

**EFFECTIVENESS OF INTERCROPPING FINGER MILLET (*Eleusine
coracana*) VARIETIES WITH COMMON BEANS (*Phaseolus vulgaris*) ON
WEED MANAGEMENT AND YIELD IN TRANS - NZOIA COUNTY, KENYA**

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DECLARATION

Declaration by the student

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DEDICATION

I dedicate this document to my Father Joseph Mauka and loving Mother Rosemary Mauka who highly inspired me throughout the University period.

ABSTRACT

Weed infestation is considered as one of the most important constraints affecting finger millet production causing significant yield losses. Management of weeds is important for enhancing the productivity of finger millet. Recent research efforts suggested that intercropping legumes with cereals can have potential for weed suppression and may decrease the need to use herbicides. This study was aimed at evaluating the effectiveness of intercropping finger millet varieties with common bean on weed management and yield. Field experiments were conducted on-farm at Kiminini Sub-County in Trans-Nzoia County. The treatments were laid out in a Randomized Complete Block Design (RCBD) over two seasons (2020 short rains and 2021 long rains season). The three improved finger millet varieties (Gulu- E, U-15 and P-224) and common bean variety (Rosecoco) were used. Each finger millet variety was grown in monoculture and intercropped with beans. The treatments were replicated three times giving a total of 27 plots. The plots measured 1.8 m x 1.5 m each and a path of 0.5 m was used to separate one plot from the other. Parameters that were recorded during the growing season on weeds included; weed type, weed count and weed biomass while for finger millet included; plant height at physiological maturity/grain milk stage, panicle length, days to 50% flowering, number of tillers per plant, dry grain yield (kg/ha) and days to 50% physiological maturity. The parameters that were measured and recorded on beans included; plant height, leaf width, number of pods per plant; number of seeds per pod, dry grain yield (kg/ha), days to 50% physiological maturity, days to 50% flowering and 100-grain weight. Data collected was subjected to analysis of variance (ANOVA) to determine the effects of seasons, treatments and their interaction using the mixed procedure of SAS (Institute 2012) software. The means of seasons, treatments and their interaction were compared by least significance difference at $P \leq 0.05$. The sole cropping recorded the highest weed count and weed biomass. Finger millet -bean intercrop recorded the lowest values of weed count and weed biomass which led to the increase in the finger millet yield. The long rains season recorded significantly higher weed biomass than short rains season. Intercropping is an effective approach of weed management. It also enhances growth and development of finger millet. Farmers should be encouraged to grow finger millet varieties intercropped with different leguminous crops to assist in weed suppression and improve finger millet yield.

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CHAPTER ONE

INTRODUCTION

1.1 Background information

Finger millet (*Eleusine coracana*) is one of the most important staple food crops in Kenya. Finger millet grain is the basic foodstuff for farm households in the world's poorest countries and among the poorest people. The crop is a highly nutritious and versatile grain that would be worthy adding to one's diet (Shadang *et al.*, 2014).

Finger millet is an important crop in tropical regions of the world due to its resistance to pests and diseases, short growing season and productivity under hardy and drought conditions when major cereals cannot be relied upon to provide sustainable yields (Gebreyohannes *et al.*, 2021; Sood *et al.*, 2019; Devi *et al.*, 2014). The crop was domesticated in Western Uganda and Ethiopian highlands at least 5000 years ago before introduction to India (Ouma, 2016). Finger millet is majorly grown in semi-arid tropics of Asia and Africa (Antony *et al.*, 2018)

In Kenya, the adoption of improved finger millet varieties is reported to have reduced poverty and enhanced food security in most parts including Trans – Nzoia County, where the crop is considerably popularized. The result is increased production that meets farmer's household requirement and surplus that has helped to generate household income (Gitu *et al.*, 2014).

It also has a higher and stable market price when compared to other cereals like maize. (Mgonja *et al.*, 2007). Finger millet grain is sold at between Ksh.10, 000 and Ksh.12, 000 per 90 Kilograms bag while that of maize ranges from Ksh.4, 700 to Ksh.5, 000 per 90kg bag in local markets. In spite of the preference for finger millet grain in Kenya, its production however is constrained by weeds, insect pests and diseases among others

(Ouma, 2016). Of all the constraints limiting finger millet production, weeds pose the greatest challenge in the study area. Weed competition is a major limiting factor for the productivity of finger millet in Trans- Nzoia County (Gitu *et al.*, 2014). As finger millet is grown predominantly in warm rainy seasons, weeds of different kinds deprive the crop.

