI water (Nsengiyumva, 2021).

Measurement of Potassium

Whatman no. 42 filter paper was used to filter a portion of the water sample. Used the Flame Photometer as directed by the manufacturer, calibrated it with a set of suitable K standards, and used a sample of DI water as a blank to check the results. The Flame Photometer with a wavelength of 767 nm was used to measure the emission from the water samples, and the readings were recorded. Installed the Flame Photometer in accordance with the manufacturer's instructions, made a calibrated curve, and calculated the K concentrations using the calibration curve (Nsengiyumva, 2021).

K (meq/L) is equal to ppm K (from the calibration curve) / 39.1. *{Equation 3.18}*

Where K's atomic weight is 39.1

Measurement of Sodium

Whatman filter paper No. 42 was used to filter a portion of the water sample. Use the Flame Photometer according to the manufacturer's instructions. Flame photometer that has undergone calibration using a variety of acceptable Na standards and a blank sample of DI water. The Flame Photometer's emission values at a wavelength of 589 nm were recorded along with the measurements of the water samples. Turned off the flame photometer in accordance with the manufacturer's instructions, made a calibration curve, and then used the calibration curve to calculate Na concentrations (Nsengiyumva, 2021).

ppm Na (from the calibration curve) / 23 equals Na (meq/L). *{Equation 3.19}*

where: 23 = Na's atomic weight

Measurement of Calcium and Magnesium

Pipette a suitable volume (10 mL natural water sample) of the water sample into a 250 mL Erlenmeyer flask to conduct a calcium test. Add 50 mg of ammonium purpurate indicator and 2-3 mL of 2 N NaOH solution to 20–30 mL of DI water that has been diluted. When 0.01 N EDTA is added, the hue shifts from red to purple or lavender. Since the color change at the completion point does not occur immediately, EDTA should be added one drop at a time (Nsengiyumva, 2021).

Pipette a suitable aliquot (10 mL natural water sample), then dilute it with DI water to 20–30 mL for calcium and magnesium. Next, include 3–5 mL of the buffer solution. Eriochrome black indicator drops in more quantity. Titrating is carried out with 0.01 N EDTA until the red color changes to blue. Pipette 10 mL of 0.01 N calcium chloride solution, handle it as in the Ca and Ca+Mg procedures, take a reading, and compute the EDTA normality to standardize the EDTA solution used to determine Ca and Mg (Nsengiyumva, 2021).

$$N_{EDTA} = \frac{10 * N_{cacl_2}}{V_{EDTA}} \qquad \textit{\{Equation 3.20\}}$$

The terms NEDTA and $NCaCl_2$ stand for the normality of the EDTA solution, the volume of EDTA solution utilized (in milliliters), and the normality of the $CaCl_2$ solution, respectively.

$$\text{Ca + Mg (meq/L)} = 1000\ N\ V_1 / V \qquad \textit{\{Equation 3.21\}}$$

$$\text{Mg (meq / L)} = \text{Ca + Mg (meq/L)} - \text{Ca (meq/L)} \qquad \textit{\{Equation 3.22\}}$$

Where N is the normality of the EDTA solution, V is the volume of the water sample used for testing, and V1 is the volume of EDTA titrated for the sample (mL) (mL).

$$\text{Sodium adsorption ratio (SAR)} = \frac{\text{Na}}{\sqrt{\frac{\text{ca+Mg}}{2}}} \qquad \textit{\{Equation 3.23\}}$$

Where the concentrations of the relevant ions in water, Na, Ca, and Mg, are given in meq/L (solution).

Table 3.2 indicated the results of water quality analyzed. The pH of 6.5-8, is viwed to make no limitation to irrigation practice (Park et al., 2014). The electrical conductivity (EC) shows that the water from Muvumba River was suitable for irrigation purposes. Water salinity rating was very low and with no limitation to crops (French beans). Sodium adsorption ratio value was low and had no hazard when used for irrigation (Ogunfowokan et al., 2012).

Table 3.2: Laboratory data for water quality assessment for irriagting French beans in the study area

Assessed parameters	Optained value	Criteria limit	Category
Potassium (K^+)	5.00 ppm	< 20	Medium
Calcium (Ca^{2+})	27.50 ppm	20-250	Very Low
Magnesium (Mg^{2+})	12.00 ppm	< 25	Low
Sodium (Na^+)	43.30 ppm	<70	Significant
Soluble salts, or electric conductivity (EC)	0.22 mmhos/cm	< 0.75	No limitation
pH (H20)	6.6 pH Value	6.5-8.0	Acceptable
Sodium adsorption ratio (SAR)	9.8 meq/L	<10	No hazard

Assessment of water quality based on the rating suggested by Park et al., (2014) and Guset User, (2017).

3.3 Experiment Design and Layout

The site selected in Muvumba valley was generally very gently undulating with slopes of 1% . The experimental blocks were divided into uniform units across the slope to prevent erosion and waterlogging. The randomized complete block design (RCBD) was used and the distance between plots were separated from each other with a 2 meters width path. The treatments were. EM: irrigation once only in the morning from 6H30'AM to 8H30'AM of 2 hours ahead of GMT; LE: irrigation once only in the evening from 4H00'PM to 6H00'PM of (GMT+2) and ELE: irrigation twice a day early in the morning and late in the evening and CP: control plot without irrigation practice.

Sprinklers were installed in the middle of each plot so that the irrigation water from one plot does not sprinkle to the nearby plots. In this study, control plot was used only during Wet-Dry season given that during Dry-Wet season, French beans do not grow or survive without applying water (rainfall). The size of each experimental plot was 8m*8m, which is equivalent to 64 m^2 spaced by two meter paths; thus giving a total of experimental area of 1,064 m^2 (Figure 3.2).

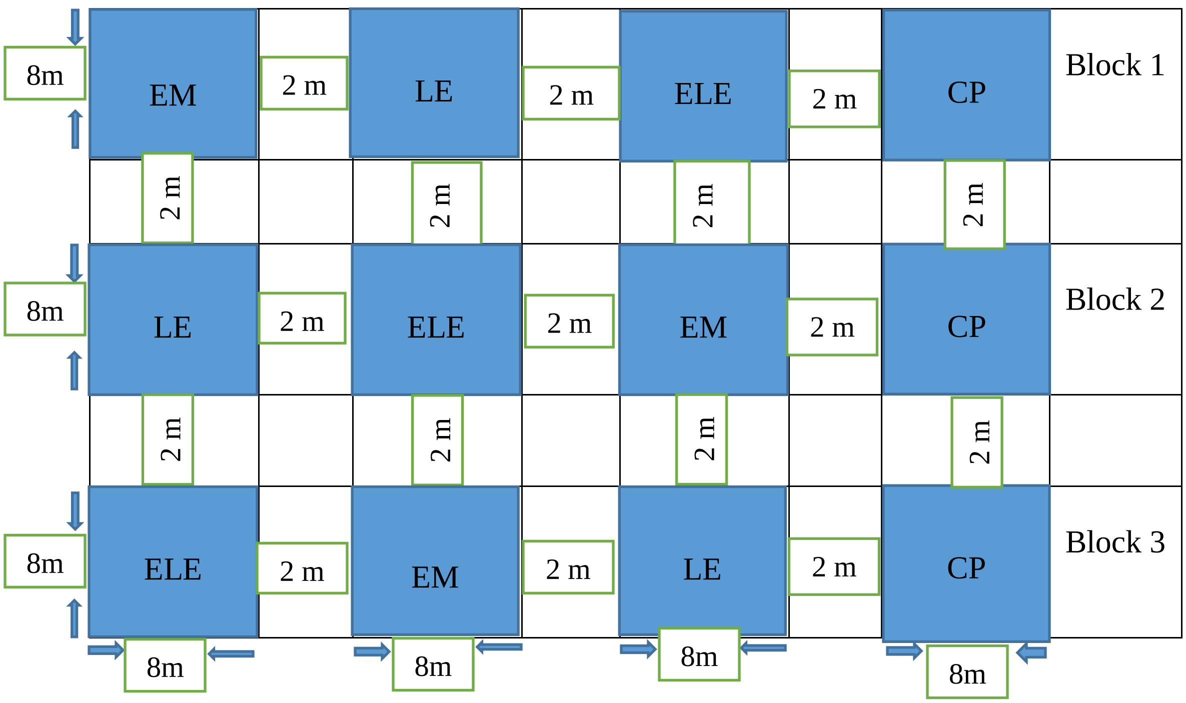

Figure 3.2: Experimental field layout

In two seasons (Dry-Wet season and Wet-Dry season), the treatments were replicated three times. Dry-Wet season (1st season) was started on August 17th, 2019 and ended on October 30th, 2019 and covering both part of the dry season (mid-August - September) and part of short rain season (October). Wet-Dry season (2nd season) was started in November 18th, 2019 and ended on January 30th, 2020 and covering a part of short rain season (mid-November-December), and part of short dry season (January).

The total growing period of French been was 75 days. Based on rainfall availability, soil moisture content and crop water requirement of French beans, irrigation in each plot was done as follows: 28 mm /week/plot from planting days up to ten days post emergence, 35mm /week/ plot from ten days after emergence until flowering stage and lastly 28 mm /week/plant at podding stage of French bean. One sprinkler was placed at each plot making a total of nine sprinklers (hand move). The discharge was 1.95 cubic meter/hour and the diameter of discharge was 8 m. Soil moisture content was monitored in the root zone of French beans using gravimetric method. This helped in making decisions concerning irrigation depths and frequencies.

3.4. Rainfall Data

The daily and monthly records of rainfall obtained from Nyagatare District meteorological station were used to get data on the distribution pattern of rainfall in the area during the experiment period. To calculate water supplied by rainfall for the French bean crop production, daily data of rainfall was used.

3.5. Sprinkler Irrigation Installation

Muvumba river was the source of water used for irrigation and it was pumped by the electrical engine operated pump. The pumped water was stored in the tanks located in upper part of the hill. The installation of the hand-move sprinkler irrigation system began with the excavation of the trenches where the pipes are laid; the trenches were dug about 30 cm deep, and the pipes and fittings were installed. The pipes were appropriately aligned and adjusted in their laid positions (i.e straight form). The system leakage was tested before backfilling of the trenches. The installation was finished by operating the system to check for leaks along the system's layout after the installations had been correctly set up and the dug trenches had been appropriately covered with earth The operational test of the system found no evidence of leaks anywhere in the design of the system. The sprinkler watering system was tested by first carefully linking the pump to the wash bore to prevent leaks, and then connecting the pump's discharge outlet to the main pipe through a hose. The sprinklers soon began to sprinkle water as planned and overlapped one another after the pump was initially primed before being started and water pushed into the main line to the sprinkler nozzles via the laterals. (Shanono et al., 2012).

3.6. Determination of Water Distribution Uniformity

The catch can test was used to determine distribution uniformity under different irrigation regimes. At the site, the catch can method was used to assess the uniformity of the water distribution pattern in order to gauge the depth of the water application and the sprinkler coverage. The samples were collected using disposable cups that had stones inside to prevent them from falling, and the cups were numbered and arranged in a rectilinear manner to test homogeneity (Kent and Leinauer, 2013; Gan et al., 2018). After every 25 minutes of irrigation, beakers were used to measure the amount of water, and the measurement was repeated for the same area after the next lateral motion. Three rectilinear arrangements comprising a total of 36 catch cans (12 catch cans for each irrigation regime) were used. The watering rate was determined by measuring the can's diameter and surface area. The amount of time it took to collect this amount of water was divided by the area of the cans and the average amount of water that was collected in each can. Low quarter distribution uniformity, or D_U, was calculated as the average of the bottom 25% of results divided by the average of all results.

3.6.1. The Christiansen's Coefficient of Uniformity (C_U)

The depth of the water collected was calculated by dividing the volume gathered by the open area of each catch-can. The Christiansen uniformity coefficient, which is frequently used to measure uniformity for sprinkler irrigation systems, depends on the catch-can volumes (or depth). The Christiansen uniformity coefficient was utilized to calculate the degree of water distribution uniformity that could be inferred from the data from the catch can volumes. Christiansen uniformity coefficient (C_U), low quarter distribution uniformity (DU_{lq}), and coefficient of variance were used in this investigation (C_V). C_U which is a measure of the uniformity of water application (Andreas and Karen, 2001), depends on the amount of water collected by each singular catch-can; given n (n = 36) catch cans distributed over the field. The coefficient of uniformity expressed as percentage and it is defined by the equation (Christiansen, 1942; Irmak et al., 2011; Abd El-wahed et al., 2016, Braber et al., 2017; Darko et al., 2017; and Hailu, 2017):

$$C_U = 100 * \left[1 - \frac{\sum_{i=1}^{n} |X_i - \bar{X}|}{n\bar{X}}\right] \qquad \textit{\{Equation 3.24\}}$$

Where C_U is the Christiansen uniformity coefficient (%), X_i [mm] is the depth of water collected (stored) in the i^{th} catch can, $\bar{X}$ [mm] is the average depth of water collected in catch can and n is the number of catch cans (collectors) measured.

