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Department of Plant and Horticultural Science

Integrated weed management through planting types and intra-row spacing on sugarcane (*Saccharum officinarum L.)* yield at Wolkayit, Western Tigray, Ethiopia

By

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A thesis

Submitted to post graduate programe directorate in partial fulfilment of the requirements for the Master of Science Degree in Agronomy

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DECLARATION

I, **Hagos Hailu,** hereby declare that, this MSc thesis entitled **"Integrated weed management through planting types and intra-row spacing on sugarcane (*Saccharum officinarum L.)* at Wolkayit, Western Tigray, Ethiopia"** is a research work that has been carried out under the Supervision of **Haftamu Gebretsadik (PhD) and Alemu Araya (Associate professor)** College of Dryland Agriculture and Natural Resource, Mekelle University during the 2019 – 2020 cropping season until the final write up of the thesis as part of the Master of Science Program in Agronomy in accordance with the rules and regulations of the University. I further declare that this work has not been submitted to any other University or institution for the award of any degree or diploma and all the sources of materials that I have used or quoted have been indicated and duly acknowledged by means of complete references.

______________________	03/03/2025
Hagos Hailu	Date

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As thesis research advisors, we hereby certify that we have read and evaluated this thesis entitled **"Integrated weed management through planting types and intra-row spacing on sugarcane (*Saccharum officinarum L.*), at Wolkayit, Western Tigray, Ethiopia** prepared by Mr. **Hagos Hailu** under our guidance. We recommend that to be submitted as fulfilling the thesis requirements.

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As Members of the examiners board of the final MSc. thesis open defense examination, we certify that we have read and evaluated the thesis prepared by **Mr. Hagos Hailu**, and examined the candidate. We recommend that the thesis be accepted as fulfilling the thesis requirements for the degree of Master of Science in Agronomy.

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Final approval and acceptance of the thesis is contingent upon the submission of its final copy to the council of graduate program through the candidate's department graduate committee.

DEDICATION

This thesis is dedicated in memory of my late Father **Hailu Hagos** and my late mother Kahsa W/Mariam for nursing me with endless affection and love and for their devoted affiliation in the success of my life. I can never repay you for all that you have done for me, but it is a debt. May the almighty God pay you in my behalf and rest your soul in heaven.

I also would like to dedicate this work to all members of my family, friends and colleagues whose consistent encouragement and support has significantly contributed to the successful completion of my study.

Abstract

Sugarcane is the most important industrial and cash crop that is commercially cultivated for its sugar and bioenergy in the world. Weeds are among the major constraints that limit sugarcane production at Wolkayit, western parts of Tigray. Therefore, a field experiment was conducted at Wolkayit Sugar Development Project, during the 2019/20 cropping season to estimate the effect of intra-row spacing and planting types on major weeds, growth, yield and yield attributes of sugarcane. The experiment was laid out in RCBD in a factorial arrangement and replicated three times. Ten treatments consists of two sugarcane-planting types (sett planting and seedling transplanting) and five levels of spacing (5, 10, 20, 30 and 40 cm) with plot size of 25m^2. The result revealed that the main and interaction effects of intra-row spacing and planting types significantly ($P<0.05$) affected weed and yield related parameters. The highest (230.5 tha^{-1}) fresh cane yield was obtained from a set planting at 10 cm intra-row spacing while the lowest weed density (3.93m^{-2}) was recorded from 5 cm transplanted field. However, the lowest weed sun dried weed weight (3.73 gm^{-2}) was recorded from a set planting at 30 cm intra-row spacing. The lowest fresh cane yield (173 tha^{-1}) and denser weed (17.6 m^{-2}) was recorded from sett planting of 40 cm intra row spacing. Indicating integrated use of optimum intra- row spacing and transplanting reduced weed density, frequency, dominance and improved crop yields. It can be concluded that narrower intra-row spacing of 5cm generally resulted in lower weed infestation while higher cane yield was recorded from 10 cm intra-row spacing. This suggested that optimizing intra-row spacing to 10cm with set planting type is crucial technique to manage major weed species and improve sugarcane productivity. Besides, further research in different agro ecologies with prior consideration of major weed seed bank was recommended.

Key words: *Sugarcane, weed density, weeds dominance, row spacing, planting method, Wolkayit,*

BIOGRAPHICAL SKETCH

The author was born on 16 April 1979 in southeastern zone of Tigray, Hintalo woreda to his father Hailu Hagos and his mother Kahsa weldemariam. He attended his primary school education at Hiwane elementary school from (1986 to 1988) and junior and senior secondary school at Tilahun Yigzaw comprehensive secondary school (1989-1993) in Maichew town, Southern zone of Tigray. In 1994, he joined Wukro Agricultural College for three years, graduated in 1996 with diploma in plant science from the department of the then plant science. After graduation, he was employed as development Agent (DA) in woreda Hintalo wejerat from (1997 E.C) to August (2004 E.C.). Since December (2006 E.C.) he joined Mekelle university and served as Technical Assistant. After serving at this position for one year, he attended his BSc degree in Mekelle University, college of Dryland Agriculture and natural resource department of Dryland crops and horticultural science and graduated in 2009 E.C. with Bachelor of Science in Crop Science. Having served at the position of Chief Technical Assistance, he joined the school of Graduate Studies at Mekelle University in September 2011E.C. to pursue a Master of Science degree in Agronomy.

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List of Abbreviations and Acronyms

ANOVA	Analysis of Variance
CSA	Central Statistics Agency
CV	Coefficient of Variance
DAP	Di-Ammonium Phosphate
DAT	Days after Transplanting
DM	Dry Matter
FAO	Food and Agricultural Organization of the United Nations
ISO	International Standards Organization
IWM	Integrated Weed Management
LSD	Least Significant Difference
M.a.s.l.	Meters above sea level
RCBD	Randomized Complete Block Design
RF	Rainfall
RH	Relative Humidity
t/ha	Ton per hectare
WAT	Week after Transplanting
WCE	Weed Control Efficiency
WSFP	Wolkayit Sugar Factory Project

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CHAPTER ONE:

1. INTRODUCTION

1.1. Background Information

Sugarcane (*Saccharum officinarum* L) is the most important industrial and cash crop that is commercially cultivated for its sugar and bioenergy in about 200 tropical and sub-tropical countries of the world (Wada *et al*., 2017; Singh *et al*., 2018; Mohamed *et al.,* 2019). Sugarcane also called a "noble cane" is one of the world's major C4 crops having high efficiency in storing solar energy and most efficient converter of solar energy to sucrose (Zhao *et al.*, 2015; Hassin, 2016). It is well known for its ability to accumulate high concentration of sucrose in the internodes of the stalk (Kim *et al*., 2011),

It is known that the origin of sugarcane (*Saccharum officinarum* L.) is in Papua New Guinea and the South of pacific progressed westwards, particularly in the form of the hybrids *Saccharum sinense* (in China) and *S. barberi* (in India) and dated back to 326 BC (Verheye, 2010). Sugarcane is a ratoon crop that is well grown in tropical and sub-tropical regions of the world and easily propagated by a means of vegetative stem cuttings for its high levels of sucrose accumulation.

The crop grows in an altitude of 1000 m and/or little more with an annual rainfall ranging from 1200 to 1500mm. The minimum, optimum and maximum temperatures for sugarcane growth and development are 20°c, 30°c and 38°c respectively. Optimum temperature for sprouting (germination) of stem cuttings is 32°c to 38°c. It slows down below 25°c, reaches plateau between 30°c -34°c °, is reduced above 35°c and practically stops when the temperature is above 38°c (Ackbar, 2007; Verheye, 2010).

Sugarcane is one of the major source of income in many countries all over the world and it provides about 80% of the total sugar produced worldwide per annum while the remaining 20% is produced from sugar beet (Overholt *et al*., 2003; Brumble *et al*., 2009; Sentíes-Herrera *et al*., 2017). Besides, it is a source of green energy in the form of bio-fuels (raw material for bio-ethanol production), bioelectricity (generating power), bio-fertilizer, paper making and many other bio-based products such as animal feed (Australian Government., 2004, Solomon and Swapna.,2022, Saleem., 2022). Globally, Brazil is the leading sugar producing country, followed by India, China, Thailand, Pakistan and Mexico respectively, While Republic of South Africa and Egypt are the major sugar producing countries in Africa (Solomon., 2014; Zhao *et al*., 2015; Hassin, 2016). In terms of area of land allocated for sugarcane and its production, Ethiopia ranked 13th from African countries (FAO STAT, 2017).

It is thought that sugarcane was first introduced to Ethiopia during the Italian occupation of 1936-1941 and commercially started in 1955 cultivated on a large scale by Dutch Company called “Handles-Vereening Amsterdam (HVA)" at Wonji sugar factory project (Mukerji, 2000). In Ethiopia, sugarcane production plays an important role in the socio economic development, providing raw sugar and its by-products that are vital for local consumption and used as a major source of foreign currency. Due to the presence of Ethiopia’s sugar industry, an employment opportunity had been created for an enormous people and serving as a means of their income (Girma and Awulachew, 2007). Several Ethiopian smallholder farmers are also growing non-commercial sugarcane cultivars for the local market (chewing). Therefore, sugarcane currently is a source of income for thousands of people.

Although Ethiopia has fertile soil and suitable environmental condition for sugarcane production, its average cane yield is limited to about 104 ton/ha/year (Getaneh. *et al.,*2015) this could be attributed by many factors, of which weed infestation caused due to improper intra-row spacing and planting types play significant role

According Kumar, (2016) and Business Info Ethiopia, (2022), the country's local sugar demand was estimated to be 1.2 million tons during the periods of 2020/21 while the local sugar production was only 340,000 tons of sugar, leaving 860,000-ton gap. Hence, the country was forced to import sugar costed 150 million dollars of America from other countries to satisfy its domestic demand in 2020/21 (Business Info Ethiopia, 2022).

Despite of the importance of sugarcane in the Ethiopia's socio economic development, its productivity is low compared to the world sugarcane production. So, the low national sugarcane productivity could be resulted from a combination of numerous biotic (weeds, insect pests and diseases) and abiotic (Temperature, erratic rainfall, poor soil fertility, soil salinity and water logging conditions) factors, Among the many yield reducing factors, weed competition plays an important role in affecting sugarcane growth, development, productivity and quality of sugar, (Zafar *et al.,* 2010).

Weeds are the most important biotic factors, which can cause a yield loss of 38.8% in sugarcane and extensive damage to the environment (Galon *et al.,*2013; Ekwealor *et al.,* 2019). Consequently, weeds compete with crops for the same resources, such as water, nutrients (weeds contest the crops 47%N, 42%P, 50%K, 39%Ca, and 24%Mg of their nutrient uptake), light, space and carbon dioxide, hence reduces crop productivity (Rana, and Rana, 2016). Besides, some other weeds can release poisonous substance into the soil that can be harmful to the soil microorganisms and can deteriorate yield of the crop. Some of the weeds are parasitic, only can develop in the presence of the host plants. Weeds can also act as alternate hosts for crop pests and pathogens (Kumar *et al.,* 2021). Intra-row spacing and planting method are among the important factors that significantly affect weed incidence, infestation and the ability of the crop to suppress weeds due to their competition for limited resources (Kebede, 2015; Tabot, 2015). Computation bbbbbbbbb

1.2. Statement of the Problem

Cultivation of sugarcane production is increasing from time to time in Ethiopia. However, as compared to other African countries, its productivity is becoming low due to profuse biotic and abiotic factors (Livingston *et al.*, 2011). Among the biotic factors weeds are reported as the primary yield reducing factors in sugarcane production with 20 to 90% yield loss in different countries (Peng., 2012) and 41 to 51% sugarcane yield loss in Ethiopia (Firehun *et al.,* 2013). Sugarcane being as a long lasting and widely spaced crop, it affords good opportunity for several weeds to grow in empty space in its entire life.

Currently, Ethiopia is providing only 60% of sugar production demand for its national consumption and the annual per capita consumption of sugar is estimated to be 5.1 kg/person/yiear, which is lower than that of African standard (16.3 kg) and world standard (23.7kg) (ISO,2010). Therefore, in order to meet the supply and demand of sugar in the country, there is an urgent need to increase the production and productivity of sugarcane (Firehun *et al.,* 2013).

Even if the aim of Wolkayit sugar development project like all other sugarcane estates of the country is to increase sugar yield by maximizing sugarcane production per unit area of land, the production and productivity of sugarcane is getting low and low due to different biotic and abiotic factors. Wolkayit sugar development project reported in its unpublished annual report, weeds as the bottlenecks in sugarcane production. However, appropriate weed management practices were not undertaken well in the project. Keeping these problems in mind, the study was carried out in order to investigate the appropriate planting method and integrated application of intra-row spacing of sugarcane in reducing the negative impact of weed infestation on sugarcane production and ultimately to improve its production and productivity.