Weed management is an important factor for enhancing the productivity of millet because weeds compete for nutrients, water, light and space; reduce crop yield and quality during the early growth period. Because the crop canopy forms slowly and provide little shading of weeds between the rows until mid-season; by then most weeds are well established (Chandhary *et al.*, 2018).

Weeds cause nearly 37 per cent of the total crop loss, every attempt has to be made to contain the weed menace and uphold the production. Weed management takes away nearly one third of the total cost of production of field crops (Fakeerappa *et al.*, 2017). Farmers in Trans- Nzoia County respond to the problem of weeds through various traditional control methods. These methods include use of manure, hand weeding and uprooting of the weeds. However, research findings indicate that these methods are insufficient to control weeds once they have well established on a field (Woomer *et al.*, 2004).

Modern approaches to control weeds in finger millet such as crop resistance and intercropping cereals with legumes has been developed. Yield production through intercropping is higher than single cropping because in intercropping light, water, and nutrient uptake is more effective than sole cropping pattern (Ali *et al.*, 2016). Intercropping has gained interest because of potential advantages it offers over yielding, that is, improved utilization of growth resources by the crops and improved reliability

from season to season. When a legume is grown in association with another crop, commonly a cereal, the nitrogen nutrition of associated crop may be improved by direct nitrogen transfer from the legume to the cereal (Giller and Wilson, 1991).

Growing of intercrops in a widely spaced row will not only reduce the intensity of weeds but also gives an additional yield. Chandhary *et al.*, (2012) concluded that intercropping of pearl millet with green grams at 2:2 pair row ratio was clearly superior over sole pearl millet and found most profitable by making the highest net return and LER. While second weeding may be needed in sole crop, this is frequently not required in intercropping since the canopy coverage is nearly complete and weed growth after the first weeding is minimal (Chaudhary *et al.*, 2018).

In addition, legume intercrops are included in cropping systems because they reduce soil erosion and suppress weeds (Giller and Cadish, 1995). One of the most reliable and less costly approach in controlling weeds in finger millet has been intercropping with common beans (*Phaseolus vulgaris*) (Ali *et al.*, 2016). The common bean is one of the most important legumes in the world because of its commercial value, extensive production, consumer use and nutrient value (Xavery *et al.*, 2006; CABI, 2007). In Kenya, over 75% of rural households depend on beans for home consumption as well as cash crop income. Common beans were used in intercropping since being legumes are able to increase soil nitrogen. Also, beans have an extensive canopy hence ability to suppress weeds.

Despite the competitive benefits associated with intercrops, the ability of beans to suppress weeds has still not been extensively studied. Also in the current study, the finger millet varieties that were used are new and have not been tested for weed management in the area. Although several studies of intercropping have been

conducted, there is limited literature published on the effectiveness of intercropping finger millet varieties with common bean on weed management and yield in Trans-Nzoia County, thus this study.



Plate 1: Finger millet (*Eleusine coracana*) (Source: Author, 2020.)



Plate 2: Common beans (*Phaseolus vulgaris*) (Source: Author, 2020)

1.2 Statement of the problem

The potential yield of finger when proper agronomic practices are carried out is 2500 kg per hectare. However, weeds alone account for 16 to 94 per cent reduction in yield (Umrani *et al.*, 1980). Weed infestation is therefore considered as one of the most important constraints that limit yields in finger millet. Thus, weed control has become crucial for quality production and higher yields (Hari *et al.*, 2017). Manual hand weeding is by far the most widely adopted method of weed control in finger millet by smallholder farmers in Trans-Nzoia County. But this method is weather dependent, laborious, more time consuming and costly due to high cost of labour (Hari *et al.*, 2017).