The chosen sprinkler should typically have a C_U of 85% or more because a figure of 100% implies perfect uniformity, which means that the water is applied to the same depth throughout the field (Andreas and Karen, 2001). The Christiansen uniformity coefficient measures how effectively an irrigation system distributes water throughout a field on a whole. Christiansen uniformity coefficient of 85% is thought to not require significant changes to the sprinkler package, while specific parts of the irrigator may benefit from tweaks. It may be necessary to conduct additional research on the sprinkler package and make modifications to the Christiansen uniformity coefficient, which ranges from 80% to 85%. The sprinkler package design must be modified, and each section of the sprinkler package must be corrected, if the Christiansen uniformity coefficient is less than 80% (Oweis and Hachum, 2009).

3.6.2. Distribution of uniformity (D_U) in the field

The ratio between the distribution's shortest cumulative depths and its average depths is commonly used to describe an equal distribution of the low quarter irrigation D_U (Abd El-wahed et al., 2016). It is calculated as the field's average average depth of infiltration divided by the field's average depth of infiltration as a whole (Irmak et al., 2011). To assess the uniformity of applied water by sprinkler systems, the ratio of the mean of 25% of the samples with the lowest mean to the mean of all tested samples was determined (Irmak et al., 2011; Braber et al., 2017; Darko et al., 2017 and Hailu, 2017).

The formula used to calculate it is as follows:

$$D_U = \frac{X_{lq}}{\bar{X}} * 100 \qquad \textit{\{Equation 3.25\}}$$

Where X_{lq} [mm] is the average water depth collected by the 25% of the catch cans that collected the least amount of water (the average of the lowest one-fourth of catch can measurements means the average observed applied depths in the low quarter of the field). $\bar{X}$ is the average depth of application overall catch can measurement (average observed applied depths in the entire field).

When $D_U < 77\%$, it is assessed as very poor, D_U range between 77% - 82%, it is considered Poor, D_U range between 83% - 90% it is assessed as acceptable, while $D_U > 90\%$, it is assessed as excellent (Dudek and Fernandez, 2017). When the DU is low (60%), irrigation water is applied irregularly over the field, whereas when the DU is high (80%), the application is rather uniform (Irmak et al., 2011). The D_U was calculated by measuring the depth of water entering the catch can grid during an irrigation event and comparing the water depths in the catch cans (located between sprinklers along the laterals) within the same plot at the operating pressure of 2.7 (bar). The lowest quarter of values was found by ordering the 36 catch can readings in ascending order. Then collected water in each container was measured using a graduated cylinder tube of 200 ml and converted into an hourly discharge rate. The discharge was taken as the collected water in all containers with respect to the time of 25 minutes. For each lateral of sprinkler discharge was measured. Maximum, minimum and average discharge was determined. The water flow was used to evaluate water distribution uniformity along laterals in sprinkler irrigation system.

3.6.3. Coefficient of variation (C_V)

The coefficient of variation C_V was computed as the standard deviation of all catch cans measurements divided by the average $\bar{X}$ (Abd El-wahed et al., 2016).

$$Cv = \left(\frac{S}{\bar{X}}\right)$$

{Equation 3.26}

where [S] represents the measurement-related standard deviation for catch cans.

If Cv value is less than 0.05 it is assessed as perfect, Cv < 0.10 is assessed as good, 0.11-0.15 is assessed as poor and if it is more than 0.15 that is unacceptable (Haupenthal et al., 2021). The S value is given in the following Equation.

$$S = \left(\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}\right)^{½}$$

{Equation 3.27}

Where “xi” is the depth of water collected (stored) in the i^{th} catch can (lph) and “n” is the number of catch cans.

The Table 3.3 showed that the overall average coefficient of variation (Cv) of the irrigation regimes was 0.11 and Cv was poor as prescribed by Haupenthal et al., 2021. It was also assessed as good (0.09 and 0.10) for the plot irrigated once only in the evening (LE) and for the plot irrigated both early in the morning and late in the evening (ELE); while for the plot irrigated once only in the morning (EM), the Cv was poor (0.11 to 0.15).

The overall average Christiansen's Coefficient of Uniformity (C_U) was 98.4 % which indicates perfect uniformity as prescribed by Andreas and Karen, 2001, Oweis and Hachum, 2009. The C_U for EM was 97.9%, for EL was 98.5% and for ELE was 98.7%. This showed that each irrigation regimes were indicates perfect uniformity but ELE had best perfect uniformity compared to other irrigation regimes (EM and EL). As approved by Oweis and Hachum, 2009, the water in different irrigation regimes were applied to the same depth at each point in the field and Although specific irrigator components may benefit from repairs, it was determined that the sprinkler package didn't require any significant changes.

The overall average Distribution of uniformity (D_U) was 92 % and it was excellent as prescribed by Dudek and Fernandez, 2017. The Distribution of uniformity for EM was 91.2%, for EL was 91.8% and for ELE was 92.9%. The ELE had highest Distribution of uniformity than EL and EM. According to Irmak et al., 2011, the obtained results indicates that the water application in different irrigation regimes were relatively uniform.

The farm's entire sprinkler irrigation system is homogeneous, meaning that it uses the same sprinkler head spacing, nozzle type, sprinkler height, length of laterals, and number of sprinklers per lateral During testing for various irrigation regimes, the operating pressure head measured at field control heads (clusters) was 2.7 bar, and it fell within the designer's suggested ranges (2.5 to 3.0 bar). All irrigation regimes (ELE, EM and EL) were conducted at the same condition and the two most common methods used of expressing the application uniformity of sprinkler irrigation system were C_U and D_U. The obtained results agree with Hailu, 2017 who reported that the wind speed, relative humidity, and air temperature had little to no impact on how evenly the sprinkler system applied water while it was in operation. The outcome of the irrigation run time and sprinkler head height may be to blame for this.

Table 3.3: Christiansen' s coefficient uniformity (C_U) and Distribution Uniformity (D_U) for sprinkler irrigation system

Irrigation regimes	Number of catch cans	$X_{25\%}$	Average water application depth (mm)	Mean	SD	Absolute difference	(CV)	C_U (%)	D_U (%)
EM	36	0.415	455	0.455	0.061	0.3412	0.13	97.9	91.2
EL	36	0.419	457	0.457	0.041	0.2508	0.09	98.5	91.8
ELE	36	0.429	461	0.461	0.045	0.2125	0.10	98.7	92.9
Total	36	0.421	458	0.458	0.049	0.268	0.107	98.4	92

EM: Irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in the evening, $X_{25\%}$: The low quarter of the field, SD: Standard Deviation, CV: Coefficient of Variation, CU: Christiansen's Coefficient of Uniformity and Deviation, DU: Distribution of uniformity.

3.7. Crop Management

Samantha variety of French bean was used during the experiment in the two seasons from August 17th, 2019 to October 30th, 2019 and from November 18th, 2019 to January 30th, 2020. Plant spacing was 15 cm x 25 cm within and between the rows respectively. The population density was 270 000 seeds per hectare. Soil was harrowed to ensure a fine filth. The 60 percent of the total nitrogen was applied before planting, and the remaining 40 percent was applied by week 4 following planting. A total of 120 kg N/ha was applied in nitrogen. For the production of French beans, a total of 65 kilogram of phosphorus, 95 kg of potassium, and 55 kg of calcium per hectare were applied.

Weeding was done manually (hand weeding and hoeing) at an interval of 2-3 weeks in all plots after planting. To control fungal diseases and insects, fungicides and insecticides were applied at an interval of one week. The fungicides used were 4kg/ha of mancozeb (75 g/20L) and 3 kg/ha of copper oxychloride (50g/20L) while insecticides included 1.5 L/ha of cypermethrin (40ml/20L), 3 kg/ha of methomyl (50g/20L) and 1.5.L/ha of Alpha-cypermethrin (30ml/20L). Methomyl and Alpha-cypermethrin were used to control Flower Thrips and Bean Flies while Alpha-cypermethrin was used to control White Flies. Mancozeb and Copper Oxychloride were used to control Rust while Mancozeb was used to control Angular Leaf spots and Anthracnose (AgAware, 2014).

French beans were harvested manually by hand during cool periods (early morning or late afternoon) when the pods were bright green, fleshy and seeds were small and green. Only physically ready pods were picked. Harvesting was thus done four times per season. The pods were categorized in 3 types including Extra- fine, fine and bobby. The extra-fine and fine pods (Figure 3.3) were sold to the Garden Fresh Ltd, which exported to the international markets (USA, Europe), while bobby pods were sold to local markets. Pods were sorted in order to allow processors to maximise factory and to control pod quality parameters. Plastic crates were used for packing French beans. These were taken to the pack house with a vehicle of refrigerator (10-15 ^{0}C) or with light-cored covered absorbs less heat. The pods were straight and had a darker green colour. The look of the pods was important given that buyers look for quality and evidence of good packing.

Extra-fine pods of French beans	Fine pods of French beans	Bobby pods of French beans

Figure 3.3: Figure of different pods of French beans harvested

3.8. Plant growth parameters

The germination of sowed seeds was determined by daily examination from 8 days after sowing. Plant growth parameters were the diameter of stem, the height of plant, the determination of leaf width and leaf length for leaf area index in every growth stage (intial, development, flowering and harvesting stages) for each treatment. By using a ruler, the height of plant, the width and length of leaf were measured while Vernier caliper was used to measure stem girth. The yield of French beans was calculated in kg/ha and leaf area index was determined as demonstrated by Daughtry (1990) and Mahinda (2014) using the data on leaf width and leaf length as follows:

LAI = AL / Ag {*Equation 3.28*}

Where LAI = Leaf Area Index; AL = Leaf Area; Ag = Ground Area;

$AL = bLW$ {*Equation 3.29*}

Where b = French bean coefficient factor of leaf regression (0.9), L= length of leaf (cm) and W= leaf width (cm).

Ag = N*AL/P {*Equation 3.30*}

Where N is total number of leaves per plot and P is plot size (Toyin et al., 2015).

3.9. Water use efficiency

Efficiency is a term frequently used to describe how much of a given output is made possible from a particular input. Thus, the output from using the specified amount of water is known as water user efficiency. The term "water user efficiency" (WUE) refers to how much biomass is produced per unit of area and per unit of water evapotranspiration (Singh et al., 2012 and Eba, 2018). The most common method:

$$WUE\ (kg\ ha^{-1}\ mm^{-1}) = \frac{Yield\ (Kg/ha)}{Evapotranspiration\ (mm)}$$ {*Equation 3.31*}

The CROPWAT program (version 8.0) developed for the FAO Penman-Monteith method (FAO, 2005) was used for analyzing reference evapotranspiration (ETo) and the crop water requirement (ETc) of each of the French beans studied (Adeniran et al., 2010 and Abirdew et al., 2018). A meteorological station located in the Nyagatare District provided the climatic information needed for the computations. A computer program called CROPWAT 8.0 for Windows calculates irrigation needs and crop water needs depending on weather, crop data, and soil (Ragavan and Jeyamani, 2017). With the use of this program, irrigation schedules may be advanced for a variety of management scenarios, and scheme water supply calculations for changing crop patterns are also made possible.

3.10. Costs and benefits of growing French bean under different irrigation watering regimes

The total production cost includes: labour, pesticides, fertilizers, seed, ploughing, sprinkler irrigation, water fee, weeding and sorting. Based on the price of the available markets, the cost of inputs was determined. Land was assumed as a fixed cost and was excluded from the analysis. Under sprinkler irrigation regimes, the analysis of gross margin was used to determine financial returns of French beans. This was done by subtracting the cost of production from the total income in order to obtain the justification of the net profit (FAO, 2007; Kuboja and Temu, 2013; Mahinda, 2014; Lal et al., 2016; Adeola and Ayegbokiki, 2018). The total cost of production includes paying for ploughing, seeds, fertilizers, pesticides, irrigation, water fees, harvesting, weeding and sorting.