1.3. Objectives of the Study

1.3.1. General objective:

- ☞ The aim of the study was to assess the performance of sugarcane in response to identify and estimate effectiveness of the combined application of intra-row spacing and planting types on reducing the effect of weed species on growth, yield and yield components of sugarcane.

1.3.2. Specific objective

- ☞ To examine the effect of intra-row spacing of sugarcane on weed infestation and cane yield.
- ☞ To evaluate the effect of sugarcane planting method on weed infestation and Sugarcane yield and yield components
- ☞ To determine the interaction effect of intra-row spacing and planting methods on weed infestations, cane yield and its components.

1.4. Research question

The purpose of this study was to answer the following questions: -

- ☞ Does the combination of intra-row spacing and seedling transplanting effective in reducing sugarcane weeds infestation?
- ☞ To what extent the combination of spacing and planting types reduce weed computation and enhance sugarcane yield?
- ☞ Does transplanting of sugarcane seedlings affect weed population over set planting?
- ☞ Does intra-row spacing and transplanting of sugarcane seedlings significantly affect yield and yield components of sugarcane?

1.5. Hypothesis

H0: A combination of planting types and spacing can not reduce weed computation in sugarcane.

H1: A combination of planting types and spacing can reduce weed computation in sugarcane.

CHAPTER TWO

2. Literature Review

2.1. Origin, Center of Diversity and Distribution of Sugarcane

Sugarcane (Saccharum officinarum L.) which is the main source of sugar & bioenergy (ethanol), a renewable transportation fuel is an important tall growing monocotyledonous and industrial crop that is cultivated throughout the tropical & subtropical regions of the world as a cash crop mainly for its ability to store high concentration of sugar in the internodes of its stalks (Bakker, 2012; Zhao and Li, 2015). The crop having high efficiency in storing solar energy and most efficient converter of solar energy to sucrose can produce multiple tillers from a single plant, each having a number of nodes separated by internodes, containing sucrose storing parenchyma cells and vascular tissue, with the stem being the major sink for photosynthetic (sucrose) (Australian Government, 2004).

It is unanimously thought that the noble cane or *Saccharum officinarum* was domesticated from two wild species of *Saccharum robustum* and *Saccharum spontaneum* (Overholt *et al.,* 2003; Bakker, 2012). The origin of sugarcane (*Saccharum officinarum* L.) is estimated in Papua New Guinea and the South of pacific spread westwards, particularly in the form of the hybrids *Saccharum sinense* (in China) and *S. barberi* (in India) and dated back to 326 BC (Verheye, 2010; Menon, P., 2021). Hence, Papua New Guinea (PGN) has been supposed as the center of origin for the noble cane.

Regardless of the fact that current sugarcane plantation is highly intensifying with an existing area coverage of 98,986 ha and production of 400,000 tons of sugar as well as 25,388 m^3 of ethanol per annum. Commercial Sugarcane cultivation in Ethiopia was started since 1955 by a Dutch company with 5,000 ha of an initial area at Wonji sugar Estate (CSA, 2017; Ftwi *et al*., 2018).

2.2. Botanical, morphological and physiological description of sugarcane

Sugarcane belongs to the Andropogoneae tribe of the Poaceae/grass family is an erect long-lasting crop having an un branched stalk with a variable plant height of 3-5 meters tall & approximately 5cm in thickness (Shezi., 2017; Wekesa., 2017). The genus Saccharum from the grass family is one of the tallest, perennial and most important commercial and food crops that is widely cultivated throughout the tropical and subtropical regions of the globe (Tew and Cobill, 2008).

The novel cane plant having 10-15 stalks per a single crop is a clumped, erect, perennial and tall leafy grass that may grow up to a height of 3-5 m with a stalk diameter of 2-6 cm. The leaves of sugarcane are alternatively arranged in opposite side & are linear with 1-2 m long and 3-8 cm wide. Sugarcane has a long root system that can grow up to 3 to 6 m deep (Kew Science, 2017; Van Antwerpen *et al.,* 2022).

2.3. Agro ecological requirements of sugarcane

Sugarcane is a warm season crop in which its cultivation expanded from tropical to sub-tropical regions of the world (Sharma and Pathak., 2017; Singh *et al*.,2020). Globally, sugarcane is cultivated between 33° N, 33° S latitudes, and an altitude of up to 1,600 M.a.s.l (Griffee, 2000). Therefore, the genus Saccharum is best suited to the tropical and subtropical regions of the world with climatic conditions having hot, sunny, humid, alternatively dry and frost free periods (Srivastava *et al.,* 2012). The noble cane responds well to a long period of sunlight of about 12 to 14 hours and high humidity (probably 80–85 %). It can also be grown on a wide variety of soil types ranging from sandy and clay loams, acidic volcanic soils and calcareous sedimentary soils

(Silva., 2019). Fine textured sandy loam, clay loam and clay soils are also favorable (Blair and Stirling, 2007).

Although the crop tolerates soil PH that ranges from 4.0 – 10.0, the preferred soil PH for sugarcane cultivation varies from 5.0 to 5.8 (Helgason and Storgaard. 2023). The crop cycle, growth and maturation are largely influenced by climatic conditions; moisture and heat favor growth, while dry sunny periods and low night temperatures are favorable for maturation and sugar accumulation (Kumar *et al.*, 2018).

2.4. Economic importance of sugarcane

Sugarcane is an important food and commercial crop that plays a significant role in societal and economic development all over the world (SASA, 2014). It is one of the world's major food crops providing about 75- 80% of the sugar harvested for human consumption (FAO 2004; Shukla *et al.*, 2017).

It is thought that sugarcane has been established as a domestic garden crop mainly as a source of sugar probably as early as 2500 BC (Grivet 2004). Globally, most of the sugarcane producing countries have understood that even though the production of sugar from sugarcane is the most paying proposition, it is better to produce different value added products by diversification and utilizing by-products of the sugar industry instead of depending on just one product, sugar. The key by-products of the sugar industry, which have greater economic value, are bagasse, molasses and filter cakes or press mud. Other by-products, which are of less commercial value, are sugarcane trash, sugarcane tops, wax, boiler or fly ash, factory and distillery sewages (Dotaniya and Datta, 2014). Sugar and its byproduct are used for local consumption and export. Sugarcane is an important cash crop providing socio-economic importance to the community (Hamza and Alebjo., 2017), such as dietary value, improving living standard of the society, job opportunity creation (high man power use), government revenue (main source of revenue), source of energy, electric power (bio fuel), source of food (for the society), fodder (for animals) and fertilizer.

2.5. Sugarcane Production in Ethiopia and its production constraints

Sugarcane which is vegetatively propagated under commercial production (Verma, 2004) is cultivated in more than 200 world countries, of which, Brazil, India, China, Thailand, Pakistan, Mexico, Colombia, Australia, Philippines and the USA with 420,121,000 MT, 232,320,000MT, 88,730,000MT, 49,572,000MT, 47,244,100 MT, 45,126,500 MT, 39,849,240 MT, 38,246,100 MT, 31, 000,100 MT and 25,803,960 MT respectively are the top ten countries in production (FAO,2005). Sugarcane, grown in the tropical and sub-tropical regions of both Northern and Southern hemisphere countries (FASTAT, 2009) produces a total production of 1,328 million metric tons (FAOSTAT, 2005). The noble cane is the most promising and high yielding cereal crop (1.9 billion tons/year) of which only 5% is the contribution of Africa to the current world sugar production. Out of this 83% is from Sub- Saharan Africa (SASA, 2014). Hence, it is the world's leading sugar producing crop accounting for about 80% of world sugar supply (Dillon *et al.*, 2007).

Sugarcane was first introduced to Ethiopia during the Italian occupation of 1936-1941 and commercial sugarcane Development was begun on a total area of 5,000 hectares since 1951 with a joint venture between a Dutch company also known as Handlers -Vereeniging Amsterdam (HVA) and the Ethiopian government and started sugar production in 1954/55 when the Wonji Sugar Factory was established and produced 15,843 tons of white sugar in its first campaign. Likewise, Shoa, Methara and Fincha sugar factories were also established in 1962, 1969 and 1998 E.C respectively (EARO, 2000; Mukerji, 2000, Tafese., 2001, Tafese and Leul.,2009). Sugar industry plays a great role in the Ethiopian socio-economy and provides employment opportunity for the people (Girma and Awulachew, 2007).

Sugarcane is an important commercial crop in Ethiopia covering about 30,000 ha of irrigated lands commercially with average cane and sugar yield of 145 tons per ha and 300,000 tons per year, respectively (ESDA, 2010). However, the current sugar production of the country is below the national demand and this resulted in importing of over 150,000 tons of sugar per annum. Therefore, to satisfy the current demand consumptions and fill the gap between the ever-increasing population of the country and sugar production, Ethiopia is expected to produce more than 80,000 MT of sugar per year (ISO, 2003). Regardless of the importance of sugarcane in Ethiopia, Production and productivity of sugarcane is constrained by various Biotic (weeds, insect pest and diseases) and abiotic factors (erratic rainfall, soil factors, irrigation water supply, temperature and sun light) as well as environmental and management factors (Abera *et al.,* 2009). However, weeds are the major limiting factors in production and productivity of the crop (Bahadur *et al.,*2015). Weeds reduce sugarcane yield by competing moisture, nutrients and light during its growing period (Khan *et al.*, 2004).

Table 1: Sugarcane production, yield and area cultivated in years 2013-2022.in Ethiopia

Year of cultivation	Cane production (in tons)	Area harvested (hectare)	Yield (tons of cane per hectare)
2013	1401089	29027	48.3
2014	1556942	30053	51.8
2015	1376981	29358	46.9
2016	1407680	31228	45.1
2017	1136020	27492	41.3
2018	1294081	27827	46.5
2019	1499134	32069	46.8
2020	1345431	29520	45.6
2021	815327	19659	41.5
2022	392967.8	9724	40.4

Source: compiled from FAOSTAT (2022).

2.6. Agronomic management of sugarcane

Sugarcane is an important cash crop in which its production depends on crop agronomic managements including planting time, planting type, inter and intra-row spacing (plant spacing & density), watering, fertilizer application, weeds, insect pest and disease. Weeds are among the major problems in sugarcane production due to a wide row and plant spacing, slow sprouting and initial growth, heavy fertilization and frequent irrigation. Weeds lead to yield reduction by competition or allelopathic effect and interference with harvesting machinery, which reduces product quality (McMahon *et al.,* 2000; Raskar, 2004). According Firehun *et al*., (2009), weeds cause 64 to 80% sugarcane yield loss in Ethiopia,

2.6.1. Spacing and planting method of sugarcane

2.6.1.1. Spacing and optimum density of sugarcane

Inappropriate intra-row spacing is among the most crucial factors reducing sugarcane production (Bashir *et al.,* 2000). Yield and yield attributes of sugarcane directly depend on the early stand density and their tiller numbers, influencing by the number and health of the setts or seedlings planted (Ehsanullah *et al.,* 2011). Both too high and too low population density can affect the yield and yield components of sugarcane. Hence, Optimum plant population is an important issue to attain maximum production of any crop (Solomon, 2003).

Sugarcane planting density is the result of inter and intra-row spacing, varietal differences (Ayele *et al*.,2014) and environmental conditions (Amolo and Abayo, 2004). Widely spaced sugarcane setts/seedlings can cause sub-optimal plant population density that may lead to a reduced amount of millable canes per a given area, which is the most vital component of cane yields (Mahmood *et al.,* 2019). Similarly, widely spaced crop of sugarcane allows wide range of weed flora to grow abundantly in the interspaces between the rows (Singh *el al.,* 2008).

2.6.1.2. Effect of spacing and planting types on weeds infestation on sugarcane yield

It is very important to know the planting types of sugarcane is essential to increase yield by reducing weed interference (Zafar *et al.,* 2010). A certain planting types for sugarcane may provide an optimum space to maximize vegetative parts, which subsequently receives higher solar energy and results in maximum yield. Adjusting spacing between plants and rows is one of the most important agronomic practices for increasing yield of the crop and reducing the competition with weeds (Zafar *et al.,* 2010). Both intra-row spacing and planting types are the key determinant factors that significantly affect weed incidence, infestation and the ability of the crop to suppress weeds due to their competition for limited resources (Kebede., 2000). Weeds grow more vigorously due to more area available for growth and offer more competition with increased inter and intra-row spacing.

Spacing has a direct effect on available light, plant population, and canopy development, which significantly influences how much available light is intercepted by a plant canopy, directly affecting its development and overall growth; wider spacing generally allows for more light penetration, while closer spacing leads to a denser canopy with potentially less light reaching lower leaves, thus influencing the plant's structure, photosynthetic capacity, weed growth and dry matter yield (Fahad *et al.*, 2015; Ali *et al.*, 2017; Chiluwal *et al.*, 2018).