In addition, the use of herbicides is difficult when the crops have emerged. This is also because normally in intercropping a dicotyledonous crop species is combined with a monocotyledonous crop species and therefore the use of herbicides is harmful (Ashish *et al.*, 2012). Also, the use of herbicides in any crop mixture is a risky endeavour and not an eco-friendly approach to the environment and human health (Adikant *et al.*, 2018). Therefore, the most reliable and less costly approach to suppress weeds in finger millet is intercropping finger millet with common beans.

Intercropping has gained interest because when a legume is grown in association with another crop commonly a cereal, the nitrogen nutrition of associated crop may be improved by direct nitrogen transfer from the legume to the cereal (Giller and Wilson, 1991). In addition, legume intercrops are included in intercropping systems because they reduce soil erosion and suppress weeds (Giller and Cadish, 1995). Yield production through intercropping is higher than single cropping because in intercropping light, water and nutrient uptake is more effective than sole cropping pattern (Ali *et al.*, 2016). Therefore, there is need to establish the potential of the

common bean when intercropped with finger millet varieties in suppressing weeds to improve the productivity of millet.

1.3 Justification of the study

Finger millet is the only cereal crop that is capable of producing a reliable yield under the marginal environments and simultaneously responds to high management conditions. Its nutritious grain forms the important component of human diet and straws used as animal fodder especially during the dry season (Hari *et al.*, 2017). In Trans-Nzoia County, finger millet is considered important; mainly for food and income generation and also has a higher and stable market price when compared to other cereals (Takan *et al.*, 2002; Obilana, 2002).

Production of finger millet in its major growing areas is being affected by occurrence of weeds, pests and diseases hence significantly reducing yields and threatening food security (Makete, 2016). Weed management is an important factor for enhancing the productivity of finger millet as weeds compete for nutrients, water, light and space; reduce crop yield and quality with crop plant during the early growth period. Weeds also cause lower grain and straw yield. When improved agricultural technologies are adopted, efficient weed management becomes even more important, otherwise the weeds rather than the crops benefit from the costly inputs (Chaudhary *et al.*, 2018).

Weed management by manual weeding especially during the peak weeding season is very labour –intensive and most crops therefore pass their critical period of weed control and this results in poor or no yield. While the use of herbicides poses a serious danger to humans, animals, other non-target plants and soil microbes. This has necessitated research into less costly and eco-friendly alternative approaches like

intercropping for weed suppression in finger millet. Intercropping has gained interest because of potential advantages it offers over yielding, that is, improved utilization of growth resources by the crops and improved reliability from season to season, hence this study.

1.4 Objectives

1.4.1 Overall objective

To evaluate the effectiveness of intercropping in increasing finger millet yield through reducing weed losses in Trans -Nzoia County.

1.4.2 Specific objectives

- i. To investigate the effect of finger millet varieties and common bean combination on weeds.
- ii. To determine the effect of common bean on the growth and development of finger millet varieties.
- iii. To examine the effect of intercropping common bean with improved finger millet varieties on finger millet yield.

1.5 Research hypotheses

H_a: Intercropping finger millet varieties with common bean leads to reduction of weed density.

H_a: The common bean and finger millet varieties combination enhances growth and development of finger millet.

H_a: Intercropping finger millet varieties with common bean increases the yield of finger millet.

CHAPTER TWO

LITERATURE REVIEW

2.1 Finger millet (*Eleusine coracana*)

Finger millet (*Eleusine coracana*) is majorly grown in the semi-arid tropics of Asia and Africa. Finger millet was developed in Africa probably in the Ethiopian region. It was introduced to India perhaps more than 3000 years ago. Among the millets, finger millet ranks fourth on the global scale of production (Antony *et al.*, 2018).

2.1.1 Origin and importance

Finger millet (*Eleusine coracana*) is an annual herbaceous plant widely grown as a cereal crop in the arid and semi-arid areas in Africa and Asia. It is a tetraploid and self-pollinating species probably evolved from its wild relative (*Eleusine africana*). Cultivated finger millet was domesticated about 5000 years ago from the wild subspecies in the highlands that range from Ethiopia to Uganda. This was introduced into India around 3000 years ago; with the result that India is now a secondary centre of diversity for finger millet (FAO, 2019).