GM= TR-TVC {*Equation 3.32*}

Where GM: Gross Margin (RWF) TR: Total income from sales (RWF) and TVC: Total Variable Cost paid on production (RWF)

3.11. Statistical analysis

Data analysis was done using GenStat 15^{th} edition for the analysis of variance (ANOVA). This helped to determine the significance of the treatments. Where significance was noticed, the means were separated by least significant difference (LSD) at 5% probability level. The link among crop yield and water user efficiency by evapotranspiration was assessed using the regression analysis.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Effect of Sprinkler Irrigation Watering Regimes on Yield of French Beans

4.1.1. Effect of different irrigation regimes on germination of French beans

Table 4.1 shows that the germination of French beans ranged from 96 % to 98.7 % in both seasons. The Dry-Wet season had the highest germination percentage 98.7 % than Wet-Dry season 98.1%. The results displayed significant difference ($p<0.01$) in French beans germination among treatments in both seasons. The results obtained in the current study agree with Aghamir et al., (2016) who stated that the germination percentage of French beans is influenced by the irrigation regimes. Kelly, (2012) showed that irrigation can greatly improve germination. Springer and Mornhinweg, (2019) revealed that seed germination decreased as water potential decreased.

During Wet-Dry seasons, Irrigation once only in the evening (LE) and Control Plot (CP) have similar germination percentage (97 %). This because of that both plots had the same soil moisture at initial stage (Table 4.9). The obtained results agree with Smith-Eskridge, (2014) who reported that soil water potential or the amount of water available in the soil controls the rate of germination and when the soil moisture content is low the rate of germination is delayed.

Table 4.1: Germination of French beans at different irrigation regimes in two seasons

	Dry-Wet	Wet-Dry
Irrigation regimes	Initial stage	Initial stage
EM	96.2 a	96 a
CP	-	97.1 b
LE	97.7 b	97.2 b
ELE	98.7 c	98.1 c
LSd	0.11	0.12
CV %	0.6	0.7
LOS	**	**

LOS: Level of significance, ** Significant at < 0.01 %, EM: Irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in the evening, CP: Control Plot.

The seeds were sown during the temperatures higher enough to impact quick and uniform germination of seed and emergence of seedling in existence of suitable condition of soil moisture. The Table 4.1 shows that thelowest performance of germination for both season was 96 % for EM, while ELE had the highest (98.7 % and 98.1%) performance. This is associated with the fact that in both seasons, the LE had the highest germination percentage than EM due to the amount of water applied when the plots were irrigated late in the evening (at night) than when the plots were irrigated early in the morning (a day), where it had an opportunity to soak into the ground with less evaporation. The obtained results agree with Dukes et al., (2010) who reported that sprinkler irrigation systems apply water more efficiently at night than during the day, based on windy conditions and evaporation. During the evening soil remains moist until the next morning while in the morning soil becomes dry by sundown with the greatest evaporation during the middle of the day. Smith and Park (2008) reported that evapotranspiration is maximum for the period of the hottest of the day and plants have to respond vigorously to treat with the pressure connected with noontide climatic factors such as strong solar radiation, high temperatures and lower humidity.

Figure 4.1: French beans at germination and flowering stages

4.1.2. Effect of different irrigation regimes on plant height of French beans

The height of plant varied among irrigation regimes and seasons (Table 4.2). There was a significant difference ($p<0.01$) of plant height among treatments in all the stages of French beans development in the two seasons. Plant height was significantly higher ($p<0.01$) in all French beans stages in the Dry-Wet season contrasted to the Wet-Dry season. This was caused by higher crop evapotranspiration during Dry-Wet season than Wet-Dry season from 252.7 mm/dec to 223.8 mm/dec of ETc (Table 4.11). In addition, the conditions of environmental were more favorable for the Dry-Wet season than Wet-Dry season. This resulted in lower incidences of pests and diseases. The obtained results agree with Kakahy et al., (2013) who reported that favorable environmental conditions significantly increase plant height. The Table 4.2 shows that the highest French bean height was 55.5 cm at harvesting stage in Dry-Wet season in plots irrigated twice a day (ELE) whilts the lowest French beans height of 2.9 cm was recorded at initial stage in Dry-Wet season irrigated once only in the morning (EM).

Table 4.2: Plant height (cm) of French beans at different irrigation regimes in two seasons

Seasons	Irrigation regimes	Initial stage	Development stage	Flowering stage	Harvesting stage
Dry-Wet	EM	2.9 a	12 a	28.9 a	39 a
	CP	-	-	-	-
	LE	3 b	15.5 b	37.6 b	48 b
	ELE	3.1 c	19.9 c	45.8 c	55.5 c
	LSd	0.008	1.24	0.38	0.32
	CV %	1.3	42.3	5.4	3.6
	LOS	**	**	**	**
Wet-Dry	EM	3 a	12.9 a	33.2 a	35.7 a
	CP	3 c	14.2 b	36.4 b	41.1 b
	LE	3 b	14.5 c	36.9 b	40.7 b
	ELE	3 d	15.1 d	39 c	47 c
	LSd	0.011	0.079	1.34	0.44
	CV %	2.0	3.0	19.9	5.7
	LOS	**	**	**	**

LOS: Level of significance, ** Significant at < 0.01 %, EM: Irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in the evening, CP: Control Plot.

In addition the findings of this study agreed with Saleh et al.,(2018) who stated that height of plant increased with the rise of water supply. Abdel-Mawgoud, (2006) also reported that higher irrigation raised plant height and the number of leaves compared to lower irrigation. In addition, Rai et al., (2020) shown that increasing the application rate of irrigation increase plant height by upholding the turgor pressure of the cells which results in optimum plant growth. The highest French beans heights were 55.5 cm and 47 cm, for the Dry-Wet and Wet-Dry season. The lowest plant heights were 2.9 cm and 3 cm for the Dry-Wet season and Wet-Dry season respectively. The results show that the height of French beans irrigated twice per day (ELE) was significantly taller than plant irrigated once a day, either late in the evening (LE) or early in the morning (EM) in both seasons. The Table 4.2 also showed that the height of French beans irrigated late in the evening

(LE) was significantly taller than plant height irrigated early in the morning (EM). The obtained results agree with Cavero et al., 2008 who stated that nighttime sprinkler irrigation usually results in lower wind drift and evaporation losses and better irrigation uniformity compared with daytime irrigation. The supplemental sprinkler irrigation regimes used in this study increased plant development (height of plant, stem diameter, number of leaves and leaf area). This displays that twice a day irrigation (ELE) retains significant quantity of soil moisture that facilely taken up by the crop for optimum crop development. Similar results were reported by Mahinda, (2014).

4.1.3. Effect of different irrigation regimes on stem diameter of French beans

Stem diameter diverse among irrigation regimes and seasons (Table 4.3); there was significant difference ($p<0.01$) of stem diameter among treatments in all the growth stages of French beans in both seasons. The thickest stem diameter of French beans was 10.3 mm at harvesting stage twice a day irrigation (ELE) in the Wet-Dry season, while the thinnest stem diameter was 1.5 mm irrigated early in the morning (EM) in the Dry-Wet season.

Table 4.3: Stem diameter (mm) of French beans at different irrigation regimes in two seasons

Seasons	Irrigation regimes	Initial stage	Development stage	Flowering stage	Harvesting stage
Dry-Wet	EM	1.5 a	4.3 a	5.7 a	7.5 a
	CP	-	-	-	-
	LE	1.6 b	4.7 b	6.8 b	8.3 b
	ELE	1.8 c	5.5 c	9 c	9.5 c
	LSd	0.05	0.05	0.07	0.07
	CV %	16.8	5.3	5.6	4.3
	LOS	**	**	**	**
Wet-Dry	EM	1.8 a	5.3 a	6.3 a	8.5 a
	CP	1.9 c	5.6 c	7.4 b	9 b
	LE	1.8 b	5.5 b	7.7 c	9.3 c
	ELE	2 d	6 d	8.3 d	10.3 d
	LSd	0.03	0.04	0.08	0.19
	CV %	8.8	3.5	5.5	11.2
	LOS	**	**	**	**

LOS: Level of significance, ** Significant at < 0.01 %, NS = Non-significant, EM: irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in the evening, CP: Control Plot

The thickest stem diameters were found in ELE in both seasons. Stem diameter ranged from 9.5 mm to 10.3 mm for the Wet- Dry and Dry-Wet seasons respectively. On the other hand, the thinnest stem diameters were found in sprinkler irrigation regimes of once only in the morning (EM). These were 1.5 mm and 1.8 mm for the Dry-Wet and Wet-Dry seasons respectively. The obtained results agree with Kiremit and Arslan, (2018) who revealed that stem diameters of leek increasing with increases in irrigation water. Bekmirzaev et al., (2019) also made similar observation. Based on irrigation regimes, the stem diameter variation was in the order of ELE> EL>EM in both seasons recognized due to the different irrigation regimes that were applied to the crop to encounter crop water requirement. Frequent irrigation treatment, significantly ($p<0.01$) increased the stem diameter. Kazaz et al., (2010) made similar observations.

4.1.4. Effect of different irrigation regimes on leaf length of French beans

Table 4.4 shows that the leaf length of French beans significantly ($p<0.01$) varied among irrigation regimes and treatments in all stages of French beans growth in both seasons. For the Dry-Wet and Wet-Dry season, the longest leaf lengths of 17.7 cm and 15.1 cm were recorded respectively. The shortest leaf lengths were 3.9 cm and 4.2 cm for the Dry-Wet and Wet-Dry season respectively at initial stage.

The longest average leaf length of French beans 17.7 cm was recorded at harvesting stage which was irrigated twice a day (ELE) in the Dry-Wet season while the shortest leaf length 3.9 cm was recorded at initial stage which was irrigated early in the morning (EM) in the Dry-Wet season. The obtained results agree with Teobaldelli et al., (2019) who reported that basil (*Ocimum basilicum L.),* mint (*Mentha spp.),* and sage (*Salvia spp.)* physiological processes such as photosynthesis, transpiration, and cooling are facilitated by leaves and strongly influenced by leaf morphology. These findings are in agreement with those of Asenso, (2011) who indicated that there was a high significant difference among treatments where irrigation water applied at the surface (0 cm), 20 cm, and 40 cm below surface, with "No irrigation" as control forming the four treatments.

Table 4.4: Leaf length (cm) of French beans at different irrigation regimes in two seasons

Seasons	Irrigation regimes	Initial stage	Development stage	Flowering stage	Harvesting stage
Dry-Wet	EM	3.9 a	10.6 a	12.9 a	14.5 a
	CP	-	-	-	-
	LE	4 b	11.5 b	13.8 b	15.5 b
	ELE	4.1 c	13 c	15.3 c	17.7 c
	LSd	0.004	0.8	0.07	0.8
	CV %	0.5	36.8	2.6	28.9
	LOS	**	**	**	**
Wet-Dry	EM	4.2 a	12 a	13.1 a	13.6 a
	CP	4.5 b	13.2 b	13.8 b	14.2 b
	LE	4.6 c	13.7 c	13.7 b	14 b
	ELE	4.7 d	14 d	14.8 c	15.1 c
	LSd	0.01	0.03	0.2	0.3
	CV %	1.2	1.1	7.7	11.6
	LOS	**	**	**	**

LOS: Level of significance, ** Significant at < 0.01 %, EM: irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in the evening, CP: Control Plot

4.1.5. Effect of different irrigation regimes on leaf width of French beans

Table 4.5 shows that the leaf width varied among irrigation regimes and there was significant difference ($p< 0.01$) of leaf width between treatments in all stages of French beans in both seasons. The longest leaf width of 7.72 cm was recorded at harvesting stage when irrigated twice a day (ELE) in the Dry-Wet season while the shortest leaf width of 2.956 cm was observed from plants irrigated early in the morning (EM) in the Dry-Wet season. The longest leaf width of 7.72 cm and 7.67 cm were recorded respectively at harvesting stage for the Dry-Wet and Wet-Dry season. The shortest leaf width were 2.96 cm and 3 cm for the Dry-Wet and Wet-Dry seasons. The obtained results agree with Flayin et al.,(2019) who indicated that there was an increase in length and width of the leaves of sesame irrigated twice a day, (morning and evening), three times in a week, using sprinklers and drip irrigation. The irrigation was done twice a day, (morning and evening), three times in a week. The obtained results also agree with Asenso, (2011) who reported that there was an increase in the mean leaf width of maize for all treatments (irrigation water applied at the surface (0 cm), 20 cm, and 40 cm below surface, with “No irrigation” as control forming the four treatments) and leaf width was significantly different by depth of water application.