2.6.2. Weeds meaning, classification and their effect on sugarcane production

Weeds may generally be defined as any plants that grow where they are not wanted (CABI.,2005). They are unwanted, useless, prolific, competitive and often harmful to the crop plants which infest different crops and inflict negative effect on crop yield either by competition for water, nutrients, space and light or acting as an alternate host to insect pests and pathogens that are important biotic factors attacking crop plants (Gupta, 2001; Reddy *et al.,* 2007). Weeds are notorious yield reducers that are, in many situations, economically more important than insects, fungi or other pest organisms. The annual global economic loss caused by weeds has been estimated at more than $100 billion U.S. dollars (Appleby *et al.,* 2000). Similarly, fried *et al.,* (2017) also stated that 10-40% of global crop production is lost because of weed competition for resources.

The concept of weeds as unwanted plant was born when man started to cultivate crop plants intentionally for food and other purposes. Worldwide, there are more than 250 weed species considered as important traits for agricultural crops (Monaco, 2002).

Weeds, being as competitive and adaptable to all adverse environmental conditions, they compete with crops mainly for space, sunlight, moisture and mineral nutrients leading the crop to dwarfing in plant size, nutrient starved conditions, wilting and actual dying (Rana *et al*., 2016). Therefore, yield and yield components of the target crop will be reduced in both quantity and quality. Some weed species caused damage to crops by harboring pests and disease agents (Byron *et al.,* 2019; Kumar *et al.,* 2021).

As Kumar et al., (2021) have reported that weeds act as host for bacteria, viruses and nematodes that cause diseases in crop plants. Weeds also show allopathic effects on agricultural crops by secreting allelochemicals that inhibit their growth and germination (Deka *et al.,* 2011). Therefore, knowledge on weed management practice is crucial for economical crop production.

Morphologically, weeds can be classified as grasses, sedges and broad lived weeds and based on their life span weeds are classified as annuals, biennials and perennials. Another classification depends on their habitat, the season of the year when they appear, the crops they affect and parasite or poisons (Gupta, 2001; Balasubramaniya & palaniappan, 2001).

2.6.2.1. Critical period of weed computation in sugarcane

One of the main factors affecting sugarcane crop yield is weed interference, because of competition against a crop for biotic factors of the environment, which is a major factor of reduction of sugarcane yield. Moreover, weed control represents a large portion of production costs (Galon *et al.*, 2013 and Showler *et al.,* 2016). According Chauhan and Srivastava (2002), Sugarcane is a long lasting (perennial) crop which takes longer time for germination due to which crop faces tough competition with weeds between 60 to 120 days of its planting which causes heavy reduction in cane yield ranging from 40-67%. Weeds reduce sugarcane development, growth, yield and yield components by competing for space, moisture, nutrients, light and secreting allelopathic chemicals during its growing period.

Since sugarcane has a prolonged growing season that vary from 12-14 months (Srivastava and Rai.,2012), critical focus on weed management is an essential component of its production and productivity. In early stages of the crop, sugarcane germinates and grows very slowly, while weeds show a rapid growth rate due to the lack of competition from sugarcane crop. If not checked timely, early tillering and growth of sugarcane is likely to be affected by weed competition. Kouame *et al.* *(*2014) reported that critical period of weed control was between 30 and 120 days after planting sugarcane in spring. Similarly, Cheema *et al*., *(*2010) assured that maximum yield of cane was obtained when the crop was kept weed free from 1 to 3 months after planting. It was further observed that weeds competition for one month from planting had no adverse effect on cane yields, whereas competition for two months reduced yield by 15% and for the whole season by 55%.

As reported by Tadele *et al.,* (2022), crop -weed competition in the sugarcane plantation of Ethiopia caused a significant yield loss that ranges from 64 to 80% and 60 to 74% cane and sugar yield respectively. Moreover, as weeds are unavoidable plants in all sugar estate (Firehun *et al.*, 2007), Ethiopian sugarcane plantation financial reports indicated that weed costs about 2 million birr/year for weeding for both herbicidal and hand weeding.

2.6.2.2. Common weeds of sugarcane

Sugarcane being as a perennial crop (3-4 years in the same field), its delayed germination, slow initial growth, and wide inter & inra-row spacing and sufficient supply of nutrients of the crop provides favorable conditions for different weeds species infestation. The weed infestation is always a major problem, which seriously reduces yield of sugarcane. Hence, the crop is affected by Nearly 150 different weed species, including grasses (such as *Echinochloa colonum, Echinochloa crusgalli, Eriochloa fatmensis, Digitaria ternata, Cynodon dactylon* and *Sorghum halepense*), broad leaved weeds (*Amaranthus viridis, Commelina benghalensis, Nicandra physalodes, Xanthium strumarium* and *Celosia argentia*), climbers such as (*convolvulus arvensis* and *Spilanthes Mauritania*), parasite weeds like (*Orobanche ramosa* and *Striga hermentica*) and sedges (like *Cyperus rotundus*). Besides, the crop is suffered by seasonal, annual, perennial and parasitic weeds including *Chenopodium album, Lathyrus sativa, Vicia spp., Angallis arvensis Fumaria parviflora* and *Striga lutea* (Rathika *et al*., 2023, Tomar and Singh., 2024).

According to Hussain *et al*., (2018), the degree of yield loss may range from 10% to complete crop failure if it is heavily infested with a variety of weeds due to its long lasting nature.

2.7. Management options of sugarcane weeds

Sugarcane, having slow germination & growth nature, heavy fertilizer and frequent irrigation loving crop (Raskar, 2004), it is faced to various biotic and abiotic yield reducing factors. Among the various yield-limiting factors, weeds are the major causes for low sugarcane productivity (McMahon *et al.,* 2000). Hence, sugarcane weed control, the process of limiting weed infestation so that the crop could be grown profitably and other activities of man conducted efficiently, is a vital task in sugarcane production if an adequate yield is needed to be obtained. To avoid sugarcane yield loss caused by weeds infestation, control of weeds during critical period of crop-weed competition is very important (Rathika *et al.,* 2023). Even if the length of critical period varies depending on cane types, their competitive ability, variety, soil condition, planting techniques, weed flora composition and extent of weed infestation, the initial 120 days after planting can be considered as critical period for crop weed competition in sugarcane (Singh *et al.,* 2011). Therefore, actions have to be taken before they cause economic damage on cane yields. There are different sugarcane weed control methods including prevention, Cultural, mechanical physical, biological, chemical and integrated weed managements (Olivera *et al.*, 2015) in which, each may be used alone or all are usually integrated for successful weed control program (Qasem, 2003; Singh *et al.*, 2006).

In Wolkayit sugar development project field, weed management is done using herbicides and hand weeding methods where 2.4-D and Gessapax combi being the most common herbicides used. These two herbicides are used in combination in most cases and occasionally 2.4-D alone is used when Gessapax combi is not available in the market as well.

In farming system where 2.4-D is regularly used, the grass species are more dominant and completely challenging as compared with other weed types.

2.7.1. Agronomic practice

Under the normal growth conditions of sugarcane production, cultural weed management is a vital method to control weed growth and wellbeing of the crop. Appropriate land preparation, planting method, inter and intra-row spacing, irrigation and fertilizer application can provide favorable conditions for the cane to grow vigorously and suppress the weeds.

In wide spaced crops like sugarcane which show very slow growth in the beginning, growing of suitable intercrop not only will reduce weed population but also produce additional yield (Singh *et al.,* 2005). Hence, intercropping of some competitive and short duration crops in intensive cropping systems are effective in minimizing weed infestation. Intercropping of lowland rice in sugarcane based cropping systems can effectively check Cyperus rotundus. Cultivation of two or more early and late maturing crops simultaneously on the same land is an important practice for efficient use of environmental resources and crop production (Eskandari and Ghanbari, 2010; Malezieux *et al.*, 2009).

Transplanting/replanting, the practice that is exercised to grow healthy seedlings in a well prepared farmland after 90% of the weed seeds are germinated rather than planting of setts/cuttings directly and/or replace the non-germinated setts or gaps caused due to different factors is also another important cultural practice. According Yirefu *et al.*, (2013), the practice of gap filling or transplanting, having a significant effect on weed management via reducing the frequency and dominance of weeds is undertaken in sugarcane plantations of Ethiopia.

Crop rotation, a system of raising crops in a regular order one after the other on the same piece of land, is an effective tool of pest, disease and weeds management. If the practice of crop rotation is not frequently done in a particular field of sugarcane, production and productivity of the crop will be declined due to not only weeds infestation but also insufficient nutrients caused by repetitive cultivation of the same crop in a given area. Schaub *et al.* (2006) argue that cultural methods are useful but are expensive, labor and time consuming control methods. Therefore, chemical weed control is an important, effective and efficient alternative (Schaub *et al.*, 2006).

2.7.2. Mechanical control

Hand weeding, the oldest weed management practice which is carried out manually by using hand or hand hoes is the main weed control measure on small-scale sugarcane growing farmers (Vissoh *et al.*, 2004). Similarly, Chikoye *et al.*, 2007) reported that smallholder farmers spend 50-70% of their total labor and time on hand weeding. Besides, Women labor contributes more than 90% of the hand weeding for most crops (Gianessi., 2009.) and 69% of farm children between 5-14 years of age are forced to leave school and are engaged in the agricultural sector especially at critical period of weeding in the rural areas (Ishaya *et al.*, 2008).

2.7.3. Chemical control

Widely spaced crop of sugarcane allows wide range of weed flora to grow abundantly in the interspaces between the successive plants. Frequent irrigations and fertilizer application during early growth stages also increase weeds risk by many folds in the crop (Singh *et al.*, 2008). Hence, chemical control of weeds has been suggested to be economical in sugarcane plantations in developing countries including Ethiopia (Chauhan *et al.*, 1994).

Chemicals or herbicides are synthetic compounds that are used to kill or suppress unwanted vegetation including weeds. The potential use of herbicides would cause delay in weed growth or check its growth during the cropping season (Gianessi.,2013). In African countries such as Ethiopia, application of synthetic chemicals is considered as the most effective and time efficient method of weed management. Besides, herbicides are much more affordable than that of hand weeding as compared to the need of labor and its cost. Hence, herbicides have great potential in solving sugarcane production and productivity loss caused by weeds (Schaub *et al.*,2006). Herbicides can be applied before and after planting of sugarcane. The chemicals can be applied to the bare field before planting for residual control of germinating weed seeds or they can be directly sprayed to the existing weeds during the growing season (Overfield *et al.*, 2001).

2.7.4. Integrated weed management (IWM)

For perennial and semi-perennial crops such as sugarcane, a single weed control method is not adequate to a desirable yield loss minimization caused by weed competition for resources, screening allelochemicals and acting as host of pathogens. Thus, integrated weed management system which combines the indigenous knowledge of weed control measures and scientific once (i.e. physical, mechanical, cultural and chemical) in a coordinated manner is considered to be the most effective and economical approach to control the weeds in sugarcane fields (Peter *et al.*, 2011).

Integrated weed management practice (i.e. a combination of pre and post-emergence herbicide application, cultivation, biological control, hand weeding and other weed control practices) are commonly involved in the Ethiopia sugarcane plantations (Yirefu *et al.,* 2012; Ali *et al.,* 2018). Aiming to reduce weed population and interference with sugarcane while boosting the crop yield. As Takim and Suleiman., (2017), pointed it out an average of three to four times of hand weeding is recommended for sugarcane plantation in Ethiopia.

CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of the study area

The experiment was conducted at Wolkayit Sugar Development Project field during the 2019/20 growing season (figure 1). Geographically the site is found in the Tekeze river basin in Wolkayit woreda western zone of Tigray, northern Ethiopia that is bordered by Kafta Humera in the west, Tsegede in the South, Tahtay Adyabo and Asgede Tsimbla in the North and Tselemti in the east. The study area is situated 1,300 km north of Addis Ababa, the capital city of Ethiopia and about 420 km from Mekelle, the capital city of Tigray region in the Western Zone of Tigray regional State. Its western and eastern boundaries are geographically located 37^{o}26''31" E and 37^{o}42'36" E longitudes, respectively, and its northern and southern boundaries are located with 13^{o}39'34" N and 14^{o}00'59" N latitudes, respectively. According to the study done by TWWSDSE. (2006), the elevation of the experimental site is about 877- 2353 meters above sea level. The site is located in the northern semi-arid tropical belt of Ethiopia under "kola" agro ecological climatic zone. In the study area, low land crops such as sorghum (*Sorghum bicolor*), Sesame (*Sesamum indicum*), maize (*Zea mays*), and finger millet (*Eleusine coracana*) are the major crops, which are dominantly cultivated and grown every year. While sugarcane is a newly introduced commercial crop of the study area. Some tropical fruit crops like banana (*Musa spps*.), mango (*Mangifera indica*), avocado (*Persea american*a) and papaya (*Carica papaya*), unpublished report WSDP, (2009) are also grown in the study area. The agro ecology of the area is hot to warm semi- arid low land plains. It is characterized by hot temperature, unpredictable rainfall, immense area of plain low lands suitable for large scale and subsistence agriculture including crop production and livestock rearing. The rain season is mono modal concentrated from July to September and the mean annual rainfall ranges from 900 mm to 1800 mm. The average minimum and maximum temperature of the study area is 28 °C & 41°C respectively. The soil type of the area is classified as black soil or clay soil (WWPFO, 2015) with a PH of 7.5-8.3.