From India it spread across South-East Asia to China and Japan. In the United States it is grown on a small scale for bird - seed. However, Asian production keeps growing (by 50% in India during the last 50 years and by 8% per year in Nepal) while African production remains unchanged (FAO, 2012). Finger millet is a staple food in many African and Asian countries. It is also considered a helpful famine crop as it is easily stored for lean years (FAO, 2012). In Kenya, the crop is mainly grown in Western, Nyanza and Rift-Valley regions. The grain is readily digestible, highly nutritious and versatile and can be cooked like rice, ground to make porridge or flour, or used to make cakes. Finger millet is also used to make alcoholic beverages. The seeds are also used as animal fodder (FAO, 2012).

The green straw of finger millet is sweet smelling and consumed by livestock without any wastage (Munns and Tester, 2008). Finger millet straw is a highly nutritious fodder for the animals due to its nutritional richness (Dharam *et al.*, 2017). Finger millet straw is also valuable building material and used as source of fuel too. Among the food grains finger millet is one of the most nutritious crops for protein, minerals (Calcium and Iron) and provides 8-10 times more calcium than wheat or rice (Anon, 2014).

Finger millet is a nutritious crop which provides protein, carbohydrates and minerals. Finger millet is nutritionally superior to other cereals (Obilana, 2002) in that its grain is rich in methionine (an amino acid that lacks in the diets of people living on starchy foods like cassava, plantain, polished rice and maize meal). Finger millet has mineral nutritional profile (e.g., Calcium > 5,000%; Iron and Manganese > 350% and Copper) and essential amino acids than maize (National Research Council, 1996).

Finger millet has low glycaemic index. Therefore, low blood sugar levels have been observed after a finger millet diet thereby acting as a safer food and popular food among diabetic patients in the country. It is rich in calcium which helps in strengthening bones and as excellent source of natural calcium for growing children and aging people. It is a very good source of iron and consumption helps in the condition of anaemia. Consumption of finger millet helps to reduce body cholesterol level and also helps in relaxing the body naturally. Finger millet is good for prevention of premature aging (FCRDI, 2000). In Kenya, there is growing demand for finger millet and it fetches over double price of sorghum and maize (Oduori, 2000). Therefore, improving its production would greatly contribute to household income besides food security.

2.1.2 Botanical description

Finger millet is a robust, tillering grass which grows in tufts. The leaves of the plant are dark green, linear and mainly smooth with some hairs along the leaf edges. The inflorescence is a panicle with 5 to 7 finger-like spikes that resembles a fist when mature, hence the name finger millet. The spikes bear up to 70 alternate spikelets carrying 4 to 7 small seeds (Dida *et al.*, 2008). The seed pericarp is independent from the kernel and can be easily removed from the seed coat. The grain is reddish brown, dark brown, or occasionally cream. Finger millet can reach 1.7 m (5.6 ft) in height and it's an annual plant, harvested after one growing season (Dida *et al.*, 2008).

Finger millets possess a C₄ photosynthesis system; hence they prevent photorespiration and as a consequence, efficiently utilize the scarce moisture present in the semi-arid regions. Since C₄ plants are able to close their stomata for long periods, they can significantly reduce moisture loss through the leaves (Zerihun, 2016).

2.1.3 Crop distribution and production

In most parts of the world, finger millet is grown as a subsistence crop for local consumption. Today the crop is ranked fourth globally in importance among the millets after sorghum, pearl millet and foxtail millet. Finger millet is cultivated mainly in Africa (Ethiopia, Kenya, Sudan, Zambia, Zimbabwe and Namibia) and Asia (India, China and Sri-Lanka). Annual world production of finger millet is at least 4.5 million tonnes of grain of which Africa produce perhaps 2 million tonnes. India is a major producer of finger millet in Asia with a production of 2.1 million tonnes and productivity of 1.3 tonnes per hectare (t/ha) (Ouma, 2016). In East Africa, Uganda is the highest producer of finger millet with 500,000 hectares followed by Ethiopia with 23,800 hectares and Kenya 65,000 hectares (National Research Council 1996; Takan *et al.*, 2002).