Table 4.5: Leaf width of French beans at different irrigation regimes in two seasons

Seasons	Irrigation regimes	Initial stage	Development stage	Flowering stage	Harvesting stage
Dry-Wet	EM	2.96 a	5.4 a	6.3 a	6.6 a
	CP	-	-	-	-
	LE	3.1 b	6.4 b	6.7 b	7.5 b
	ELE	3.2 c	6.8 b	7.4 c	7.72 c
	LSd	0.01	0.4	0.05	0.05
	CV %	1.1	37.1	4.1	3.7
	LOS	**	**	**	**
Wet-Dry	EM	3 a	7.4 a	6.9 a	7.4 a
	CP	3.6 b	7.5 b	7.3 b	7.5 ab
	LE	3.4 ab	7.5 c	7.4 c	7.4 a
	ELE	4.3 c	7.6 d	7.7 d	7.67 b
	LSd	0.5	0.02	0.05	0.2
	CV %	69	1.2	3.9	13.3
	LOS	**	**	**	**

LOS: Level of significance, ** Significant at < 0.01 %, EM: Irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in evening, CP: Control Plot.

4.1.6. Effect of different irrigation regimes on number of leaves of French beans

Table 4.6 shows that the number of leaves of French beans among irrigation regimes showed a significant difference ($p<0.01$) between treatments at all stages. The highest number of leaves of French beans was 54 and was observed when the plot irrigated twice a day irrigation (ELE) during the Wet-Dry season at harvesting stage, while the lowest number was 2 in both irrigation regimes during two seasons. In both seasons, the maximum numbers of leaves were at harvesting stage and French beans which was irrigated twice a day (ELE) appeared to have a lot of number of leaves than other irrigation regimes (LE and EM). Based on irrigation regimes, the number of leaves variation was in the order of ELE> EL>EM during seasons. The obtained result agree with El-Zeiny et al., (2010) and Abdel-Mawgoud, 2006 who found that the increase of irrigation rates significantly increased vegetative parameters (plant height, number of leaves) of snap bean. The result shows that the number of leaves increased in all French beans growing stages and in both seasons. The obtained results agree with Abdel-Mawgoud, (2006) who reported that as the number of leaves increase leads to an increase in the leaf area hence higher intercepted light and photosynthesis.

Table 4.6: Number of leaves of French beans at different irrigation regimes in two seasons

Seasons	Irrigation regimes	Initial stage	Development stage	Flowering stage	Harvesting stage
Dry-Wet	EM	2 a	18 a	29 a	34 a
	CP	-	-	-	-
	LE	2 a	20 b	33 b	38 b
	ELE	2 b	25 c	45 c	49 c
	LSd	0.04	0.3	0.3	6.2
	CV %	11.6	6.9	4.9	6.2
	LOS	**	**	**	**
Wet-Dry	EM	2 a	19 a	35 a	46 a
	CP	2 b	20 b	40 b	49 c
	LE	2 b	19 a	41 c	48 b
	ELE	2 c	21 c	44 d	54 d
	LSd	0.1	0.2	0.5	0.9
	CV %	15.8	4.4	6.9	9.8
	LOS	**	**	**	**

LOS: Level of significance, ** Significant at < 0.01 %, EM: irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in the evening, CP: Control Plot

4.1.7. Effect of different irrigation regimes on leaf area of French beans

Table 4.7 shows that the leaf area progressively increased for each stage of French beans and the highest leaf area recorded of 122.8 cm^2 was recorded at harvesting stage in the time of the Dry-Wet season under supplementary sprinkler irrigation regime of early in the morning and late in the evening (ELE). The lowest leaf area of 10.37 cm^2 was observed at initial stage during Dry-Wet season under supplementary sprinkler irrigation of once only in the morning. Collection of data of leaf width and leaf length for leaf area started at 75% of each recognized growth stages. Table 4.7 shows that supplementary sprinkler irrigation regimes demonstrated direct relationship with the rising the leaf area where EM < LE < ELE. This means that the irrigation regimes largely had significant effect ($p<0.01$) at all growing stages on the leaf area in both season.

Table 4.7: Leaf area of French beans at different irrigation regimes in two seasons

Seasons	Irrigation regimes	Initial stage	Development stage	Flowering stage	Harvesting stage
Dry-Wet	EM	10.37 a	51.36 a	73.56 a	86.2 a
	CP	-	-	-	-
	LE	11.00 b	66.47 b	83.22 b	104.2 b
	ELE	11.62 c	79.26 c	102.56 c	122.8 c
	LSd	0.0265	6.51	0.786	4.86
	CV %	1.3	53.5	4.9	25.2
	LOS	**	**	**	**
Wet-Dry	EM	11.20 a	79.20 a	82.40 a	91.93 a
	CP	14.55 b	89.09 b	93.24 b	98.32 b
	LE	14.21 b	92.78 c	92.73 b	95.61 b
	ELE	18.26 c	95.29 d	104.59 c	107.42 c
	LSd	1.949	0.3408	1.247	3.659
	CV %	72.4	2.1	7.2	20.1
	LOS	**	**	**	**

LOS: Level of significance, ** Significant at < 0.01 %, EM: Irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in the evening, CP: Control Plot.

According to Alharbi and Alsamadany (2016), the leaf area (LA) is an important part of the plant that affects light interception, gas exchange, evaporation, photosynthesis and the growth rate. An increased area of leaf causes to increase the rate of evapotranspiration and water loss. These findings are in agreement with those of Maylani et al., 2020 who shown that the wider the leaf area, the greater the rate of transpiration because wide leaves tend to have more stomata. The obtained results also agree with Gigova et al., (2013) who reported that the larger the leaf area is, the more photosynthetic active radiation is absorbed by plant. In both seasons, the largest leaf areas of French beans of 122.8 cm^2 and 107.42 cm^2 were recorded both at harvesting stages under supplementary sprinkler irrigation regime of early in the morning and late in the evening (ELE). The lowest leaf areas in both seasons of 10.37 cm^2 and 11.2 cm^2 were observed at initial stage under supplementary sprinkler irrigation regime of once only in the morning. The obtain results displayed that there was significant difference ($p<0.01$) of leaf area in all French beans growing stages both seasons.

4.1.8. Effect of different irrigation regimes on leaf area index (LAI) of French beans

The results of leaf area index of French beans showed a significantly different ($P < 0.01$) for all the growing stages of French beans (Table 4.8) in both seasons. This finding corroborates with Kalaydzieva et al., (2015) who reported that irrigation has a significant impact on the leaf area and LAI of French bean. The highest leaf area index of 0.01228 was recorded at the harvesting stage of Dry-Wet season. This suggested higher photosynthesis rate that is associated with higher yield.

Table 4.8: Leaf Area Index of French beans at different irrigation regimes in two seasons

Seasons	Irrigation regimes	Initial stage	Development stage	Flowering stage	Harvesting stage
Dry-Wet	EM	0.00104a	0.00514 a	0.00736a	0.00862 a
	CP	-	-	-	-
	LE	0.0011b	0.00665b	0.0083b	0.01042 b
	ELE	0.0013c	0.00793 c	0.0103c	0.01228 c
	LSd	0.000003	0.000651	0.00008	0.000486
	CV %	1.3	53.5	4.9	25.2
	LOS	**	**	**	**
Wet-Dry	EM	0.00112 a	0.00792 a	0.00824 a	0.00919 a
	CP	0.00145 b	0.00891 b	0.00932 b	0.00983 b
	LE	0.00142 b	0.00928 c	0.00927 b	0.00956 b
	ELE	0.00183 c	0.00953 d	0.01046 c	0.01074 c
	LSd	0.000195	0.0000341	0.000125	0.0003659
	CV %	72.4	2.1	7.2	20.1
	LOS	**	**	**	**

LOS: Level of significance, ** Significant at < 0.01 %, EM: irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in the evening, CP: Control Plot

The lowest leaf area index of French beans (lower photosynthesis rate) was found at the initial stage of Dry-Wet season. The obtained results agree with Kalaydzieva et al., (2015) who reported that under irrigation, French beans develop maximum leaf area and leaf area index (LAI) during the harvesting period. Table 4.8 shows that supplementary sprinkler irrigation regime of early in the morning and late in the evening (ELE) had the highest leaf area index indicating that it might have had the highest leaf gas exchange (H_2O, O_2 and CO_2) necessary for a favorable environment. The results also agree with Cowling and Field, (2003) who reported that leaf area index is unifying measurement of water balance and carbon in plants. It is also a key parameter in interactive models of land surface and atmospheric processes and it defines the potential surface area accessible for leaf gas exchange (H_2O, O_2 and CO_2). On the other side the lowest leaf area index of 0.00104 was recorded at initial stage irrigated once only in the morning (EM) in Dry-Wet season.

Based on the supplementary sprinkler irrigation regimes, the leaf area index demonstrated the following order EM < LE < ELE. The leaf area index increased with crop development stages. This means that the irrigation regimes largely had significant effect ($p<0.01$) at all growing stages on the leaf area in both season. The leaf area index (LAI) measured under ELE was the highest compared to the remaining of the irrigation regimes in nearly all stages of the French beans. Mahinda, (2014) made similar observation.

4.2. Water Use Efficiency of French Beans in Different Irrigation Watering Regimes

4.2.1. Effect of different irrigation regimes on soil moisture content

Soil moisture content varied among irrigation regimes and seasons. Soil moisture content significantly different ($p<0.01$) between different irrigation watering regimes and at all the stages of French beans growth in both seasons except at harvesting stage of Dry-Wet season and at flowering stage of Wet-Dry season (Table 4.9).

The results agree with Shirazi et al., (2014) who reported that at different growth stages, irrigation improved the growth of wheat on the strength of well circulated soil moisture. Soil moisture content of French beans in Dry-Wet season was significantly higher in all French beans growth stages compared to the Wet-Dry season. This could be due to the increase of rainfall and irrigation during Dry-Wet season. Ali and Mubarak, (2017) revealed that if there is rainwater but not sufficient to satisfy the crop water requiremen,t irrigation water has to supplement the rainfall in such a way that the rainwater and the irrigation water together satisfy the crop water needs. Similar finding was reported by Singh et al., (2007) who showed that soil moisture increased with increased water application. As soil moisture regimes increase, the loss of water through deep percolation increase resulting in reduction of effective rainfall in sugarcane (Singh et al., 2007).

Table 4.9: Soil moisture content (%) at different irrigation regimes

Seasons	Irrigation regimes	Initial stage	Development stage	Flowering stage	Harvesting stage
Dry-Wet	EM	29.64 c	30.47 a	26.78 b	42.39 b
	CP	-	-	-	-
	LE	28.71 b	31.48 b	25.92 a	41.17 a
	ELE	26.90 a	30.47 a	27.24 b	40.92 a
	LSd	0.719	0.579	0.604	0.970
	CV %	13.7	10.2	12.2	12.6
	LOS	**	**	**	NS
Wet-Dry	EM	25.13 a	25.66 a	20.78 a	31.08 c
	CP	26.70 b	26.71 b	21.13 ab	29.15 b
	LE	26.97 b	27.18 bc	21.49 b	28.79 b
	ELE	27.98 c	27.28 c	21.13 ab	27.58 a
	LSd	0.5057	0.5342	0.3966	0.717
	CV %	10.2	10.8	10.1	13.3
	LOS	**	**	NS	**

LOS: Level of significance, ** Significant at < 0.01 %, NS = Non-significant (0.006 and 0.07), EM: irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in the evening, CP: Control Plot

Table 4.9 shows that the highest percentage of soil moisture content of French beans obtained was 42.39 % at harvesting stage in Dry-Wet season irrigated once only in the morning while the lowest percentage of soil moisture content was 20.78 % at flowering stage in Wet-Dry season which was irrigated once only in the evening. In both seasons, the highest percentage of soil moisture content were 42.39 % and 31.08 %, for the Dry-Wet and Wet-Dry season respectively while the lowest percentage of soil moisture content were 25.92 % and 20.78 % for the Dry-Wet and Wet-Dry season. These results corroborate those of Abdel-Mawgoud, (2006), who shown that increasing irrigation rate may rise the obtainability of water in the root zone causing enhanced plant water status and better stomatal conductance. This was increased the crop production with efficient assimilation of photos. Soil moisture content was reduced during Dry-Wet season compared to Wet-Dry season. The reduced soil moisture content enhanced root development of French beans by extensive growth and greater number of root hairs in which facilitate absorption of available soil moisture to maintain plant growth (Sangakkara et al., 1996). The management of irrigation water target to deliver enough water to stock up exhausted soil water in a period to limit physiological water stress in growing plants. The management of soil moisture in green beans is significant at all stages of plant growth due to its impact on stand establishment, fungal problems and pod set and quality (Abdel-Mawgoud, 2006, Bill and Oregon State University, 2010).