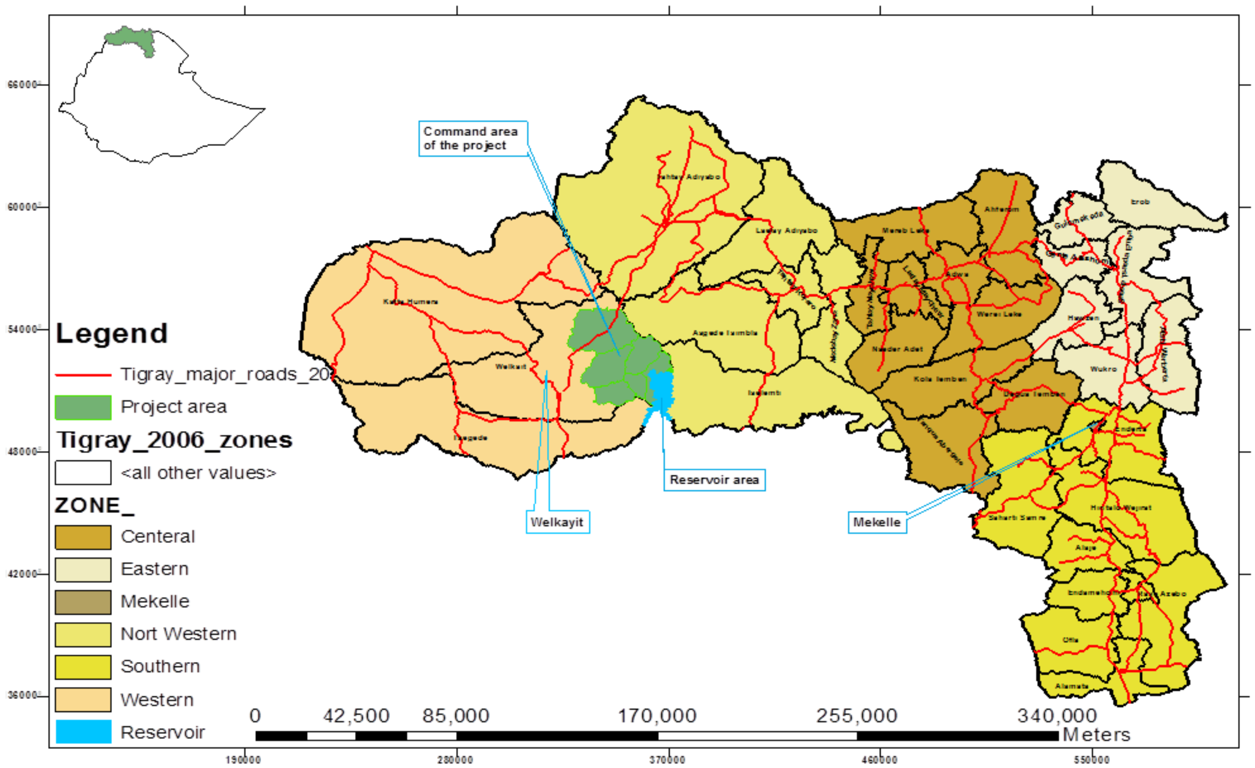

Figure 1: Map of Tigray regional state and the study area

The experimental area is categorized under the Kola (warm lowland) zone categorization. Based on the data found from a Metrological station in the project area, the mean minimum and maximum air temperature is 19.94°C and 36°C respectively. The mean annual rainfall is ranging from 900–1800 mm. The relative humidity (RH) increases from May to October following the rainfall pattern, with maximum of 84.19% in August and drops in March to 36.42%, with annual average of 51.53%. The mean minimum Relative humidity ranges from 25.13 % to 66.67%. The monthly wind speed ranges from 1.33 m/s to 3 m/s; whereas the mean monthly wind speed is 2.01 m/s. The mean monthly sunshine hour ranges from 5.1 to 9.8 hours in a day. (Ethiopian Meteorological Agency, Station of WSDP, 2018).

3.2. Experimental Design and Field Layout

The experiment was laid out in randomized complete block design (RCBD) in a factorial arrangement and replicated three times. The treatments comprised two practices of sugarcane planting types (sett planting and seedling transplanting) and five levels of spacing: 5, 10, 20, 30 and 40 cm). The experiment consisted of ten treatments and randomly assigned to each plot once in a block. Individual plot size was measured $5m \times 5m = 25m^2$. The distance between blocks and plots was 3m and 2m respectively. The total experimental area was $21m * 68m = 1{,}428m^2$. In every experimental plot, there were five rows and the three middle rows were used for data collection, leaving the two border rows as border effect. The planting material (var. B52/298) used in this experiment was obtained from Wolkayit sugarcane development project nursery site. The experiment was conducted during the 2019 and 2020 cropping season in the rainy season and supplementary irrigation was used during the off-season.

Table 2: Description of treatment combinations

Sett planting		Seedling transplanting	
Treatments	Description	Treatments	Description
T1	5 cm	T6	5 cm
T2	10 cm	T7	10 cm
T3	20 cm (WWF-India 2018)	T8	20 cm
T4	30 cm	T9	30 cm
T5	40 cm	T10	40 cm

NB: According WWF- India 2018, the recommended intra-row spacing is 20 cm.

3.3. Experimental procedure and crop management

The experimental field was thoroughly cleared and ploughed to an optimum depth of 30-50 cm using tractor and plots were levelled manually. Having done that, all land preparation methods (ridges and furrows), vital for moisture conservation were well prepared.

Sett planting and transplanting was done on May 06, 2019 at Wolkayit sugarcane project. B52/298 **S**ugarcane variety (i.e. High yielding variety) was used as a planting material. Both sugarcane planting materials, setts and seedlings were planted at a depth of 10 cm in the soil at different intra-row spacing (5, 10, 20, 30 and 40 cm) and 1m inter row spacing. There were five rows in each plot with row length of 5 m. Of these, the three middle rows were harvestable rows while the two other rows were considered as border effect and data were not collected from the two outer rows to avoid rim effect.

All agronomic management practices recommended for sugarcane production such as seedbed preparation, irrigation, fertilizer application, insect pest and disease control except spacing and planting types were uniformly applied for all treatments. Both DAP and Urea fertilizers were used as source of mineral nutrients at a rate of double full dose (200kg/ha) in which DAP fertilizer was incorporated at planting time while Urea fertilizer was applied in split method starting from 90 days after planting two times at an interval of 60 days. Sugarcane, being as a semi perennial crop, the experiment was carried out under both rain fed and off-season. Hence, sprinkler irrigation system was used to supplement the field with irrigation water at a time of rainfall cessation.

3.4. Data collection

Weed assessment was done before planting at 5-10 km interval, in which a quadrat was randomly thrown along bisects in each field, and the weed types and amounts in a quadrat were recorded and identified according to the methodology (Thomas., 1985; Kevine McCully *et al*., 1991). Then, weed data was recorded six times starting 45 days after planting once a month.

Crop data, growth and yield parameters were collected from 10 randomly selected plants of the harvestable rows of each plot.

Sprout emergence percentage, Tiller number, cane height, Number of millable canes, cane diameter, number of internodes, cane weight and total fresh cane yield were calculated from 10 randomly sampled plants. The canes were randomly selected from the three inner rows of each plot.

Fresh millable cane height was determined by measuring the height of canes from the ground to top visible dewlap leaf. Fresh millable cane weight was also determined using weighing balance while Cane diameter was determined by measuring diameters at the bottom, middle and top part of the cane using venire caliper and taking an average diameter. Number of internodes was determined by counting from each sample canes and then the mean was calculated. Cane yield was determined from the net plot area by weighing all the canes using a weighing balance, get a single cane weight and multiplying the single cane weight by the total number of fresh millable canes then converting to tons per hectare.

3.4.1. Data on crop growth, development and yield attributes of sugarcane

Sprout emergence percentage (%):-data on sprout emergence percentage of sugarcane bud was made 30-45 days after of planting from three harvestable rows of each plot in the treatments. Sprout emergence percentage (%) was calculated from the ratio of the number of two-budded setts emerged to the numbers of two budded planted and multiplied by 100 as described by (Ftwi *et al.*, 2018; Rajput *et al.*, 2019).

$$\text{Sprout emergence (\%)} = \frac{\text{Number of emerged buds}}{\text{Total number of buds}} \times 100 \ldots\ldots \text{(Equation 1)}$$

Tiller count: - starting from 120 -180 days after planting, data on number of tillers per plant was taken once a month from each randomly selected ten plants of harvestable interior rows in each experimental plots and average tiller number per plant was calculated for each plots in each treatments.

Cane height (cm): was measured with measuring tape (meter) at 90% physiological maturity of sugarcane from the ground level to the top of ten randomly selected plants from each harvestable row in each plot and the mean was recorded from the plot.

Cane diameter or plant girth (mm): The cane diameter or plant girth was measured using an instrument called caliper in millimeters from top, middle and the bottom of the 10 randomly sampled canes and then the average girth per cane was taken as described by Ftwi *et al.* (2018).

Crop stand count (number of fresh millable canes ha^{-1}): the plants from the net plot area were counted from the three middle rows of each plot at a time of crop harvesting to determine the change in stand count and converted to hectare basis (ha $^{-1}$) Ftwi *et al*. (2018).

Cane fresh weight (kg): From each treatment, a sample of 10 fresh millable canes were taken randomly at harvest. The canes were weighted using weighing balance and determined in kilograms after removing the tops and trash leaves. Then, average single cane weight was determined in kg/cane.

Cane yield (tha^{-1}): - the total fresh cane yield, t/ha was determined by multiplying the average single cane weight with total number of fresh millable canes recorded per hectare basis^{-} and changed to fresh cane yield in tons per hectare as described by Teklewerk (2014).

Cane Yield (t/ha) = (Average cane weight (kg) x Number of millable canes per hectare / 1000.

3.4.2. Weed data collection

Data on weed density, weed dry-weight, weed frequency and weed dominance were monthly collected starting from 60 days after planting six times.

Weed species composition: Using the formula described by Taye & Yohannes. (1998), weed density, weed frequency and dominance issues were analysed, by Dominance (D) and Frequency (F) determinations.

Weed density: weed density was determined using 0.5 m X 0.5 m, 0.25m^2 self-made quadrat via randomly placing once on a plot every month. From the entire quadrate placed in the plot, weed species were identified, counted and pulled out.

Sun dried weed dry weight: To determine the dry mater (sun dried weight) accumulation of the weeds at each weeding time, the above ground portion of the weeds collected from the quadrate placed in the net plot were cut, Sun dried for a week and weighed using a sensitive balance.

Frequency: is the percentage of sampling plots or vegetation registrations at which a particular weed species is found. It describes how often a particular weed species occurs in the survey area. Frequency is calculated for all weed species as follows under.

Frequency (F) = y/z*100, where y=number of individual quadrats with a particular species and z=total number of quadrats used

Abundance (A) = x/y, where x=total number of individual weed species and y=number of individual quadrats with a particular species.

Dominance: It is the infestation level of an individual weed species in relation to the total weed abundance.

Dominance (%): =A/∑A x 100... (3) Where; A = abundance, D= dominance and ∑A=total abundance of all weed species.

3.5. Statistical Data analysis

All the measured crop parameters and weed data recorded were subjected to Analysis of variance (ANOVA) following statistical procedures described by Gomez and Gomez (1984) to normalize the data to analysis with the help of Genstat software package version 18, appropriate to factorial experiment in RCBD using 18th edition Genstat software package and interpretation was done accordingly. Least significant difference (LSD) was used to separate the means at 5% level of significance.

Interaction effect of planting method and intra-row spacing was analyzed to evaluate their relationship on crop growth and yield parameters.

4. CHAPTER FOUR: RESULT AND DISCUSSION

4.1. Yield and yield attributes of sugarcane

4.1.1. Main and Interaction effect of planting types and intra-row spacing on sugarcane sprout emergence percentage

There was a significant ($P < 0.05$) difference in sprout emergence percentage among treatments (Table 3). The highest sprout emergence percentage (93.04%) was recorded from the treatment sett planting with 10 cm intra-row spacing followed by 5 cm sett planting (92.47%) and sett planted with 20 cm (91.56%). Contrarily, the lowest sprout emergence percentage (87.03%) was obtained from the treatment with wider intra-row spacing of 40 cm sett planting. Intra-row spacing and planting types are the key determinant factors that significantly affected sugarcane seedling vigorousity and the ability of the crop plant to suppress weeds due to their competition for limited resources (Kebede, 2015; Tabot, 2015). It has been reported that transplanting seedlings often results in more uniform development, resulting in better initial growth of sugarcane may be due to reduced planting shock and better soil-seed contact (Ghanem *et al.,* 2020). Similar interactive effects have been reported with regard to spacing and planting types for maize, whereby an optimum combination maximizes crop establishment and yield potential.