2.1.4 Climatic and soil requirements

Finger millet is highly valued by local farmers for its ability to grow in adverse agro-climatic conditions where cereal crops such as maize (*Zea mays*), wheat (*Triticum* spp) and rice (*Oryza sativa*) fail and has been noted to tolerate wide variety of soils (Ouma, 2016). Bwai *et al.*, (2014) has outlined the ecological requirements for the crop; it requires annual rainfall ranging from 500 – 1000 mm, which is well distributed throughout the growing season; adapted to a wide range of soil conditions though it prefers fertile, well-drained sandy to loamy soils with p^H ranging from 5 – 7. Finger millet also grows on lateritic or black heavy vertisols and has some tolerance for alkaline and moderately saline soils. In terms of altitude, the crop is found between 1000 – 2000 metres above the sea level in Eastern and Southern Africa and up to 2500 - 3000 metres above the sea level in the Himalayas.

2.1.5 Finger millet production constraints

Despite of the preference for finger millet in Kenya, its uptake both in area and production has not been expanding but rather declining (Mitaru *et al.*, 1993). The factors which have contributed to the decline have to be addressed if production is to be increased. Finger millet has the greatest labour requirement as compared to other crops. Most of the labour input is required for weeding and land preparation. These two operations are laborious. The high labour requirement has greatly increased the cost of finger millet production.

A study funded by the United Kingdom's DFID in 2004, surveyed three districts in Western Kenya (Bungoma, Busia and Teso) which produce the bulk of finger millet in Kenya. The investigation showed that high demand for labour is a limiting factor in finger millet production (Ouma, 2016). Finger millet production scenario in Trans

Nzoia County is characterized by a negligible use of improved seeds, fertilizer, agro-chemicals and a low level of mechanization (Ouma, 2016).

The current low level of technology continues to produce poor yields of finger millet which in turn means poor returns to farmers' efforts. Inadequate extension services and poor dissemination of information to the farmers due to weak research – extension linkages have been a major technical constraint (Ogecha *et al.*, 1997). The means of transport are either lacking or too expensive for small holders. The situation is worsened by poor road network or inaccessible rural roads when wet. The negative growth in the production of finger millet could also be attributed to poor marketing and its limited use (Jaetzold *et al.*, 1983). Production of finger millet in its major growing areas is affected by occurrence of weeds, pests and diseases hence significantly reducing yields and threatening food security (Makete, 2016). Weed management is an important factor for enhancing the productivity of finger millet as weeds compete for nutrients, water, light and space; reduce yields and quality of crop plant during the early growth period.

2.1.6 Finger millet varieties

In Trans- Nzoia County, many farmers initially planted indigenous finger millet varieties which were low yielding and less resistant to drought and blast disease. Research intervention tested local varieties using proper agronomic practices and found that improved varieties are yielding higher than the indigenous ones. Currently, farmers are adopting the improved finger millet varieties. In most cases, the improved finger millet varieties have unique characteristics which describe each one of them. A description of the characteristics of improved varieties that were used in this study are summarized in Table 1 below.

Table 1: Improved finger millet varieties.

Variety	Abbreviate d Name	Origin	Key traits
P-224	P-224	Uganda	Green with no plant pigmentation, High yield (2,925 kg/ha) Susceptible to striga, blast and lodging
U-15	U-15	Uganda	Purple plant pigmentation, High yield (2,475 kg/ha) Resistant to striga and blast, short.
Gulu-E	GE	Uganda	Green with no plant pigmentation, High yield (2,475 kg/ha) Resistant to blast and lodging

Source: Oduori, 2008.

2.2 Beans as an intercrop for weed suppression

2.2.1 Origin and domestication

Common bean (*Phaseolus vulgaris*) originated in the Central Americas and was domesticated in Mexico, Peru and Colombia 8000 years ago. It was introduced in East Africa and other parts of the old world by the Portuguese. It is now widely cultivated in many parts of tropics and subtropics and throughout the temperate regions. Common bean is a minor crop in India and most of tropical Asia where indigenous pulses are preferred (Nassar *et al.*, 2010).

2.2.2 Botanical description

Phaseolus vulgaris belongs to the botanical family of *leguminosae*. The common bean is a highly variable species showing considerable variation in growth habit, vegetative

characters, flower colour and size, shape and colour of both seeds and pods (Laing *et al.*, 1984). Like many flowers, those found on legume plants are hermaphroditic, containing both the stamen and pistil. This makes the plants self-fertile meaning that an individual plant is able to reproduce by itself which can have the effect of limiting genetic diversity (Nassar *et al.*, 2010).