4.2.2. Reference evapotranspiration (ETo) of French beans in study area

The results in the Table 4.10 shows that the lowest value of monthly reference evapotranspiration (ETo) of 100.5 mm was observed in the month of November when rainfall was higher for the Wet-Dry season. The maximum ETo was regarded at 123.38 mm in August when rainfall was low during Dry-Wet season. The high values of ETo in Dry-Wet season (August, September and October) could have been associated with low rainfall occurrences together with high temperatures (with high sunshine hours and high wind speed) and low relative humidity. The Wet-Dry season (November, December and January) is characterized by low temperatures (with low sunshine hours), High relative humidity and low windy speed which could be the reason for the low ETo. The results agree with Mong'ina et al., (2017) and Bouraima et al.,(2015) who indicated that ETo is affected by climatic parameters including solar radiation, relative humidity, temperatures and wind. High relative humidity is also known to cause low ETo while the low relative humidity escalating temperatures resulted in increased evapotranspiration.

Table 4.10: Climate and evapotranspiration (ETo) data of Muvumba valley in Nyagatare District

Month	Min Temp	Max Temp	Humidity	Windy	Sun	Rad	ETo
	^{o}C	^{o}C	%	Km/day	hours	$MJ/m^2/day$	mm/month
August	16.9	30	65	81	6.4	18.6	123.38
September	17.2	29.8	77	85	6.6	19.5	123
October	17	28.2	79	81	6.6	19.5	122.76
November	16.4	26.3	83	80	5.3	16.9	100.5
December	15.9	27	81	78	5.7	17.2	104.16
January	17	28.2	75	83	6.2	18.2	115.01

Source of Data: Rwanda Meteorology Agency

Figure 4.2 shows that the highest relative humidity of 83% was observed in November with the lowest ETo of 100.5 mm which was observed during Wet-Dry season and the lowest relative humidity of 65% was observed in August with the highest ETo of 123.4 mm which was observed during Dry-Wet season.

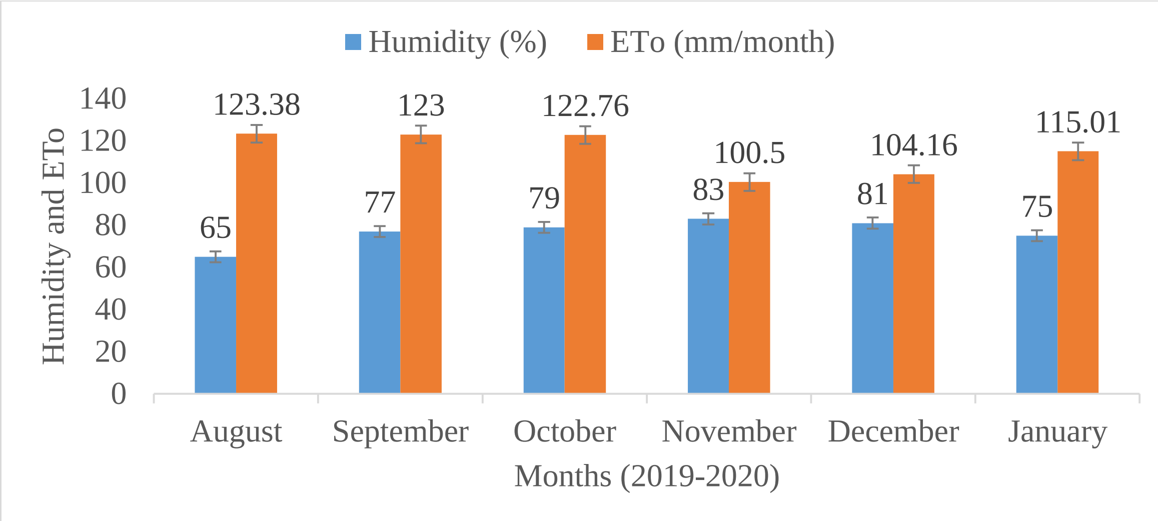

Figure 4.2: Humidity and ETo in Muvumba valley

The low values of ETo in Wet-Dry season might be associated with high amount of rainwater during Wet-Dry season than Dry-Wet season united with high relative humidity and low temperatures (Bouraima et al.,2015). Figure 4.3 shows that in Dry-Wet season, when temperature decreases rainfall increases while in Wet-Dry season, when temperature increase rainfall decreases. Nkuna and Odiyo, (2016) and Issahaku et al., (2016) made similar observations.

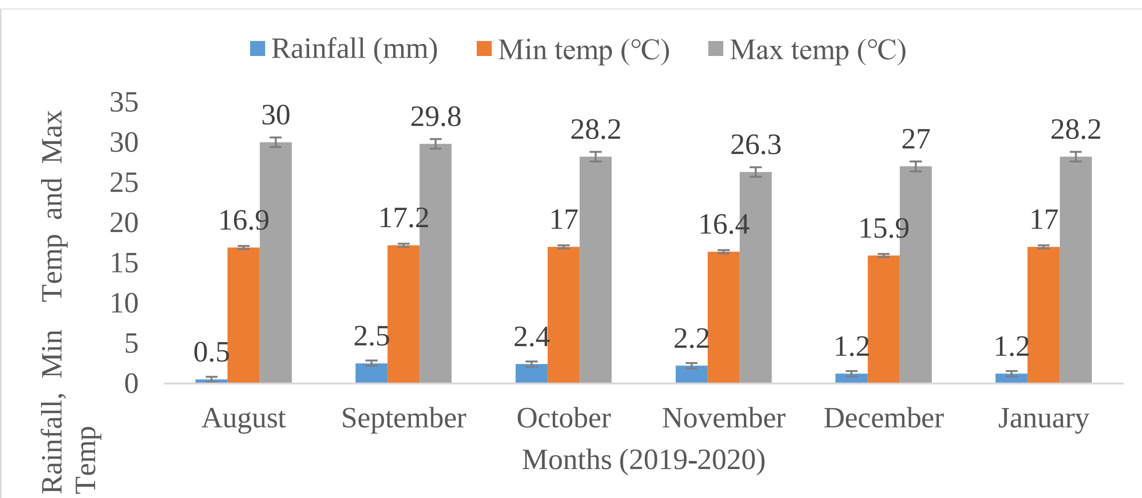

Figure 4.3: Rainfall and temperature in Muvumba valley

4.2.3. Crop evapotranspiration (ETc) of French beans in Muvumba valley

The table 4.11 shows that evapotranspiration (ET_C) effective rainfall (Eff. Rain) and Irrigation water requirements (Irr. Req) values increased at day 7 to day 43 (after planting) of the development stage and they were highest at the mid-season stage at 44 to 71 day after planting in both seasons. The values of ET_C decreased as the French beans on the way to the last stage of growth (day 72 to day 77) in both seasons. The Dry-Wet season as indicated in the Figure 4.4, demonstrate a higher crop evapotranspiration (ET_C) effective rainfall (Eff. Rain) and Irrigation water requirements (Irr. Req) than the Wet-Dry season (Figure 4.5). This higher ET_C happened in both seasons, when evapotranspiration (ET_C) effective rainfall (Eff. Rain) and Irrigation water requirements (Irr. Req) values were low during development and harvesting stages of French beans. The obtained results agree with Mong'ina et al., (2017) who reports that the ETc varies significantly throughout the development cycle of the crops due to the prevailing climatic conditions and the development of the crop during the growth stages. Smith and Park (2008) reported that evapotranspiration is highest for the hottest h of the day and plants try to adapt with the pressure connected with nootide climatic factors such as high temperatures, strong solar radiation and lower relative humidity.

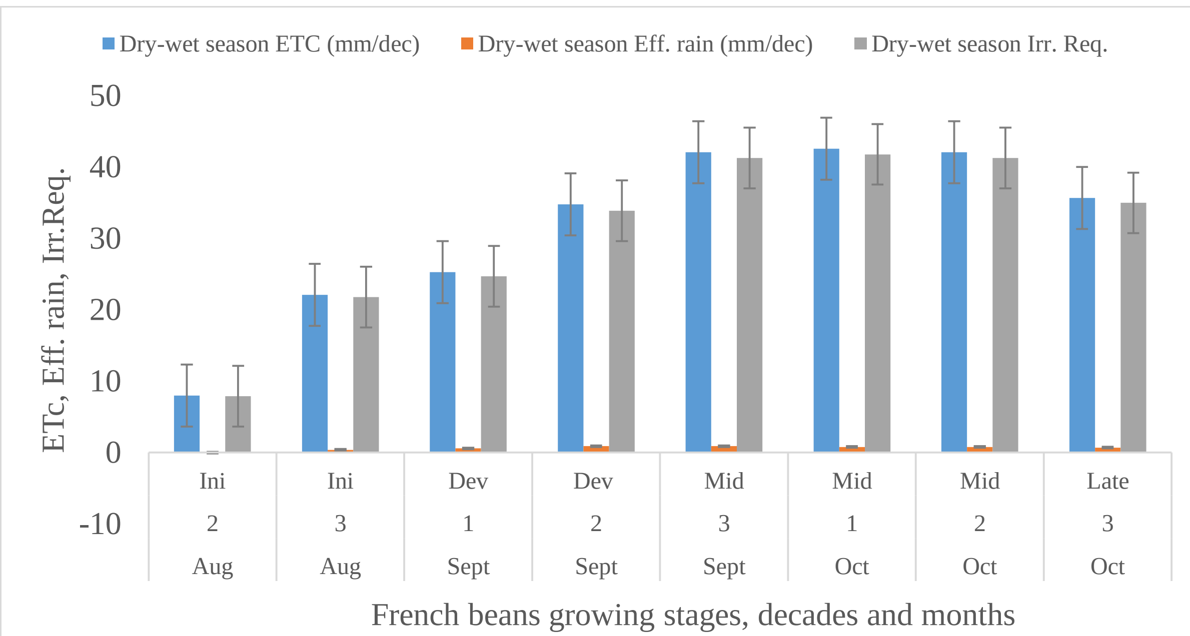

Figure 4.4: The FAO CROPWAT model for French beans grown under supplemental sprinkler irrigation during Dry-Wet season from August 17th to October 30th, 2019

ETc: crop evapotranspiration, Eff rain: effective rainfall and Irr. Req: Irrigation water requirements, Ini: Initial stage, Dev: Development stage, Mid: Middle stage.