The present investigations may give hints for sugarcane growers about transplanting and use narrower intra-row spacing in order to achieve higher yield and production of sugarcane. This information is important in ensuring sustainable and long-term sugarcane production with the use of least amount of resources.

Table 3 Interaction effect of Planting types and intra-row spacing on sugarcane sprout emergence percentage

Spacing	Planting method		Mean
	Seedling transplanted	Sett planting	
5 cm	95.7ab	92.4cd	94.05
10 cm	96.2a	93.04cd	94.62
20 cm	95.3ab	91.5d	93.4
30 cm	94.02bc	88.4e	91.21
40 cm	94.4abc	87.03e	90.72
Mean	95.12	90.5	92.81
P-value		0.025	
LSD (0.05)		1.99	
CV (%)		1.3	

LSD= Least Significant Difference at 5% level of Significance, CV=Confident of variance in percent, means in column and followed by the same letters are not significantly different at 5% level of significant.

4.1.2. Main and Interaction effect of planting types and intra-row spacing on sugarcane tiller number per plant

Result from the Analysis of variance revealed that, the main effect of intra-row spacing had highly significant ($p<0.001$) effect on tiller number per plant while the main effect of planting type and the interaction not significantly ($p > 0.05$) affected number of tillers per plant (Table 4).

The highest tiller number per plant (12.37) was recorded on plots with sett planted and spaced with 10 cm intra-row space apart followed by seedlings transplanted with 5 cm intra-row spacing (11.477) and sett planted at 10 cm intra-row spacing (10.927) respectively. While the lowest tiller number per plant (7.167) was obtained from the treatment of sett planting with 40 cm apart between plants followed by 40 cm apart transplanted seedling (7.360) (Table 4). The variation in number of tillers per plant might be mainly due to the main effect of intra-row spacing within plants.

In line with these findings, it has been reported that planting types directly affects tiller initiation and development of rice and direct seeding often stimulates greater tillering compared to transplanting (Li *et al.*, 2021). This is due to reduced disturbance to the root system and earlier establishment in the soil. Moreover, the effect of intra-row spacing on tiller numbers was pronounced, with narrower spacing intervals (5 cm and 10 cm) generally promoting higher tiller counts (Table 4). The findings emphasis to the complex interaction between planting types and intra-row spacing on tiller numbers of sugarcane cultivation, offering actionable insights for agronomic management aimed at enhancing crop performance and profitability.

Table 4: Interaction effect of planting type and intra-row spacing on sugarcane tiller number/plant

	Planting type		
Spacing	Seedling transplanting	Sett planting	Mean
5 cm	11.477[ab]	9.640[bc]	10.56
10 cm	10.927[ab]	12.370[a]	11.65
20 cm	7.930[cd]	8.493[cd]	8.21
30 cm	7.710[cd]	8.343[cd]	8.03
40 cm	7.360[cd]	7.167[d]	7.27
Mean	9.08	9.20	9.14
P- value	0.257		
LSD (0.05)	2.158		
CV (%)	13.8		

SD= Least Significant Difference at 5% level of Significance, CV=Confident of variance in percent, means in column and followed by the same letters are not significantly different at 5% level of significant.

4.1.3. Main and interaction effect of planting type and intra-row spacing on sugarcane number of internodes

Analysis of variance revealed that the main and interaction effect of planting type and intra-row spacing had highly significant ($p < 0.001$) effect on number of internodes per plant (Table 5).

The highest number of internodes per plant (22.00) was recorded on plots with transplanted at a distance of 5 cm within plants followed by 10 cm apart transplant (21.00). The lowest number of internodes per plant (16.33) was obtained from the treatment of sett planting with 30 cm apart between plants (Table 5). This could be the reason that the narrower spacing plants compute for light and would have longer height that could counted highest internode numbers.

Higher internode numbers in the case of transplanting agreed with the findings from many studies indicated that transplanting is associated with increased development of the root system and early vigor, hence more extensive internodes' growth in sugarcane plants (Rodrigues *et al.*, 2018). The variation in the number of internodes at different levels of intra-row spacing pointed out the need for proper spacing. The closer intra-row spacing tends to enhance tillering and intermodal elongation of the sugarcane for better yield attributes of the crop (Lobo *et al.*, 2019). This might be due to lesser weed infestations observed from the narrower intra row spacing that enabled the crop exploit the available growth resources with less computation with weeds (Singh *et al.*, 2020).

Table 5: Interaction effect of Planting type and intra-row spacing on number of internodes

	Planting type		
Spacing	Seedling transplanting	Sett planting	Mean
5 cm	22.00[a]	18.33[cde]	20.17
10 cm	21.00[ab]	20.00[abc]	20.50
20 cm	17.33[de]	18.33[cde]	17.83
30 cm	19.67[bc]	16.33[e]	18.00
40 cm	20.33[abc]	18.67[cd]	19.50
Mean	20.07	18.33	19.20
P- value		0.019	
LSD (0.05)		2.016	
CV (%)		6.1	

LSD= Least Significant Difference at 5% level of Significance, CV=Confident of variance in percent, means in column and followed by the same letters are not significantly different at 5% level of significant

Table 6: Main effect of planting types and intra-row spacing on sugarcane growth parameters

Spacing (cm)	Ger.%	TN	NIPP
5	94.1[a]	10.55[a]	20.17[a]
10	94.6[a]	11.64[a]	20.5[a]
20	93.4[a]	8.21[b]	17.83[a]
30	91.2[b]	8.02[b]	18[b]
40	90.7[b]	7.26[b]	19.5[a]
LSD	1.41	1.52	1.42
Sett planting	90.5	9.2	18.33
Seedling transplanting	95.2	9.28	20.07
LSD	0.42	0.96	0.902

Keys of abbreviation: Ger.%= germination percentage in percent, TN= number of tiller per plant, NIPP= number of internode per plant, LSD=list significant difference at 5% level of significant.

4.1.4. Effect of planting type and intra-row spacing on sugarcane cane height (cm)

The result revealed that the main effect of planting type and intra row spacing had a highly significant ($P < 0.001$ & 0.05) effect on plant height. However, their interaction effect was not significant (Table 7). The highest mean plant height (182.3 cm) and (180.7 cm) were obtained from plots spaced at 20 & 5 cm, and transplanted respectively followed by a treatment transplanted with 10 cm intra-row spacing (175.7cm) and 40 cm apart-transplanted (173.3cm) (Table 7).

On the other hand, the lowest mean plant height (160.7) was recorded from the setts planted with 30 cm apart between plants followed by a treatment with setts planted at 40 cm apart spaced within plants (161.7cm. Cane height was higher in treatments with transplanted canes than that of treatments with direct sett planting at different spacing.

The results showed that cane height was higher in treatments with transplanted canes than that of treatments with direct sett planting at different spacing. Besides, increasing in intra-row spacing from 20 cm to 30 cm and 40 cm led to a significant decrease in cane height (Table 7), The variation in mean cane height among the treatments might be mainly due to the competition between the weed species and the sugarcane grown in wider intra-row spacing for growth elements (Singh, 2021). In narrow intra-row spacing, the plant may suppress the weeds form competition. The finding is in line with Ayele and Tegene, (2014) who found significantly higher mean cane height from 5 cm intra-row spacing than that of the wider intra-row spacing and observed that mean cane height increased with a decrease in intra-row spacing and decreased with an increase in intra-row spacing. Fakkar *et al.* (2009) also reported that an increase in inra-row spacing resulted in reduced cane height while there was an increment in cane height from treatments adjusted in narrow intra-row spacing. This could be due to the longer, slender and thin stem sugarcane could have reduced its biomass weight.

Across all spacing levels (5 cm to 40 cm), transplanting consistently resulted in taller sugarcane canes compared to sett planting. This aligns with previous studies emphasizing the role of transplanting in promoting stronger initial growth and root establishment, which are crucial for achieving taller cane heights (Santos *et al.*, 2021).

The variation in cane heights across different spacing intervals highlights the importance of spacing management. Similar findings have been reported in studies on other crops, where specific planting types significantly affect plant height and subsequent yield potential (Ferreira *et al.*, 2020).

Table 7: Interaction effect of Planting types and intra-row spacing on sugarcane stalk height (cm).

Spacing	Planting type		Mean
	Seedling transplanting	Sett planting	
5 cm	180.7ab	165.3cd	173.0
10 cm	175.7abc	169.3bcd	172.5
20 cm	182.3a	167.3cd	174.8
30 cm	167.7cd	160.7d	164.2
40 cm	173.3abcd	161.7d	167.5
Mean	175.94	164.86	170.40
P- value		0.680	
LSD (0.05)		3.383	
CV (%)		0.8	

LSD= Least significant difference at 5% level of significance, CV=Confident of variance in percent, means in column and followed by the same letters are not significantly different at 5% level of significant

4.1.5. Effect of planting type and intra- row spacing on sugarcane cane diameter/cane

The result presented in (Table 8) indicated that sugarcane cane diameter was significantly (*P<0.001*) influenced by the main effect of intra-row spacing, but was not affected by the planting type. Among the treatments, the highest plant girth (258.0 mm and 257.8 mm) per plant was obtained from the treatments of 40 cm apart transplanted and sett planted plots respectively followed by treatments with 30 cm intra-row spacing of transplanted and sett planting respectively (Table 8) while the lowest cane diameter (208.1mm) was obtained from 5 cm sett planting followed by a treatment with an intra-row spacing of 5cm transplanted seedlings.

In the analysis of variance, treatment with 5 cm in sett planting had significantly lower cane diameter than the other treatments. The increment in cane diameter with an increase in intra-row spacing might be attributed to the availability of growth resources and lesser competition of essential nutrients, sunlight and water availability under wider intra-row spacing. Small diameter in closely spaced sugarcane might be due to reduced photosynthesis rate resulted from less light penetration and nutrients uptake (Ullah *et al.,*2016). Increasing spacing within plants was significantly associated with an increase in cane diameter (Shafai,2010; Yesuf.,2018), the maximum cane dimeter was recorded from 10 cm intra-row spacing than that of 5 cm plant to plant spacing (Alehegn *et al.,* 2021).

This tendency underlines the benefit of transplanting for strong cane development. This point emphasized by some studies that referred to transplanting as a technique to ensure good root establishment and nutrient uptake in the early stages of growth. With regard to this, variation in cane girth at different levels of spacing emphasizes the proper control of spacing. On the other hand, according to Verma *et al*. (2019), wider spacing may provide thick canes in sugarcane due to lesser competition among plants for light, nutrients, and other factors. In contrast, narrow spacing might enhance the competition, thus restricting cane diameter, but may increase overall crop density and yield per unit area.

The planting density and type will have effects on cane or stem characteristics of crops other than sugarcane. A good example of maize shows closer spacing often causes thin but taller plants, while wider spacing can result in thicker canes (stems) with shorter plants (Li *et al.*, 2020).

Table 8: Interaction effect of planting type and intra-row spacing on sugarcane cane diameter

Spacing	Planting type		Mean
	Seedling transplanting	Sett planting	
5 cm	211.5e	208.1f	209.8
10 cm	219.5d	218.6d	219.05
20 cm	241.4c	241.0c	241.2
30 cm	253.1b	252.6b	252.85
40 cm	258.0a	257.8a	257.9
Mean	236.7	235.62	236.16
P-value		0.607	
LSD (0.05)		3.383	
CV (%)		0.8	

LSD= Least significant difference at 5% level of significance, CV=Confident of variance in percent, means in column and followed by the same letters are not significantly different at 5% level of significant

4.1.6. Effect of planting type and intra-row spacing on sugarcane fresh millable canes.

Analysis of variance revealed that yield of millable canes was significantly ($p<0.001$) affected by the main effect of intra-row spacing. However, there was no a significant ($p>0.05$) effect of the main effect of planting type and the interaction of the two factors on yield of millable canes ton per hectare (Table 9).

The result for millable cane yield presented in (Table 9). Notably, the maximum yield of millable canes per hectare (137.8) and (137.4) were found under 10 cm intra-row spacing planted sett and transplanted canes, respectively, followed by 5 cm under sett planting (135.3) and a treatment that transplanted plants 5 cm apart (132.2). However, sett planting with 40 cm between plants (95.4) produced the least yield of millable cane, followed by seedling transplanting with 40 cm intra-row spacing (98.0). The yield of millable canes decreased with increasing intra-row spacing. Inadequate intra-row spacing and poor planting type may be the cause of the observed variation in the amount of millable canes tons per hectare. Similarly, it has reported that the key component of fresh cane yields, millable canes per unit area, is reduced when plant population density is low due to both suboptimal seeding density and improper intra-row spacing (Firehun, 2018).