Common bean is a herbaceous plant. The stem is erect, green in colour, ribbed, cylindrical and solid. The plant is not more than 60 cm in height (determinate type) and stem nodes are few (6-8 in number). The flower typically has five petals and an ovary with one carpel, cavity and style. The general pattern of legume flowers follows that of the pea blossom. The result of this arrangement is that of a papilionaceous design, which means butterfly like. The petals of the legume plants are shaped into a cup. Due to their shape, these petals are referred to as the keel (Nassar *et al.*, 2010). The white, pink or purple flowers are about 1cm long and they give way to pods.

After pollination the flower will die and reveal the growing ovary which becomes the pod. The pod is 8-12 cm long and 1-1.5 cm wide. This may be green, yellow, black or purple in colour, each containing 4-6 beans. The beans are smooth plump, kidney-shaped up to 1.5 cm long, range widely in colour. Legume pod is one-celled container formed by two sealed part called valves. Legume pods always split along the seam which connects the two valves. This characteristic is called dehiscent: from the Latin word meaning burst open. However, some pods are winged or indehiscent (meaning pods do not split open at maturity) (Nassar *et al.*, 2010).

Beans are annual legumes with great variation in growth habit. Liebenberg (2002) distinguished two types of common bean growth habits; (1) determinate growth habit, in which the main axis terminates in an inflorescence and produces no vegetative nodes

after flowering: and (2), indeterminate growth habit in which the vegetative terminal bud on the main stem and branches, node and leaf production occur after flowering commences. Time to flowering varies with cultivar, temperature and photoperiod and is usually 28-42 days after planting. Seed-filling period may take from as few as 23 days to nearly 50 days. Full maturity with dry seed is reached 65-150 days after sowing (CABI, 2007).

2.2.3 Climatic requirements

Common bean is a quantitative short-day plant. Beans grow in temperatures ranging from 15-33°C. An optimum growing temperature of 20-25°C is essential. Relatively high temperatures during flowering stage led to poor flower development and a low pod set resulting in yield loss. The crop is very sensitive to night frost. Day temperatures below 20°C will delay maturity and cause empty mature pods to develop (CABI, 2007).

Beans require a well distributed annual rainfall of between 800-2000 mm. Irrigation should be done if rainfall is inadequate. Excessive rainfall during flowering causes flower abortion and increased disease incidences. Dry weather conditions are needed during harvesting. Continuous lack of rainfall and inaccessibility of water during critical growth periods affect growth and development and yield of beans (Anon, 2005).

Beans thrive well in a well-drained soil which is rich in organic matter and weed free. They will not grow well in soils that are poorly drained or waterlogged. Suitable soil types range from light to moderately heavy soils with good drainage. Beans prefer an optimum soil p^H range of 6.5 to 7.5 and are very sensitive to acidic and saline soils (Anon, 2005). The crop does well at an optimum altitude range of up to between 1000 to 2100 m above the sea level. It however, tends to grow and mature faster in low altitude zones.

2.2.4 Importance of beans

The common bean is an important source of protein (dry beans contain 20 to 28 percent protein) and calories in human diets in tropical and sub-tropical developing countries. Beans health benefits include; regulating blood sugar level, a good source of fibre, improving cholesterol levels, reducing iron deficiency, may help prevent cancer and improving eye health. The immature pods are eaten as green vegetables worldwide (Laing *et al.*, 1984). In some plants of the tropics, young leaves are used as vegetables. The straw can be used as forage (CABI, 2007).

2.3. Intercropping as a cropping system

Intercropping can be defined as a system in which two or more crops are grown simultaneously in rows in a definite pattern and on the same field. Intercropping is a common cropping system in Africa, Asia and Latin America of which more than 80% of small holder farmers grow the bulk of the food crops and some of the cash crops (Waddington *et al.*, 1989).

In East Africa, finger millet is often intercropped with legumes such as beans, cowpeas and pigeon peas. In Kenya, small holder farmers intercrop finger millet and legumes such as beans, cowpeas, pigeon peas and soya beans (Oduori 2000). Intercropping increases the use of natural resources by the canopy and competes better with weeds for light, water and nutrients (Liebman and Dyck, 1993).