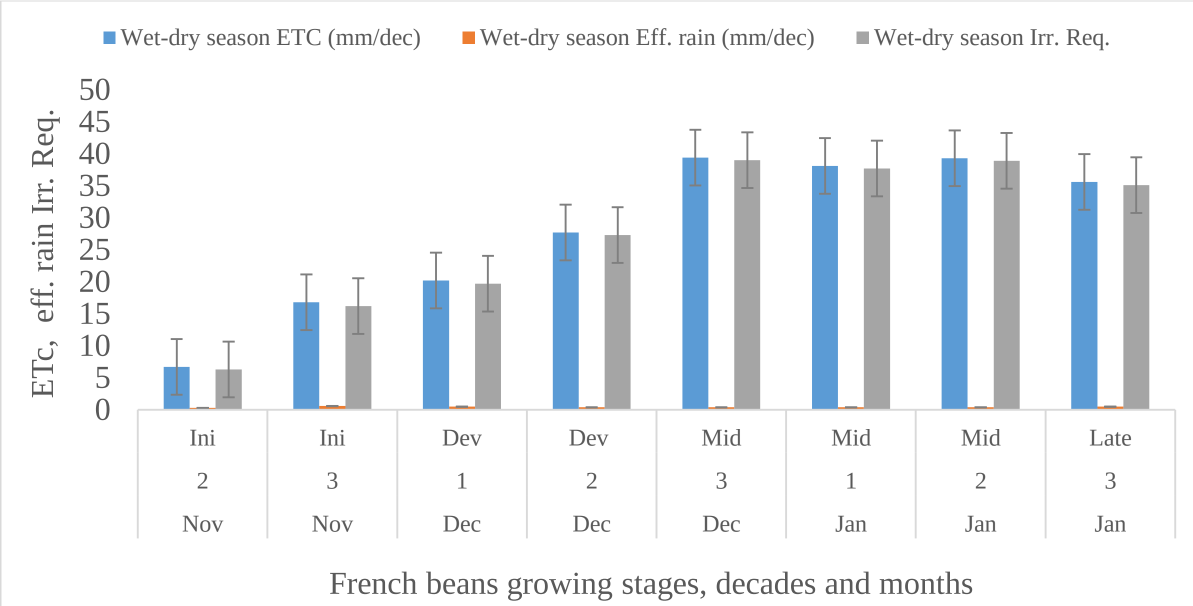

Figure 4.5: The FAO CROPWAT model for French beans grown under supplemental sprinkler irrigation during Wet-Dry season from November 17th, 2019 to January 30th, 2020

Table 4.11: Amount of Water used for French beans production during Dry-Wet season and Wet-Dry season

Seasons	Month	Decade	Growing stage	days	Kc	ETc (mm/dec)	Eff. rain (mm/dec)	Irr. Req. (mm/dec)
Dry-Wet	August	2	Initial	0-7	0.5	8	0	7.9
	August	3	Initial	8-16	0.5	22.1	0.4	21.8
	September	1	Development	17-27	0.62	25.3	0.6	24.7
	September	2	Development	28-43	0.85	34.8	0.9	33.9
	September	3	Middle	44-59	1.04	42.1	0.9	41.3
	October	1	Middle	60-70	1.06	42.6	0.8	41.8
	October	2	Middle	71-76	1.06	42.1	0.8	41.3
	October	3	Late	77-82	0.95	35.7	0.7	35
	Total			**75**		**252.7**	**5.1**	**247.6**
Wet-Dry	November	2	Initial	0-7	0.5	6.7	0.3	6.3
	November	3	Initial	8-16	0.5	16.8	0.6	16.2
	December	1	Development	17-27	0.6	20.2	0.5	19.7
	December	2	Development	28-43	0.82	27.7	0.4	27.3
	December	3	Middle	44-59	1.03	39.4	0.4	39
	January	1	Middle	60-70	1.06	38.1	0.4	37.7
	January	2	Middle	71-76	1.06	39.3	0.4	38.9
	January	3	Late	77-82	0.95	35.6	0.5	35.1
	Total			**75**		**223.8**	**3.5**	**220.2**

Kc: Crop coefficient, ETc: Crop evapotranspiration, Eff. Rain: effective rainfall and Irr. Req. Irrigation requirement.

Table 4.11 shows that, with a growing period of 75 days (November 17th, to January 30th, 2019) crop evapotranspiration was 253 mm depth of rainwater and 248 mm used as supplementary sprinkler irrigation during Dry-Wet season in semi-arid of Muvumba valley. During Wet-Dry season, 224 mm depth of rainwater was in addition to 220 mm used as supplementary sprinkler irrigation in the same area of study for an individual farmer in order to offset the effect of water stress on yield of French beans. The obtained results show that the absence of supplementary sprinkler irrigation during Dry-Wet and Wet-Dry season resulted in French beans yield reduction. Abirdew et al., (2018) made similar observation.

4.2.4. Yield of French beans under different irrigation watering regimes in two seasons

Generally, green pods of French beans harvested for each season over a period of two weeks at an interval of 3-4 days ensured the right pod quality was harvested. The response of French beans to supplemental sprinkler irrigation varied between seasons. The Table 4.12 shows that French beans, which were irrigated in Dry-Wet season produced lower yields (949.7 $Kgha^{-1}$) than the one, which were irrigated in the Wet-Dry season (1,338.7 $Kgha^{-1}$). This could be explained by the reduction of crop evapotranspiration (ETc) from Dry-Wet season to Wet-Dry season and increasing of water use efficiency during Wet-Dry season. The obtained results agree with Saleh et al., (2018) who revealed that reducing water application increased water use efficiency (WUE) and pod yields. Muñoz-Perea et al., (2007) also reported that crops with high WUE must be used to decrease the necessity on irrigation water and to improve aridity-resistant cultivars for maximization of yield and WUE.

The study showed that in the two seasons (Dry-Wet and Wet-Dry), yield of French beans that exhibited the highest significant value was in the plot irrigated early in the morning and late in the evening (ELE). The yield of French beans trend was in the order: ELE> LE > EM. The decreasing of temperature (min and max), sun radiation, and crop evapotranspiration, also increasing of relative humidity during Wet-Dry season compared to Dry-Wet season were the reasons of having a higher yield than in the control plot (non-irrigated plot). The obtained results agree with Muñoz-Perea et al., (2007) who reported that crops with high WUE must be used to decrease the necessity on irrigation water and to improve aridity-resistant cultivars for maximization of yield and WUE.

Table 4.12 shows that French bean yields significantly varied depending on irrigation watering regimes and seasons. The highest French bean yield was 366.8 $Kgha^{-1}$ obtained in plots irrigated both early in the morning and late in the evening during Wet-Dry season and the lowest yield was 245.1 $Kgha^{-1}$ in plot irrigated once only in the morning during Dry-Wet season. The obtained results indicated that in the two seasons, the highest French bean yield were 355.9 $Kgha^{-1}$ and 366.8 $Kgha^{-1}$, during the Dry-Wet season and Wet-Dry season respectively for ELE and the lowest French bean yield were 245.1 $Kgha^{-1}$ and 307.1 $Kgha^{-1}$ for the dry-wet and wet - dry season, irrigated for EM.

Table 4.12: Yield of French beans under different irrigation watering regimes in two seasons

	Yield ($Kgha^{-1}$)	
Irrigation regimes	Dry-Wet season	Wet-Dry season
EM	245.1	307.1
CP	-	334.7
LE	348.7	330.1
ELE	355.9	366.8
LSd	4.787	2.986
CV %	8.2	4.8
LOS	**	**

LOS: Level of significance, ** Significant at < 0.01 %, EM: irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in the evening, CP: Control Plot, WUE: Water User Efficiency (Kg/mm).

4.2.5. Water use efficiency under different irrigation regimes in two seasons

Table 4.13 shows that the irrigation twice a day (ELE) resulted in the higher WUE and the lowest WUE value was 0.97 Kg mm^{-1} obtained from French beans irrigated once only in the morning. The highest WUE value was 1.637 Kg mm^{-1} obtained in the irrigation of early in the morning and late in the evening. The results obtained show that during Dry-Wet and Wet-Dry seasons the highest water user efficiency of French bean were 1.407 Kg mm^{-1} and 1.637 Kg mm^{-1}, irrigated both early in the morning and late in the evening. The lowest water user efficiency of French bean were 0.969 Kg mm^{-1} and 1.371 Kg mm^{-1} irrigated both once only in the morning during Dry-Wet and Wet-Dry seasons. The water use efficiency of French beans trend was in the order: ELE> LE > EM. As the trends for the WUE related to the production of total fresh pod yields and the total volume of irrigation water for the various treatments. Thus the lower the volume of irrigation water received (from 252.7 mm/dec during Dry-Wet season to 223.8 mm/dec during Wet-Dry season), the higher the water use efficiency. This explains reason why wet-dry had the highest water use efficiency compared to Dry-Wet season. The obtained result are in agreement with those obtained by Saleh et al., (2018).

Table 4.13: Water Use Efficiency (WUE) of French beans production under different irrigation regimes in two seasons

	Water User Efficiency (Kg mm^{-1})	
Irrigation regimes	Dry-Wet season	Wet-Dry season
EM	0.969	1.371
CP	-	1.494
LE	1.378	1.474
ELE	1.407	1.637
LSd	0.01892	0.01333
CV %	8.2	4.8
LOS	**	**

LOS: Level of significant, ** is significant at < 0.01 %, EM: irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in the evening, CP: Control Plot CP: Control Plot, WUE: Water User Efficiency (Kg/mm).

Under three irrigation regimes during the two , the response of water use efficiency and French beans yield were significantly different ($p<0.01$). This shows that water use efficiency and yield of French beans were greatly affected by cropping seasons and irrigation regimes.

Table 4.14: The relationship between French beans crop yield and water used by evapotranspiration evaluated using regression analysis

	Dry-Wet season		Wet-Dry season	
Irrigation regimes	Yield (Kgha^{-1})	WUE (Kgmm^{-1})	Yield (Kgha^{-1})	WUE (Kgmm^{-1})
EM	245.1	0.969	307.1	1.371
CP	-	-	334.7	1.494
LE	348.7	1.378	330.1	1.474
ELE	355.9	1.407	366.8	1.637
LSd	4.787	0.01892	2.986	0.01333
CV %	8.2	8.2	4.8	4.8
LOS	**	**	**	**

LOS: Level of significance, ** Significant at < 0.01 %, EM: irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in the evening, CP: Control Plot, WUE: Water User Efficiency (Kg/mm).

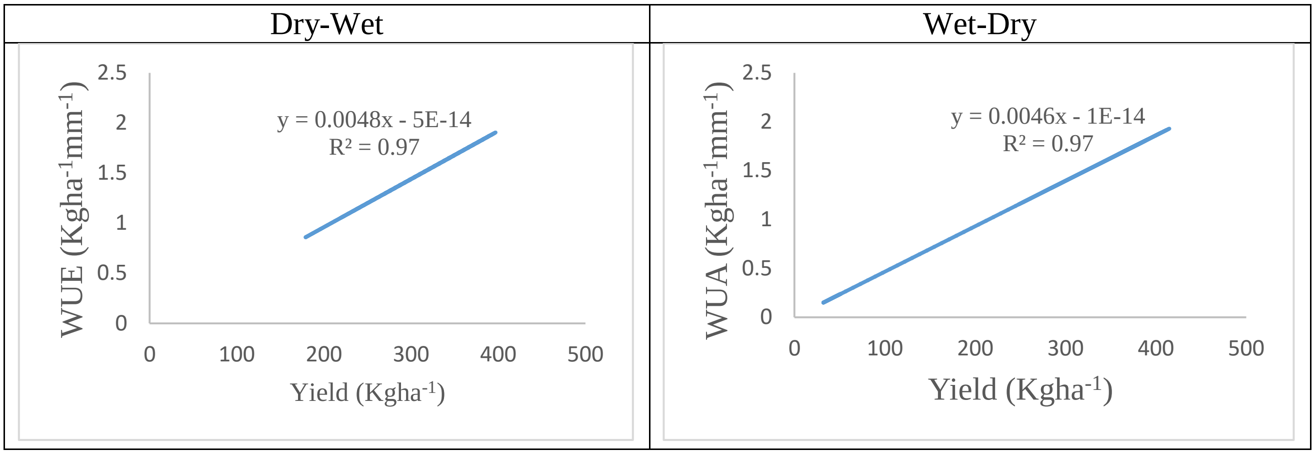

Figure 4.6: Relationship between yields and water use efficiency

Results of the statistical regression analysis (Figure 4.6) showed a close relationship between yields and water user efficiency of French beans at different irrigation regimes in the two seasons. The reference level was irrigation regime irrigated twice a day (ELE).

4.3. Financial returns of French beans grown under different irrigation watering regimes and seasons

Table 4.15 shows that the highest net income of French beans production was 98,414 RWF equivalent to 103.5 USD and it was obtained from the ELE treatment during Wet-Dry season. The lowest net income of French beans production was 28,601 RWF equal to 30.1 USD, obtained from the treatment irrigated once only in the morning during Dry-Wet seasons. In Dry-Wet season, the total net income of French beans production was 207,974 RWF (218.7 USD) and in Wet-Dry season was 320,443 RWF (337 USD), which gave the general total net income equal to 528,417 RWF (555.7 USD). The cost benefit ratio (CBR) of French bean was determined to get the economic benefits of production.

Depending on cost benefit ratio (equal to Gross income / Total production cost) in French beans production, obtained results showed that in Dry-Wet season for every Rwandan Franc invested, there was a return of 2,574 RWF, 7,886 RWF, and 8,257 RWF for EM, LE and ELE. In Wet-Dry season for every Rwandan Franc invested, there was a return of 5,808 RWF, 7,221 RWF, 6,987 RWF and 8,868 FRW for EM, CP, LE and ELE treatments, respectively as shown in table 4.16.

This explains that regardless of the higher cost connected with the ELE treatments, it had the best financial performance in two seasons. From the financial point of view, these results suggest that, supplemental sprinkler irrigation system increase the yield and the income of French beans in Wet-Dry season than Dry-Wet season. This may be explained with the reason that for Dry-Wet season much water had to be paid for irrigation; therefore this affected the total production cost to be higher.