Table 9: Interaction effect of Planting type and intra-row spacing on sugarcane fresh millable cane yield (000) ton/hectare

Spacing	Millable cane		Mean
	Seedling transplanting	Sett planting	
5 cm	132.2^{bc}	135.3^{ab}	133.75
10 cm	137.4^{a}	137.8^{a}	137.6
20 cm	130.4^{bc}	128.4^{c}	129.4
30 cm	107.6^{d}	106.7^{d}	107.15
40 cm	98.0^{e}	95.4^{e}	96.7
Mean	121.12	120.72	120.92
P- value	0.778		
LSD (0.05)	4.758		
CV (%)	2.3		

LSD= Least significant difference at 5% level of significance, CV=Confident of variance in percent, means in column and followed by the same letters are not significantly different at 5% level of significant

4.1.7. Effect planting type and intra-row spacing on sugarcane cane weight (kg) and total fresh cane yield (t/ha)

The analysis of variance showed that cane weight (kg) and total fresh cane yield ton per hectare were significantly ($p<0.001$) affected by the main effect of spacing. However, the main effect of planting type and the interaction effect had no significant ($p>0.05$) effect on cane weight & total cane yield ton per hectare (Table 1o).

The highest cane weight (1.857 kg/cane) was recorded from the plots treated with 30 cm plant intra-row spacing of transplanted cane followed by the same planting type with 40 cm spacing (1.83kg/cane). The lowest cane weight (1.573kg/cane) was obtained from the plots with 5 cm intra-row spacing of direct sett planting. The significant increment in cane weight with an increase in intra-row spacing could be related to better availability of growth resources, which promotes thickness of sugarcane cane. The current study is in line with the finding of Alehegn *et al*. (2021) who found that planting setts at an optimum spacing of 10 cm gap showed statistically higher cane weight compared with 5cm intra-spacing. Hence, the minimum significant cane weight was observed due to planting of setts at 5 cm intra-row spacing.

Of the treatments, direct sett planting with a 10-cm intra-row spacing and transplanted seedlings spaced at 10 cm apart produced the highest fresh cane yield ton per hectare (230.5 tha-1) (228.6 tha-1) (Table 1o). Compared to plants (173.4 tha-1) that received the same planting type but different in intra-row spacing, this value was noticeably higher from treatments of direct sett planning at a distance of 40 cm.

The plots that were treated with sugarcane sett planting under wider intra-row spacing of 40 cm, followed by transplanting a seedling at a distance of 40 cm (179.3), had the lowest mean cane yield (173.4 t/ha). The value derived from setts planted with 10 cm intra-row spacing (230.5 tha-1) was substantially higher than this (Table 1o). The best intra-row spacing and suitable planting type may be the cause of the significant differences between treatments. Azhar and associates (2007) found that inefficient use of land space caused by suboptimal plant density and improper planting type results in yield loss.

Simultaneously, it has been highlighting how transplanting helps to promote early establishment, root development, and general plant vigor all of which are essential for optimizing potential yield (Santos *et al.*, 2021). Additionally, closer spacing frequently results in denser plant populations, which may improve competition for resources with weeds and increase yield per unit area (Verma *et al*., 2019). On the other hand, greater spacing may limit the number of plants per hectare and lessen the crop's ability to compete for resources, while weeds may grow stronger and use more resources than the intended crop, affecting sugarcane yield overall. Certain combinations of planting types and spacing configurations can have a significant impact on yield components such as tiller number, cane weight and ultimately total fresh cane yield, according to studies on other crops that have documented similar interactive effects (Ferreira et al., 2020).

Profitability is increased by implementing the optimum intra-row spacing of 10cm intervals, which improves sugarcane yield and resource use efficiency.

Table 10: Interaction effect of Planting type and intra-row spacing on cane weight (kg/cane) and total fresh cane yield ton/hectare

Spacing	Cane weight		Fresh cane yield (t/ha)	
	Seedling transplanting	Sett planting	Seedling transplanting	Sett planting
5 cm	1.627^{de}	1.573^{e}	215.1^{bc}	212.8^{c}
10 cm	1.663^{cd}	1.673^{cd}	228.6^{ab}	230.5^{a}
20 cm	1.730^{bc}	1.727^{bc}	225.6^{abc}	221.8^{abc}
30 cm	1.857^{a}	1.790^{ab}	199.8^{d}	191.0^{de}
40 cm	1.830^{a}	1.817^{a}	179.3^{ef}	173.4^{f}
Mean	1.7414	1.716	209.68	206.9
P- value	0.494			
LSD (0.05)	0.07391		12.67	
CV (%)	2.5		3.6	

LSD= Least significant difference at 5% level of significance, CV=Confident of variance in percent, means in column and followed by the same letters are not significantly different at 5% level of significant

Table 11: Main effect of planting types and intra-row spacing on sugarcane yield parameters

Spacing (cm)	NMC	CH	CD	CW	TCY
5	133.7^{b}	173^{ab}	209.8^{e}	1.6^{d}	213.9^{b}
10	137.6^{a}	172.5^{ab}	209.8^{e}	1.67^{c}	229.9^{a}
20	129.4^{c}	174.8^{a}	241.2^{c}	1.72^{b}	215.9^{b}
30	107.1^{d}	164.2^{b}	252.9^{b}	1.82^{a}	195.4^{c}
40	96.7^{e}	167.5^{ab}	257.9^{a}	1.82^{a}	176.3
LSD	3.36	8.32	2.392	0.052	8.96
Sett planting	120.7	164.9	235.63	1.71	231.9
Seedling transplanting	121.1	175.9	236.71	1.74	209.7
LSD	2.12	5.26	1.513	0.033	5.67

Keys of abbreviation: NMC = number of millable cane ton per hectare, CH= cane height, CD=cane diameter, CW=cane weight, TCY= total cane yield ton per hectare, LSD=list significant difference at 5% level of significant.

4.2. Major Weed Species Recorded in the Experimental Site.

The most frequent and problematic weed species that have been recorded in the experimental filed of the plantation were, *Xanthium strumarium* (W1), *Cassia mimosides* (W2), *Commelina benghalensis* (W3), *Nicandra physalodes* (W4), *Rumex napalensis* (W5), *Clemon monophylla* (W6), *Convolvulus arvensis* (W7), *Eriochloa fatmensis* (W8), *Oxalis latifolia* (W9), *Corchorus trilocularis* (W10), *Digitaria ternata* (W11), *Spilanthes mauritania* (W12), *Sorghum halepense* (W13), *Orobanche ramosa* (W14), *Striga hermentica* L (15) and *Corrigiola capensis* (W16)

4.2.1. Effect of planting types, intra-row spacing and their interaction on weed density and sun dried weed dry weight

The result revealed that the main and interaction effect of planting types and intra row spacing a highly significant ($P < 0.001$) effect on weed density, weed dry-weight, weed frequency and dominance (Table 12, 13 and 14). Planting types (sett Planting (SP) and transplanting (ST), and intra-row spacing (5, 10, 20, 30, and 40 cm) significantly changed weed density and the total dry weight of weeds in sugarcane production (Table 13).

4.2.2. Weed density

The least density of weeds has been observed with the narrow intra- row spacing of (5 cm) for both sett planting (5.75m^{-2}) and transplanting (3.93m^{-2}). Higher weed densities were found with the wider intra-row spacing of 40 cm for both sett planting (17.6m^{-2}) and transplanting (14.47m^{-2}) (Table 12). Narrower intra-row spacing significantly reduced weed densities. This might be due to sugarcane close to each other compete for light, water, and nutrient which could suppress weeds to germinate and grow (Zafar *et al.*, 2010). Because sugarcane plant height is very longer and its shade may suppress weeds (Firehun *et al*., 2012). Similar result has been reported in crops such as corn and sorghum with narrow intra-rows spacing (Chauhan and Mahajan., 2022).

At wider intra-row spacing (20-40 cm), there was a notable increase in weed density indicating wider intra-row spacing facilitated higher weed infestations. The highest weed density was recorded at 40 cm spacing for both planting methods. This can be attributed to reduced competitive pressure from the crop (Tadele *et al.,* 2022). In such conditions, weeds exploit the available resources more aggressively than sugarcane plant (Singh *et al*., 2021). This is due to the availability of more space and light that favors growth of weeds. This underscores the need for effective weed management strategies at wider spacing and as strategy to prevent significant yield losses due to weeds.

4.2.3. Sun dried Weed weight

Sun dried weed weight was significantly affected by the main and interaction effect of intra-row spacing and planting types (Table 12). The response of sun dried weed weight to intra-row spacing and planting types was complex. Despite the low weed density, sun dried weed weight was relatively high at 5cm intra-row spacing comparing with10 cm intra-row spacing. This suggests lesser in number, but more aggressive and competitive weed species might have infested. In line with this, Sharma and Mishra (2023); Abiy *et al.,* (2016) have demonstrated that, in dense crop stands, fewer but more competitive weeds can dominate.

Sett planting type and intra-row spacing (30 cm) had resulted in the lowest sun dried weed weight while transplanting type significantly increased sun dried weed weight. This disparity could be due to differences in canopy structure and light interception. Sett planting might provide more uniform canopy that shades out weeds more effectively and reduce their sun-dried weight (Martin *et al.,* 2013). On the other hand, transplanting might create microenvironments that favor weed growth (Singh *et al.*, 2023). Therefore, varying planting configurations can significantly influence light availability and weed growth dynamics (Jet *et al.*, 2022).

The highest sun dried weed weight was recorded at 30 cm spacing of sett planting followed by 40 cm intra-wow spacing of both sett planting and transplanting; indicating wider spacing not only increase weed density but also promote growth of more competitive weeds. This finding aligns with the work of Dille and Stoltenberg (2022) who reported that wider intra-row spacing inclines to support higher sun dried weed weight. This is due to reduced crop competition and contributed to increased crop growth resource availability.

To some up, this investigation highlighted the critical role of intra-row spacing and planting types in managing weed density and dry matter accumulation in sugarcane production. Narrower spacing with 10cm combined with sett planting types offer better in reducing sun dried weed weight. This may contribute to improve sugarcane growth and yield potential. Therefore, it is important to refine these strategies under varying environmental conditions with prior weed seed bank determination and exploring their impacts on other agricultural pest management.

Table 12: Interaction effect of plating types and intra row spacing of sugar cane on weed density and sun dried weed weight.

Spacing	Interaction effect			
	Weed density		Sun dried weed weight	
	Sett Planting	Seedling Transplanting	Sett planting	Seedling transplanting
5	5.75	3.93	6.33	6.87
10	9.33	6.2	5.56	5.5
20	11.13	9.47	6.03	13.83
30	14.6	13.13	3.73	10.26
40	17.6	14.47	6.65	11.85
$LSD_{0.05}$	1.036		3.02	
CV (%)	2.03		2.01	

Keys of abbreviation: WD= weed density, SDWW= sun dried weed weight, SP=sett planting, ST= Seedling transplanting, LSD= list significant difference at 5% level of significant and CV= coefficient of variance in percent.

4.2.4. Effect of intra-row spacing and planting types on sugarcane weed frequency

At the narrowest spacing (5 cm), there had been a noticeable difference in weed frequency between seedling transplanting and sett planting types (Table 13). The frequency of weed species; *Xanthium strumarium, Clemon monophylla, Orobanche ramose,* and *Striga hermentica* demonstrated a higher significant difference between transplanting and sett planting types (Table 13 and 14).

When comparing plots covered with sett planting to those planted with transplanting, a higher frequency of weeds of various types was noted. In sett planting, *Xanthium strumarium* and *Oxalis latifolia* were found in 33.3% and 46.7% at 10 cm respectively, but was reduced to 13.3% & 26.7% in plots covered with transplanting types. Particularly when using the sett planting types, weed frequency rises as spacing increases. Using sett planting types, higher weed frequencies were found for *Rumex napalensis* (93%), *Eriochloa fatmensis* (80%), *Orobanche ramus* (93%), *Xanthium strumarium* (46.7%), and *Clemon monophylla* (47%). *Rumex napalensis, Convolvulus arvensis* and *Orobanche ramosa* were among the weed species that demonstrated a higher frequency at wider spacing, particularly under the transplanting type, suggesting that these specific weed types may thrive more in less competitive environments. In contrast, *Xanthium strumarium* displayed a frequency of 46% in sett planting at 40cm spacing, compared to only 13.33% in transplanting. This might be because transplanted seedlings have an early competitive edge over weeds (Jha and Kumar, 2017), which enables them to outcompete weeds for vital resources like sunlight, water, and nutrients. According to Mahajan *et al*., (2015), the increased intra-row space also gives weeds more chances to establish and spread. Wider rows also result in less crop competition, which increases weed pressure (Murphy *et al*., 2015).