The success of intercropping relies on optimizing the use of available light, water and nutrient resources by the intercrops while at the same time minimizing competition between them (Mgonja *et al.*, 2007).

Grossman and Quarles (1993) divided intercropping into basic spatial arrangements which include;

- i) Mixed or multiple cropping – the cultivation of two or more crops simultaneously on the same field without any distinct row arrangement.
- ii) Relay cropping – the planting of the second crop into already standing crop at the time when the standing crop is at its reproductive stage or has completed its development but before harvesting.
- iii) Row intercropping – the cultivation of two or more crops simultaneously on the same field with a row arrangement.
- iv) Strip cropping – the planting of two or more crops together in strips wide enough to permit separate crop production practices using machines but close enough for the crops to interact.

Intercropping and cover cropping are practices that increase diversity in the cropping system and enhance the utilization of resources such as light, heat and water. These practices can also help to suppress weeds in the cropping system.

Research and experience from around the world have shown that intercropping and cover cropping systems tend to suppress weeds better than sole cropping system (Liebman and Dyck, 1993). This is especially true with cover crops or “smother” crops such as common beans interceded with finger millet. This practice is an attractive strategy to small holder farmers for increasing productivity and land labour utilization per unit area of available land through intensification of land use (Seran and Brintha, 2010). Furthermore, intercropping cereals with legumes have huge capacity to replenish soil mineral nitrogen through its ability to biologically fix atmospheric nitrogen (Giller, 2001).

2.3.1 Advantages of intercropping

In many parts of the world, intercropping as a common practice of agro ecosystem management has several advantages compared to monoculture (Banik *et al.*, 2006). Intercropping will help to increase fertility and soil structure stability (Vasilakoglou *et al.*, 2005). Biological nitrogen fixation is the major source of nitrogen in legume-cereal mixed cropping systems when nitrogen fertilizer is limited. Moreover, because inorganic fertilizer has much environmental damage such as nitrate pollution, legumes grown in intercropping are regarded as a sustainable and alternative way of introducing nitrogen into lower input agro ecosystems (Fustex *et al.*, 2010).

Carlson (2008) found that intercropping maize with legumes was capable of reducing the amount of nutrients taken from the soil as compared to a maize sole crop; this was due to the fact that when nitrogen fertilizer was added to the field, intercropped legumes use the inorganic nitrogen instead of fixing nitrogen from the air and thus competition with maize for nitrogen. However, when nitrogen was not applied, intercropped legumes fixed most of their nitrogen from the atmosphere and no competition with maize for nitrogen resources was observed (Adu-Gyamfi *et al.*, 2007).

Intercropping of cereal with legumes is an excellent practice for reducing soil erosion and sustaining crop production. Intercropping systems control soil erosion by preventing rain drops from hitting the bare soil where they lead to seal surface pores, prevent water entering the soil and increase surface run-off (Seran and Brintha 2010). Kariaga (2004) mentioned that in maize + cowpea intercropping system, cowpea act as best cover crop and reduced soil erosion than maize + bean system.

Reddy and Reddi (2007) found that tall crops act as wind barrier for short crops in intercrops of tall cereals with short legume crops. Similarly, sorghum-cowpea

intercropping reduced runoff by 20-30% compared with sorghum sole crop and by 45-55% compared with cowpea monoculture. Moreover, soil loss was reduced with intercropping by more than 50% compared with sorghum and cowpea monocropping.

The principle advantage of intercropping is the more efficient utilization of the available resources and the increased productivity compared with each sole crop of the mixture (Mucheru-Muna *et al.*, 2009). Yield advantage occurs because growth resources such as light, water, and nutrients are more efficiently absorbed and converted into crop biomass by the intercrop over time and space as a result of differences in competitive ability for growth resources between the component crops which exploit the variation of the mixed crops in characteristics such as rates of canopy development, final canopy size, photosynthetic adaptation of canopies to irradiance conditions and rooting depth (Tsubo *et al.*, 2001).