Table 4.15: Financial returns of French beans grown under different irrigation regimes and seasons

Season	Irrigation regime	Yield (Kg/ha)	Market price RWF/Kg	Other cost (RWF)	Irrigation water cost(RWF)	Total production cost(RWF)	Gross income (RWF)	Net income (RWF)	Cost benefit ratio
Dry-Wet	EM	245.11	570	109,260	1,851.85	111,111.85	139,713	28,601	0.2574
	LE	348.67	570	109,260	1,851.85	111,111.85	198,740	87,628	0.7886
	ELE	355.89	570	109,260	1,851.85	111,111.85	202,857	91,745	0.8257
	LSd	4.787	*	*	*	*	2728.6	2,728.6	0.02456
	CV %	8.2	0.0	0.0	0.0	0.0	8.2	21.3	21.3
	LOS	**	-	-	-	-	**	**	**
Wet - Dry	EM	307.11	570	109,260	1,388.89	110,648.89	175,053	64,404	0.5808
	CP	334.67	570	109,260	1,388.89	110,648.89	190,760	80,111	0.7221
	LE	330.11	570	109,260	1,388.89	110,648.89	188,163	77,514	0.6987
	ELE	366.78	570	109,260	1,388.89	110,648.89	209,063	98,414	0.8868
	LSd	2.986	*	*	*	*	1701.8	1701.8	0.01533
	CV %	4.8	0.0	0.0	0.0	0.0	4.8	11.5	11.5
	LOS	**	-	-	-	-	**	**	**

LOS: Level of significance, ** Significant at < 0.01 %, EM: Irrigation once only in the morning, LE: Irrigation once only in the evening, ELE: Irrigation early in the morning and late in evening, CP: Control Plot, WUE: Water User Efficiency (Kg/mm).

The highest maximum return from this season (Wet-Dry) due not only to lowest cost of irrigation and highest yield, but also due to the reduction of crop evapotranspiration (ETc), temperature (min and max), sun radiation and increasing of relative humidity during Wet-Dry season. In addition, weather conditions and the presence of control plot in Wet-Dry season, which was not presence in Dry-Wet season; thus increase the cumulative yield for this season. Muñoz-Perea et al., (2007) made similar observation. The Table 4.15 shows that the highest net income of French bean production was 98,414 FRW irrigated twice a day early in the morning and late in the evening (ELE) during Wet-Dry season while the lowest net income was 28,601 FRW irrigated once only in the morning during Dry-Wet season. Without (ELE), irrigate once only in the evening (LE) during Dry-Wet season give a good financial return (87,628 Frw) than irrigate once only in the morning (EM) in both season. This is because not only LE had higher seed germination, WUE and yield than EM, but also LE had less evaporation and favorable windy conditions of sprinkler than EM. The net income and cost benefit ratio of French beans production trend was in the order: ELE> LE > EM for both seasons.

The gross-margin analysis was used to analyze the profitability of French bean production. Profit maximization, is a motivating factor for crop production and it is a key among the important goals of farm enterprises (Kwasi, 2018). The cost and returns involved in the production are listed and using them to arrive at such estimates as the return to one unit of resources used the gross margin as well as the net farm income. Table 4.16 showed that, the total income for French beans production in two seasons was 1,304, 349 RWF (1,371.77 USD) and the total variable cost paid on French beans production was 775,931.1 RWF (816.04 USD) while the Gross margin in two seasons was 528,417.89 RWF (555.73 USD).

Table 4.16: Computing gross margin of French beans production

Seasons	Irrigation regime	TR (RWF)	TVC (RWF)	GM (RWF)
Dry-Wet	EM	139,713	111,111.85	28,601.15
	LE	198,740	111,111.85	87,628.15
	ELE	202,857	111,111.85	91,745.15
	Total	541, 310	333,335.55	207,974.45
Wet-Dry	EM	175,053	110,648.89	64,404.11
	CP	190,760	110,648.89	80,111.11
	LE	188,163	110,648.89	77,514.11
	ELE	209,063	110,648.89	98,414.11
	Total	763,039	442,595.56	320,443.44
Total		1,304,349	775,931.11	528,417.89

TR: Total income from sales; TVC: Total variables cost, GM: Gross margin, RWF: Rwandan Franc

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main objective of this study was to assess the effect of supplementary irrigated agriculture for increased production of French beans in Muvumba valley, Rwanda. Proper irrigation scheduling requires the farmers to apply water more efficiently and taking into account crop evaporation and rainfall. The results obtained revealed that when sprinkler irrigation was used to supplement rainfall, yield of French beans diverse with the irrigation regimes controlled. Irrigatiing twice a day early in the morning and late in the evening (ELE) increase the yield of French beans than to single irrigation regimes (irrigation once only in the morning or irrigation once only in the evening).

The response of French beans on development, yield, water use efficiency, financial returns and cost benefit ratio under three irrigation regimes and the seasons (Dry-Wet and Wet-Dry) were significantly different ($p<0.01$). The observed trend with regard to growth performance was as follows: irrigating twice a day early in the morning and late in the evening (ELE) > Irrigating once only in the evening (LE) > irrigating once only in the morning (EM). This shows the relationship between yield and financial returns of French beans production, that is the higher the yield, the higher the profit. There is indisputable evidence that irrigating land leads to increased productivity.

The study revealed that the cropping seasons and irrigation regimes determine profits in French beans production. With the target of international and local markets, growing French beans using supplementary irrigation during the Wet-Dry season was more profitable than the Dry-Wet season. Financial returns per each invested Rwandan Franc was higher when French beans irrigated twice a day early in the morning and late in the evening (ELE) than other irrigation regimes (EM or LE). The obtained results will allow farmers to optimize the water user efficiency by using supplementary sprinkler irrigation for maximizing the French beans yield and profit.

5.2 Recommendations

This study suggests that the growers of French beans must consider access to market in order to make profit in French beans production. Based on this study, the farmers need to irrigate twice a day (ELE) since it gives highest water use efficiency, yield and net income during growth period of French beans production than when using other irrigation regimes.

In semi-arid area, the study revealed that the growers of French beans must take into account proper irrigation schedules to apply water efficiently based on crop evapotranspiration, irrigation and rainfall availability. It is financially understandable to supplement water to the crop in the Wet-Dry season rather than the Dry-Wet season by using sprinkler irrigation, out of each RWF/USD invested to make benefit. On the other hand, this may differ reliant on the price variation, which is fixed by supply and market demand.

In addition, the study suggest that, other studies (including social-economic) need to carried out in different places for various agro-ecological zones. It would be significant to use further variety of French beans under different irrigation regimes to investigate their yield potential. Those studies can be taken both on the field and on the station conditions prior being approved for agriculturalists to use.

In the context of French beans production, there is need for the Ministry of Agriculture and Animal Resources (MINAGRI) and other institutions to sensitize the growers or the farmers on the important influence of irrigation regimes on the crop growth, water use efficiency and yield.

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APPENDICES

Appendix 1: Monthly ETo Penman-Monteith

Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\MIZERO Jules.PEM

Country: Rwanda — Station: Nyagatare

Altitude: 1377 m. — Latitude: 1.28 °N — Longitude: 30.31 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	17.0	28.2	75	83	6.2	18.2	3.71
February	16.8	28.9	74	84	5.7	18.1	3.81
March	17.1	29.0	79	82	5.8	18.6	3.88
April	17.4	27.1	81	86	5.5	17.7	3.58
May	17.0	28.4	81	77	5.3	16.5	3.39
June	16.0	29.1	70	80	5.9	16.8	3.54
July	15.9	29.5	62	82	7.7	19.6	4.03
August	16.9	30.0	65	81	6.4	18.6	3.98
September	17.2	29.8	77	85	6.6	19.5	4.10
October	17.0	28.2	79	81	6.6	19.5	3.96
November	16.4	26.3	83	80	5.3	16.9	3.35
December	15.9	27.0	81	78	5.7	17.2	3.36
Average	16.7	28.5	76	82	6.1	18.1	3.73

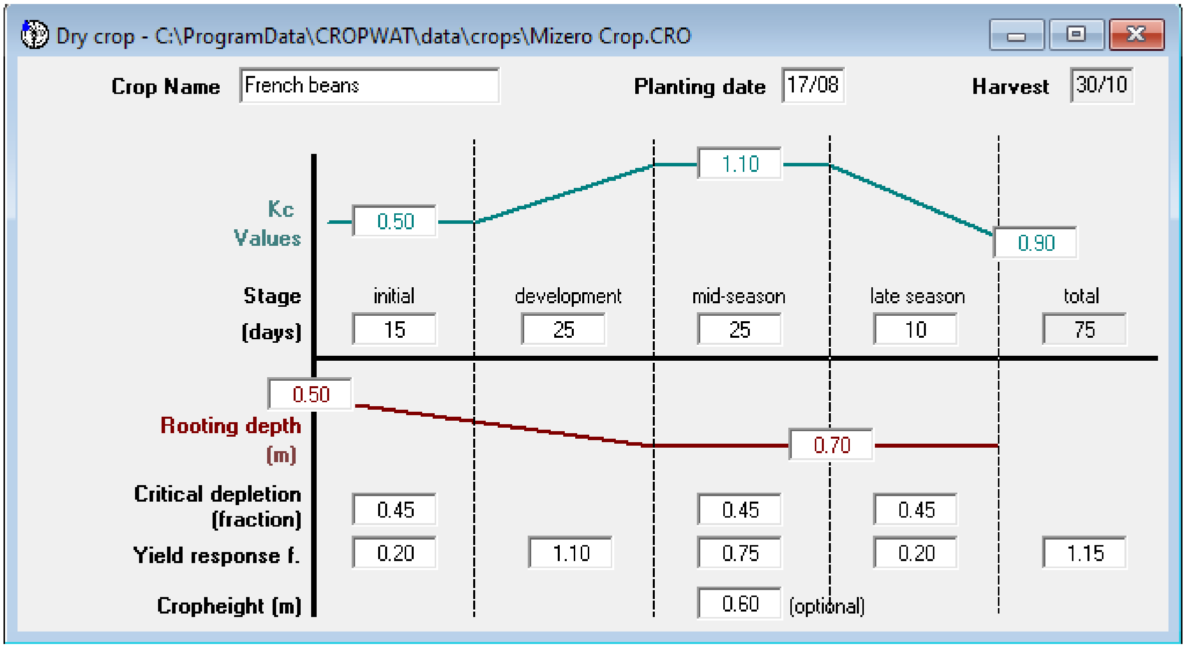
Appendix 2: Monthly rainfall during French beans production

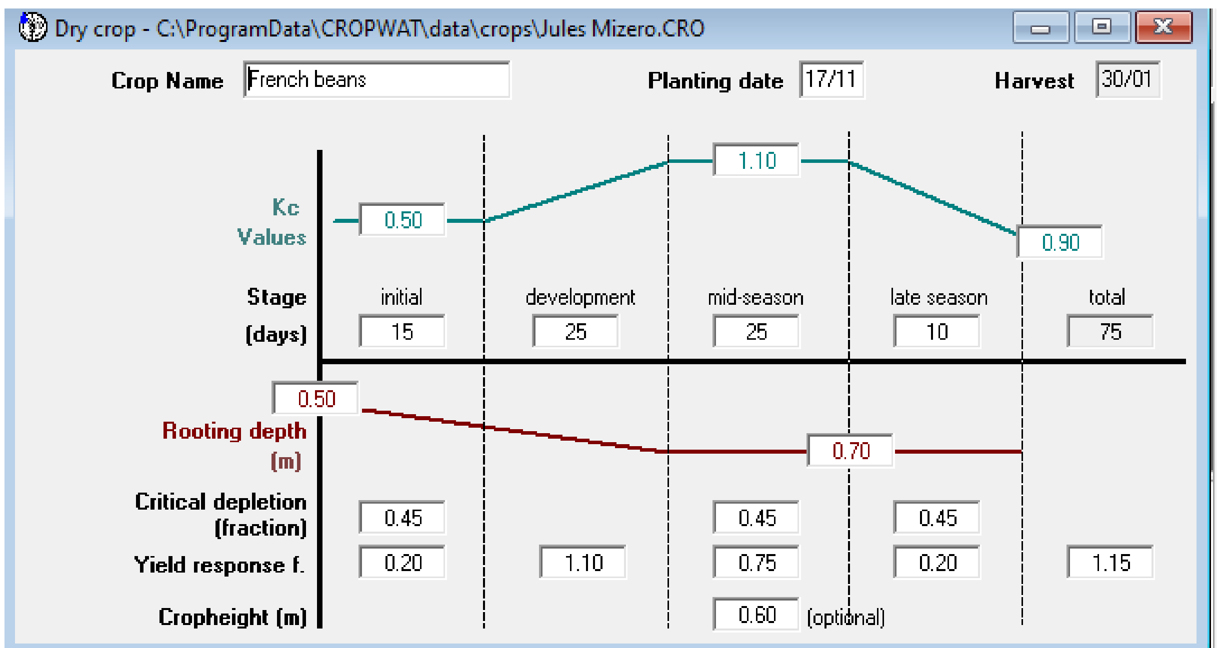
Monthly rain - C:\ProgramData\CROPWAT\data\rain\Jules Mizero.CRM