Compared to sett planting, weed frequency was significantly reduced in transplanting (Table 13). Sett planting types in wider intra-row spacing revealed a very significant increment in weed frequency for the majority of the studied weed species (Table 13). This shows that transplanting could be more effective in suppressing weed growth due to the initial establishment and potential competition advantage over weeds (Rawat *et al*., 2021). Besides, the influence of intra row spacing and planting types on weed frequency is a critical aspect of weed management in sugarcane production (Abiy *et al*., 2016; Rawat *et al*., 2021).

The result indicating that, narrow intra row spacing integrated with transplanting type can be effective strategies for reducing weed species frequencies in sugarcane production. In agreement with this, it has been reported that narrow intra row spacing and transplanting type in crop plants could be attributed to increase competition for light, moisture and nutrients, which eventually suppresses weed growth, density, frequency and seed production (Chauhan *et al*., 2017). These practices create a more competitive environment for weeds, thereby enhancing crop growth and yield. However, the specific impact on different weed types must be considered when designing weed management practices to ensure effective control mechanisms across diverse weed populations (Chauhan. 2020; Takim and Suleiman., 2017). It has been demonstrated that integrated use of narrower intra-row spacing and transplanting reduced weed frequencies and improved crop yields (Wang *et al*., 2015; Zhang *et al.*, 2021). Therefore, weed management strategies should consider both the type of weeds present and integrated transplanting method with narrower intra-row spacing.

Table 13: Interaction effect of intra-row spacing and planting types on weed frequency in sugarcane production

Spacing	PM	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16
5	TP	13.3	6.7	0.0	6.67	13.3	13.3	26.7	20.0	0.0	13.3	40	13.3	0.0	6.6	6.6	13.3
5	SP	16.7	6.7	0.0	20	33.3	33.3	46.7	33.3	0.0	33.3	40	13.3	0.0	6.6	0.0	6.7
10	TP	13.3	0.0	13.3	20	46.6	26.7	46.7	53	0.0	13.3	33.3	26.6	0.0	13.3	0.0	6.7
10	SP	33.33	0.0	13.3	20	61.6	46.7	60.0	53.3	13.3	20.0	40	20	0.0	13.3	6.6	6.7
20	TP	13.3	0.0	20.0	13.3	46.3	33.3	80.0	73.3	0.0	13.3	53.3	20	0.0	13.3	6.6	13.3
20	SP	46.7	6.7	33.3	20	53.5	60	73.3	80.0	20.0	46.7	60	26.6	6.6	33.3	13.3	20
30	TP	20.0	13.3	33.3	26	53.3	40	80.0	66.7	13.3	33.3	53.3	33.3	0.0	33.3	6.7	40
30	SP	46.7	13.3	26.7	33.3	66.7	46.6	80.0	73.3	33.3	40.0	60	40	26.6	40	13.3	26
40	TP	13.3	0.0	26.7	40	93.3	40	93.3	73.3	6.7	46.7	66.7	20	6.6	66.67	6.7	60
40	SP	46.0	6.7	33.3	30	80	47	66.7	73.3	33.3	46.6	73.3	20	40	93.33	33.3	33.3
LSD		11.33	10.27	12.61	14.61	15.14	15.17	11.78	14.5	11.5	12.2	7	10.8	12.75	14	12.56	14
$CV_{0.05}$		8	10	7	19	15.9	16.4	17.4	18.7	20.6	16.1	10.4	22.5	16.5	23.8	32.5	29

Keys for abbreviations :LSD= least significant difference, SP= sett planting, ST= seedling transplanting, CV= coefficient of variance, *Xanthium strumarium (W1), Cassia mimosides (W2), Commelina benghalensis (W3), Nicandra physalodes (W4), Rumex napalensis (W5), Clemon monophylla (W6), Convolvulus arvensis (W7), Eriochloa fatmensis (W8), Oxalis latifolia (W9), Corchorus trilocularis (W10), Digitaria ternata (W11), Spilanthes Mauritania (W12), Sorghum halepense (W13), Orobanche ramosa (W14), Striga hermentica L (W15) and Corrigiola capensis (W16),*means with different letters have significant difference while means with no and same letter are none significant.

Table 14: Main effect of intra-row spacing and planting types on weed frequency on sugarcane production

Code	weed species	Intra-row Spacing (cm)					LSD (0.05)	Planting types			
		5	10	20	30	40		SP	ST	CV	LSD (0.05)
W1	*Xanthium strumarium*	3.0	7.9	5	5	3.6	3.469	7.9	2.2	26	2.194
W2	*Cassia mimosides*	3.75	0.0	0.33	0.69	0.0	4.306	1.55	0.36	15	2.724
W3	*Commelina benghalensis*	0.0	2.3	1.7	2.88	4.3	3.008	2.87	1.63	22	1.903
W4	*Nicandra physalodes*	4.3	6.1	5.3	4.1	4.9	6.514	5.52	4.45	24	4.120
W5	*Rumex napalensis*	4.3	10.2	7.4	6.1	14.8	4.684	7.12	10.15	18	2.962
W6	*Clemon monophylla*	8.1	7.2	6.6	7.3	11.1	6.018	9.88	6.34	15	3.806
W7	*Convolvulus arvensis*	16	15	13	20	22.5	6.098	12.82	22.49	12	3.85
W8	*Eriochloa fatmensis*	9.6	12.5	14.5	12.8	12.4	9.18	11.3	13.5	13	5.81
W9	*Oxalis latifolia*	1.0	1.2	2	4.0	2.8	2.865	3.79	0.82	21	1.812
W10	*Corchorus trilocularis*	7.935	5.517	2.7	5.01	6.8	6.82	6.3	4.9	20	4.3
W11	*Digitaria ternata*	28	21	19	14	16.8	7.74	16.7	23.2	12	4.89
W12	*Spilanthes Mauritania*	4.8	4.7	2.9	1.6	1.6	1.8	2.47	3.89	19	1.14
W13	*Sorghum halepense*	0.0	0.0	0.0	0.6	1.07	0.61	0.627	0.053	29	0.39
W14	*Orobanche ramosa*	6.6	5.7	3.9	3.6	2.1	2.577	5.4	3.4	19	1.630
W15	*Striga hermentica L*	1.6	1	1.3	0.55	0.95	1.22	0.83	1.43	36	0.77
W16	*Corrigiola capensis*	5.3	4.1	3.2	2.3	1.4	4.576	1.99	4.63	21	2.894

Keys: LSD= least significant difference, SP= sett planting, ST= seedling transplanting, CV= coefficient of variance, *Xanthium strumarium (W1), Cassia mimosides (W2), Commelina benghalensis (W3), Nicandra physalodes (W4), Rumex napalensis (W5), Clemon monophylla (W6), Convolvulus arvensis (W7), Eriochloa fatmensis (W8), Oxalis latifolia (W9), Corchorus trilocularis (W10), Digitaria ternata (W11), Spilanthes Mauritania (W12), Sorghum halepense (W13), Orobanche ramosa (W14), Striga hermentica L (W15) and Corrigiola capensis (W16),*means with different letters have significant difference while means with no and same letter are none significant.

4.2.5. Effect of intra-row spacing and planting types on weed dominance on sugarcane production

The result revealed a considerable variation in weed dominance across different treatments (Table 15); highlighting the importance of optimal spacing and planting methods in managing weed infestations effectively.

At a spacing of 5 cm with the transplanting (ST) type, several weed species such as *Spilanthes mauritania* (W12), *Sorghum halepense* (W13) from 5 -30 cm at sett planting, and *Cassia mimosides* (W2) from 10 cm of sett planting to 40 cm transplanted were completely absent, indicating that the efficacy of this combination in suppressing weed growth and indicating its potential in minimizing certain weed specie. On the other hand, the same intra-row spacing with the sett planting (SP) type showed higher dominance for several weed species.

When optimizing the spacing to 10 cm, the transplanting type continued to perform well, particularly to manage for *Xanthium strumarium* (4.1), *Commelina benghalensis* (2.0), and *Digitaria ternata* (0.0). In addition, with the 5 cm intra row spacing and transplanting type, weeds growth was generally suppressed more effectively than the sett planting type. However, the dominance of *Rumex napalensis* (9.9) and *Eriochloa fatmensis* (12.3) put forward that wider spacing might increases the competitive ability of sugarcane against certain weeds.

A higher weed dominance was observed at 20cm spacing of both planting types compared to narrower spacing. A highly significant weed dominance for species such as *Rumex napalensis* (11.4) and *Eriochloa fatmensis* (16.4) at transplanting type and *Rumex napalensis* (3.5) and *Eriochloa fatmensis* (12.6) at sett planting type This indicates that as intra-row spacing increases, the effectiveness of both planting types in controlling weeds diminishes, likely due to increased space for weed growth.

Higher weed dominance for *Rumex napalensis* (7.4) and *Eriochloa fatmensis* (14.8), *Xanthium strumarium* (7.2) and *Eriochloa fatmensis* (10.9) was observed from plots spaced at 30 cm in sett planting and transplanted. Indicating wider intra row spacing initiates more weed species to germinate and compete with crops.

The sett planting type combined with an intra-row spacing of 40 cm was also showed a significant weed dominance for species such as *Commelina benghalensis* (14.29), *Sorghum halepense (*14.04), *Clemon monophylla* (12.34), *Striga hermentica L* (11.11), *Eriochloa fatmensis* (9.58) and *Corrigiola capensis* (8.10). High values, were also observed for a species *Oxalis latifolia* (8.33 & 6.95) using the transplanting and sett planting types respectively at 30 cm intra-row spacing. Interestingly, both approaches demonstrated a notable increase in weed dominance when compared to a narrower spacing, underscoring the difficulties in reducing weeds in wider intra-row combinations.

Across all spacing, the results showed that transplanting type performed better than the sett planting type in terms of weed suppression. The best weed control in sugarcane production might be achieved by combining the transplanting type with closer spacing, as the effectiveness of both approaches declined as intra-row spacing increased. The interplay between planting types and intra-row spacing is critical in weed control, and these results highlighted the necessity of integrated weed management strategies catered to particular planting type and intra-row spacing (Johnson *et al*., 1998; Rawat and associates, 2021).

Effective weed control in sugarcane production generally depends on choosing the right planting types and optimizing intra-row spacing. Its potential as a preferred practice for minimizing weed competition and boosting sugarcane growth was highlighted by the consistent lower weed dominance observed when transplanting at narrower spacing. Future studies should concentrate on improving these methods even more and investigating different integrated weed control techniques in order to maintain high sugarcane production and productivity.

The present results in line with findings reported by Amare *et al*., (2022); Singh *et al.,* (2023) who have reported that increased crop canopy cover due to narrow spacing reduces weed dominance by limiting weeds' access to light and nutrients. Additionally, transplanting may alter the way soils are disturbed, which could impacted weed seed emergence and germination (Banik *et al.,* 2021). These interactions imply that in order to maximize weed control and improve sugarcane yield, integrated intra-row spacing and planting types should take into account. In addition, to increase sugarcane yield, efficient weed control can reduce the need for herbicides and support sustainable farming methods (Kaur *et al*., 2022; Bassey and Wada, 2024). The combined application of transplanting type and optimal intra-row spacing as a weed management strategy may reduce reliance on herbicides, which will prevent the future emergence of herbicide-resistant weed populations (Loddo et al., 2019; Scavo and Mauromicale, 2020).

Table 15: Interaction effect of intra-row spacing and planting types on weed dominance in sugar cane production

Spacing	PM	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16
5	TP	1.58	2.7	0.0	1.06	0.99	1.02	2.30	1.56	0.0	1.52	1.97	2.54	0.0	1.19	4.94	2.35
5	SP	1.97	10.7	0.0	2.92	1.48	1.70	1.48	1.93	0.0	3.25	2.55	2.54	0.0	0.60	0.0	0.78
10	TP	1.57	0.0	1.29	1.59	2.34	1.53	2.01	2.23	0.0	1.22	4.53	3.81	0.0	5.37	0.0	0.78
10	SP	4.33	0.0	2.59	5.57	2.63	1.93	2.60	3.05	2.78	1.52	3.13	5.09	0.0	1.79	2.47	1.57
20	TP	0.79	0.0	1.94	3.71	2.79	1.81	2.24	2.45	0.0	1.83	2.94	2.54	0.0	4.77	7.41	3.14
20	SP	4.45	5.3	3.23	2.12	2.22	2.33	2.11	3.01	5.56	2.85	3.25	2.94	3.51	2.98	2.47	3.14
30	TP	2.17	2.7	1.94	3.18	2.79	2.22	4.53	4.20	8.33	2.74	2.67	4.24	0.0	1.19	2.47	4.18
30	SP	6.89	9.3	7..44	5.84	2.96	5.18	4.20	3.64	6.95	6.10	3.87	3.67	12.0	3.81	2.47	3.40
40	TP	2.36	0.0	1.97	3.27	5.81	3.24	4.50	4.98	2.78	6.60	3.91	3.39	3.51	7.26	2.47	5.88
40	SP	7.21	2.7	14.29	4.07	7.17	12.34	7.24	9.58	6.94	5.69	4.51	2.54	14.04	4.38	11.11	8.10
LSD		2.9	2.09	1.2	2.2	1.6	2.5	1.759	1.05	3.6	3.9	0.87	0.08	7.6	3.62	2.4	1.05
$CV_{0.05}$		11.1	7.6	6.3	5	14.7	16.2	6.9	5.7	5.2	13	8	8.7	5.8	9.7	6.1	5.7

Keys: LSD= least significant difference, PM= planting method, SP=sett planting, ST= seedling transplanting, CV= coefficient of variance, LSD= least significant difference, SP=stalk planting, TP= transplanting, CV= coefficient of variance, *Xanthium strumarium (W1), Cassia mimosides (W2), Commelina benghalensis (W3), Nicandra physalodes (W4), Rumex napalensis (W5), Clemon monophylla (W6), Convolvulus arvensis (W7), Eriochloa fatmensis (W8), Oxalis latifolia (W9), Corchorus trilocularis (W10), Digitaria ternata (W11), Spilanthes Mauritania (W12), Sorghum halepense (W13), Orobanche ramosa (W14), Striga hermentica L (W15) and Corrigiola capensis (W16)*,means with different letters have significant difference while means with no and same letter are none significant. Means with different letters have significant difference while means with no and same letter are none significant.