Station: Nyagatare — Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	1.2	1.2
February	2.2	2.2
March	2.3	2.3
April	2.6	2.6
May	2.8	2.8
June	0.9	0.9
July	0.4	0.4
August	0.5	0.5
September	2.5	2.5
October	2.4	2.4
November	2.2	2.2
December	1.2	1.2
Total	21.2	21.1

Appendix 3: Crop coefficient for French beans in two seasons





Appendix 4: Initial soil moisture depletion

Soil - C:\ProgramData\CROPWAT\data\soils\kwiga.SOI

Soil name Sandy loam

General soil data

Total available soil moisture (FC - WP)	35.0	**mm/meter**
Maximum rain infiltration rate	35	**mm/day**
Maximum rooting depth	50	**centimeters**
Initial soil moisture depletion (as % TAM)	70	**%**
Initial available soil moisture	10.5	**mm/meter**

Appendix 5: Crop water requirement of French beans during dry-wet season

Crop Water Requirements

ETo station Nyagatare **Crop** French beans

Rain station Nyagatare **Planting date** 17/08

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Aug	2	Init	0.50	1.99	8.0	0.0	7.9
Aug	3	Init	0.50	2.01	22.1	0.4	21.8
Sep	1	Deve	0.62	2.53	25.3	0.6	24.7
Sep	2	Deve	0.85	3.48	34.8	0.9	33.9
Sep	3	Mid	1.04	4.21	42.1	0.9	41.3
Oct	1	Mid	1.06	4.26	42.6	0.8	41.8
Oct	2	Mid	1.06	4.21	42.1	0.8	41.3
Oct	3	Late	0.95	3.57	35.7	0.7	35.0
					252.7	**5.1**	**247.6**

Appendix 6: Irrigation schedule of French beans during dry-wet season

Crop irrigation schedule

ETo station	Nyagatare	Crop	French beans	Planting date	17/08
Rain station	Nyagatare	Soil	Sandy loam	Harvest date	30/10

Yield red. 0.4 %

Table format
- (•) Irrigation schedule
- ( ) Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
17 Aug	1	Init	0.1	0.55	55	76	13.3	0.0	0.0	19.0	2.20
21 Aug	5	Init	0.0	1.00	100	46	8.0	0.0	0.0	11.4	0.33
26 Aug	10	Init	0.0	1.00	100	56	9.9	0.0	0.0	14.1	0.33
30 Aug	14	Init	0.0	1.00	100	46	8.0	0.0	0.0	11.5	0.33
3 Sep	18	Dev	0.3	1.00	100	53	9.3	0.0	0.0	13.3	0.38
7 Sep	22	Dev	0.3	1.00	100	56	9.8	0.0	0.0	14.0	0.41
11 Sep	26	Dev	0.0	1.00	100	63	11.1	0.0	0.0	15.8	0.46

Totals

Total gross irrigation	369.1	mm	Total rainfall	5.2	mm
Total net irrigation	258.4	mm	Effective rainfall	2.2	mm
Total irrigation losses	0.0	mm	Total rain loss	3.0	mm
Actual water use by crop	248.3	mm	Moist deficit at harvest	0.0	mm
Potential water use by crop	249.2	mm	Actual irrigation requirement	247.0	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	41.5	%
Deficiency irrigation schedule	0.4	%			

Yield reductions

Crop irrigation schedule

ETo station	Nyagatare	Crop	French beans	Planting date	17/08
Rain station	Nyagatare	Soil	Sandy loam	Harvest date	30/10

Yield red. 0.4 %

Table format
- (•) Irrigation schedule
- ( ) Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
17 Aug	1	Init	0.1	0.55	55	76	13.3	0.0	0.0	19.0	2.20
21 Aug	5	Init	0.0	1.00	100	46	8.0	0.0	0.0	11.4	0.33
26 Aug	10	Init	0.0	1.00	100	56	9.9	0.0	0.0	14.1	0.33
30 Aug	14	Init	0.0	1.00	100	46	8.0	0.0	0.0	11.5	0.33
3 Sep	18	Dev	0.3	1.00	100	53	9.3	0.0	0.0	13.3	0.38
7 Sep	22	Dev	0.3	1.00	100	56	9.8	0.0	0.0	14.0	0.41
11 Sep	26	Dev	0.0	1.00	100	63	11.1	0.0	0.0	15.8	0.46

Efficiency irrigation schedule	100.0	%	Efficiency rain	41.5	%
Deficiency irrigation schedule	0.4	%			

Yield reductions

Stagelabel	A	B	C	D	Season	
Reductions in ETc	3.0	0.0	0.0	0.0	0.4	%
Yield response factor	0.20	1.10	0.75	0.20	1.15	
Yield reduction	0.6	0.0	0.0	0.0		%
Cumulative yield reduction	0.6	0.6	0.6	0.6	0.4	%

Appendix 7: Crop water requirement of French beans during wet-dry season

Crop Water Requirements

ETo station: Nyagatare | Crop: French beans

Rain station: Nyagatare | Planting date: 17/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.50	1.68	6.7	0.3	6.3
Nov	3	Init	0.50	1.68	16.8	0.6	16.2
Dec	1	Deve	0.60	2.02	20.2	0.5	19.7
Dec	2	Deve	0.82	2.77	27.7	0.4	27.3
Dec	3	Mid	1.03	3.58	39.4	0.4	39.0
Jan	1	Mid	1.06	3.81	38.1	0.4	37.7
Jan	2	Mid	1.06	3.93	39.3	0.4	38.9
Jan	3	Late	0.95	3.56	35.6	0.5	35.1
					223.8	**3.5**	**220.2**

Appendix 8: Irrigation schedule of French beans during wet-dry season

Crop irrigation schedule

ETo station: Nyagatare | Crop: French beans | Planting date: 17/11 | Yield red.

Rain station: Nyagatare | Soil: Sandy loam | Harvest date: 30/01 | 0.4 %

Table format

- Irrigation schedule
- Daily soil moisture balance

Timing: Irrigate at critical depletion

Application: Refill soil to field capacity

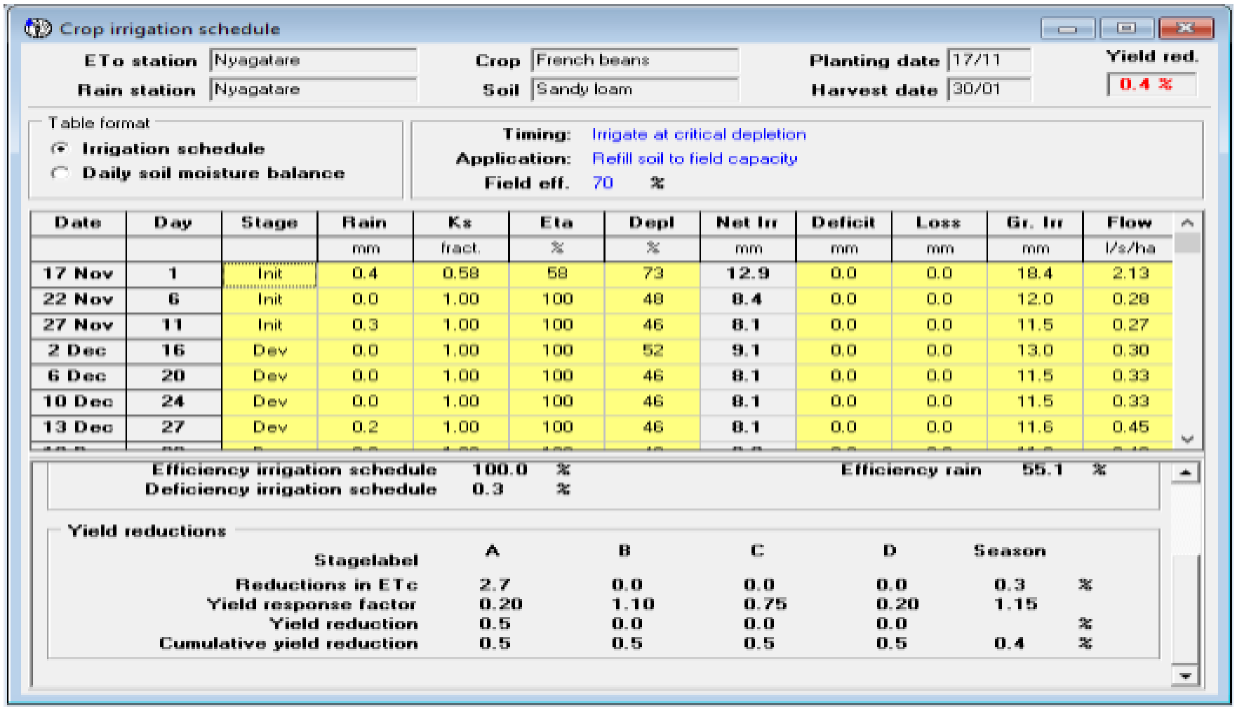
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
17 Nov	1	Init	0.4	0.58	58	73	12.9	0.0	0.0	18.4	2.13
22 Nov	6	Init	0.0	1.00	100	48	8.4	0.0	0.0	12.0	0.28
27 Nov	11	Init	0.3	1.00	100	46	8.1	0.0	0.0	11.5	0.27
2 Dec	16	Dev	0.0	1.00	100	52	9.1	0.0	0.0	13.0	0.30
6 Dec	20	Dev	0.0	1.00	100	46	8.1	0.0	0.0	11.5	0.33
10 Dec	24	Dev	0.0	1.00	100	46	8.1	0.0	0.0	11.5	0.33
13 Dec	27	Dev	0.2	1.00	100	46	8.1	0.0	0.0	11.6	0.45

Totals

Total gross irrigation	318.1	mm	Total rainfall	3.6	mm
Total net irrigation	222.6	mm	Effective rainfall	2.0	mm
Total irrigation losses	0.0	mm	Total rain loss	1.6	mm
Actual water use by crop	219.5	mm	Moist deficit at harvest	7.1	mm
Potential water use by crop	220.2	mm	Actual irrigation requirement	218.2	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	55.1	%
Deficiency irrigation schedule	0.3	%			

Yield reductions



Crop irrigation schedule

ETo station: Nyagatare | Crop: French beans | Planting date: 17/11 | Yield red.: 0.4 %

Rain station: Nyagatare | Soil: Sandy loam | Harvest date: 30/01

Table format: (•) Irrigation schedule ( ) Daily soil moisture balance

Timing: Irrigate at critical depletion

Application: Refill soil to field capacity

Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
17 Nov	1	Init	0.4	0.58	58	73	12.9	0.0	0.0	18.4	2.13
22 Nov	6	Init	0.0	1.00	100	48	8.4	0.0	0.0	12.0	0.28
27 Nov	11	Init	0.3	1.00	100	46	8.1	0.0	0.0	11.5	0.27
2 Dec	16	Dev	0.0	1.00	100	52	9.1	0.0	0.0	13.0	0.30
6 Dec	20	Dev	0.0	1.00	100	46	8.1	0.0	0.0	11.5	0.33
10 Dec	24	Dev	0.0	1.00	100	46	8.1	0.0	0.0	11.5	0.33
13 Dec	27	Dev	0.2	1.00	100	46	8.1	0.0	0.0	11.6	0.45

Efficiency irrigation schedule 100.0 % | Efficiency rain 55.1 %

Deficiency irrigation schedule 0.3 %

Yield reductions

Stagelabel	A	B	C	D	Season	
Reductions in ETc	2.7	0.0	0.0	0.0	0.3	%
Yield response factor	0.20	1.10	0.75	0.20	1.15	
Yield reduction	0.5	0.0	0.0	0.0		%
Cumulative yield reduction	0.5	0.5	0.5	0.5	0.4	%