Table 16: Main effect of intra-row spacing and planting type on weed dominance on sugarcane production

Code	weed species	Intra-row Spacing (cm)						Planting types			
		5	10	20	30	40	LSD(0.05)	SP	TP	CV	LSD
W1	*Xanthium strumarium*	3	7.9	5.1	5.5	3.6	3.46	7.96	2.23	26	2.194
W2	*Cassia mimosides*	3.75	0.0	0.33	0.69	0.0	4.3	1.55	0.36	15	2.72
W3	*Commelina benghalensis*	0.0	2.3	1.7	2.8	4.3	3	2.87	1.6	22	1.9
W4	*Nicandra physalodes*	4.3	6.1	5.3	4.1	4.9	6.5	5.5	4.4	24	4.1
W5	*Rumex napalensis*	4.3	10.2	7.4	6.2	14.9	4.6	7.12	10.15	18	2.9
W6	*Clemon monophylla*	8.14	7.2	6.6	7.3	11.25	6.01	9.88	6.34	15	3.8
W7	*Convolvulus arvensis*	16.78	15	20	22.5	22.2	6.098	12.82	22.49	12	3.857
W8	*Eriochloa fatmensis*	9.64	12.52	14.55	12.89	12.42	9.18	11.3	13.5	13	5.81
W9	*Oxalis latifolia*	1.017	1.25	2.1	4.25	2.81	2.865	3.79	0.82	21	1.812
W10	*Corchorus trilocularis*	7.9	2.7	5.5	5.01	6.8	6.82	6.3	4.9	20	4.31
W11	*Digitaria ternate*	28.1	21.7	19.0	13.9	16.87	7.74	16.7	23.2	12	4.89
W12	*Spilanthes Mauritania*	4.8	4.7	1.6	2.9	1.6	3.82.4	2.47	3.89	19	1.14
W13	*Sorghum halepense*	0.0	0.0	0.0	0.6	1.07	0.61	0.62	0.053	29	0.39
W14	*Orobanche ramosa*	2.1	6.6	3.9	3.6	5.7	5.41	3.24	5.62	19	3.42
W15	*Striga hermentica L*	1.66	1.09	1.39	0.55	0.95	2.56	0.83	1.43	36	1.62
W16	*Corrigiola capensis*	4.15	1.42	2.39	3.2	5.3	4.57	1.99	4.63	21	2.894

Keys: LSD= least significant difference, SP=sett planting, ST=seedling transplanting, CV= coefficient of variance, means with different letters have significant difference while means with no and same letter are none significant

5. CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

- This research highlights the significant impact of planting types and intra-row spacing on weed dynamics and sugarcane production. Lower weed density, frequency and dominance resulted from narrower intra-row spacing of 5 cm whereas; higher cane yield was observed from 10cm. As intra-row spacing became wider, it favors weed infestation, and dry weight. This is due to reduced competitive pressure from the crop.
- Despite the low weed density at narrow intra-row spacing of 5cm, higher weed dry-weight was observed as compared to 10cm. This suggests presence of fewer but more competitive weed species. This indicates the effectiveness of 5 cm in reducing weed density and the preeminence of 10cm in producing higher total fresh cane yield.
- Optimizing intra-row spacing to 10cm and selecting appropriate planting types are critical for effective weed management in sugarcane production.
- The integrated use of intra-row spacing and planting types are effective agronomic weed management tactics to reduce the reliance on herbicides. This promotes sustainable and organic weed management practices, which minimizes negative impacts on the environment.
- The study found that sugarcane yield was significantly affected at narrower intra-row spacing (10cm) this might be due to reduced weed competition and better resource utilization by sugarcane plants.
- Over all, it is concluded that optimizing the integrated use of intra-row spacing and selecting appropriate planting types are crucial method to manage major weed species and improve sugarcane productivity.

5.2. RECOMMENDATIONS

- It is recommended that, farmers and sugarcane industries to apply an integrated weed management through the optimum intra-row spacing (10cm) to enhance sustainable sugarcane productivity and reduce weed competition and dominance.
- Provide training to farmers and investors on the benefits and implementation of the optimum intra-row spacing of 10cm and the appropriate planting type is suggested to increase awareness and knowledge will facilitate the adoption of these practices, leading to better weed management and higher crop productivity.
- Further research is also recommended in multi environments with prior determination of weed soil seed bank and weed competitive ability.

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APPENDICES TABLES

Appendix table 1: Field layout and randomization of the experiment

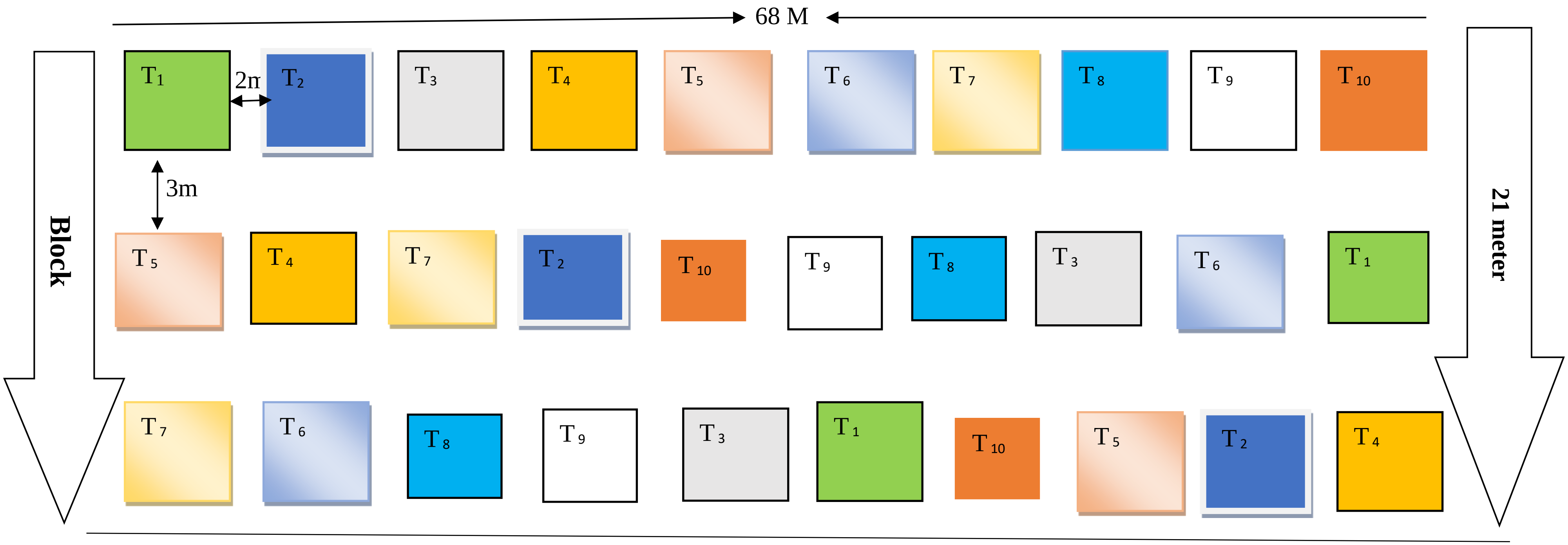


Table1: field lay out and randomization (the letters written in upper cases in the figure are treatments while the lower cases represented number of plot

Appendix table 2: Mean squares value of ANOVA for plant growth parameters of sugarcane as affected by planting method, intra-row spacing and weed infestation.

SV.	D.F	Mean squares		
		Ger.%	TN	NIPP
Replication	2		0.210^{ns}	0.900^{ns}
Spacing (S)	4		20.890**	9.033*
Planting method (P)	1		0.112^{ns}	22.533**
S*P	4		2.302^{ns}	5.367*
Error	18		1.582	1.381
Total	29			
L.S.D.			2.158	0.07391
CV (%)			13.8	2.5

SV= Sources of variation; DF = Degree of freedom; Germ % = Germination percentage; TN =Tiller number, NI=number of internodes per plant, CV = Coefficient of variation; * = Significance Difference at $p < 0.05$; ** = Significance Difference at $p < 0.01$; *** = Significance Difference at $p < 0.001$ and ns = not significant ($p>0.05$)

Appendix table 3: Mean square value of ANOVA for some yield parameters of sugarcane as affected by planting method, intra-row spacing and weed infestation.

SV.	D.F	Mean square				
		NMC	CH	SG	CW	TCYTPH
Replication	2	3.413^{ns}	50.80^{ns}	1.609^{ns}	0.004223^{ns}	136.55^{ns}
Spacing (S)	4	1936.569**	117.13^{ns}	2647.728**	0.057178**	2860.14***
Planting method (P)	1	1.154^{ns}	918.53**	8.673^{ns}	0.004813^{ns}	106.97^{ns}
Spacing & Planting	4	7.246^{ns}	27.37^{ns}	2.690^{ns}	0.001638^{ns}	24.03^{ns}
Error	18	7.693	47.06	3.889	0.001857	54.54
Total	29					
L.S.D.		4.758	11.77	3.383	0.07391	12.67
CV (%)		2.3	4.0	0.8	2.5	3.6

SV= Sources of variation; DF = Degree of freedom; NMC = number of millable canes per hectare; CH = Cane Height, SG=Stalk Girth/ cane diameter, CW= Cane Weight, TCYTPH =Total Cane yield $mtha^{-1}$, CV = Coefficient of variation; * =Significance Difference at $p < 0.05$; ** = Significance Difference at $p < 0.01$; *** = Significance Difference at $p < 0.001$ and ns = not significant ($p>0.05$).

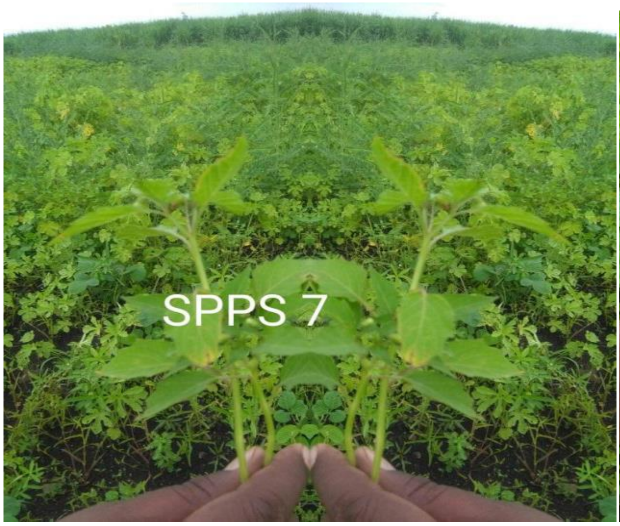
Appendix table 4: Mean square value of ANOVA for sugarcane weed density and dominance as affected by planting method and intra-row spacing.

SV.	D.F	Mean square	
		WB	WD
Replication	2	5.42^{ns}	1.1293^{ns}
Spacing (S)	4	12.8^{ns}	124.5**
Planting method (P)	1	170.8**	35.86**
S*P	4	11.99^{ns}	0.76^{ns}
Error	18	20.82	0.36
Total	29		
L.S.D.		5.07	5.7
CV (%)		5.42ns	1.12

SV= Sources of variation, DF= Degree of freedom; WF = Weed Frequency, WB= Weed Biomass, CV= Coefficient of variance, *=Significance Difference at $p < 0.05$; ** = Significance Difference at $p < 0.01$; *** = Significance Difference at $p < 0.001$ and ns = not significant ($p>0.05$)

APPENDIX FIGURES


SPPS 1
SPPS 2
SPPS 3
SPPS 4
SPPS 5
SPPS 6


SPPS 7

SPPS 8

SPPS 9

SPPS 10

SPPS 11

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