An important role of intercropping systems is the ability to reduce the incidence of pests and diseases thus minimizing the need of using expensive and dangerous chemical insecticides and fungicides. Results from 209 studies involving 287 pest species were analyzed. Compared with monoculture, the population of insects was lower in 52% of the studies, that is, 149 species and higher in 15 % of the studies, that is, 44 species (Langer, *et al.*, 2000). There was significantly lower population of insects on the cowpea crop when grown in mixture with maize at specific ratios than in monoculture (Olufemi *et al.*, 2001).

One of the most important reasons for intercropping is to ensure that an increased and diverse productivity area is obtained compared to sole cropping. For instance, using LER in a maize-soybean intercropping system, Kipkemboi *et al.*, (2001) reported that it was greater than one under inter crop. Productivity of the intercropping system indicated yield advantage of 263% as depicted by LER of 1.02 – 1.63 showing efficient

utilization of land resources by growing the crops together. Raji (2007) had also reported of higher production efficiency in maize-soybean intercropping systems.

According to Seran and Brintha (2010), the intercropping system gave higher cash return to small holder farmers than growing as the monocrops. Mucheru-Muna *et al.*, (2009), using benefit cost ratio, found that the MBILI system with beans as the intercrop resulted in 40.0% higher net benefits relative to the traditional system with beans and 50-70% higher benefit relative to the MBILI system with cowpea or groundnut.

2.3.2 Disadvantages of intercropping

Waddington *et al.*, (1989) reported that experimentation with intercropping was more complex, took large land size and generally difficult to manage than sole cropping experiments. Scholl and Nieuwenhuis (2004) reported that mechanization of an intercropping system was difficult to achieve in large scale farming particularly planting, weeding, harvesting and during fertilization and herbicide application.

Wolfswinkel (2006) reported that labour requirements of an intercropping system when two or more different crops planted at the same time or shortly after one another were higher than that of sole cropping. On the other hand, labour requirement might also be less in an intercropping system, for example, due to reduction in weeding requirement when weeds are suppressed by the intercrop (Thobatsi, 2009). Also, if sowing and harvesting period and duration of different intercropped crops vary, it is easier to spread the available labour over the entire season thus avoiding higher peaks of labour (Wolfswinkel,2006).

Competition is another potential problem of intercropping. Light and carbon-dioxide are absorbed by the leaves and water, nutrients and oxygen mainly by the roots. Also,

when the crops in the intercrop grow to the proximity of the shoot and root systems it leads to manual interference in the interception and absorption of the growth factors.

2.4 Intercropping cereals with legumes as a weed management strategy

Intercropping, growing of two or more crops together at the same time in the same field can be used as an effective weed management strategy. Recent studies have suggested to use intercropping allelopathic crops as an effective element for integrated weed management particularly in low-input farming systems (Takan *et al.*, 2002). Plots with intercrops possess lower weed densities as opposed to their respective sole crops (Hauggaard- Nielsen *et al.*, 2009). This makes weed management easier since it reduces the number of times weeding has to be done eventually lower weeding costs.

Weed suppression, the reduction of weed growth by crop interference has been referred to as one of determinants of yield advantage of intercropping being a viable alternative to reduce the reliance of weed management on herbicide use (Agegnehu, 2008). There are two possible reasons for the reduction of weed biomass in intercropping systems. Some intercrop species release allelopathic compounds which limit the occurrence of weeds (Olufemi *et al.*, 2001). Intercropping also encourages efficient utilization of the environmental resources.

Hence, recent studies have addressed intercropping as an option for an integrated weed management particularly in farming systems with low external inputs (Agegnehu, 2008). Weed suppression in intercropping through more efficient use of environmental resources by component crops has also been reported (Celette *et al.*, 2005). It is well known that the weeds interfere with crops causing serious effects through either competition for light, water, nutrients and space or allelopathy (Dhima *et al.*, 2007). Lawson *et al.*, (2006) reported that in maize –legume intercropping, legume crops are

generally suppressed by weeds and shade effect by the corresponding maize crop which cause difference in photosynthesis efficiency of the two intercropped crops.

Intercropping helps in smothering weeds in crop fields by providing an above ground micro-climate that causes shading on the weeds below. This cuts off light from the growing weed hence suppressing it. Shading may also inhibit the germination of some weed species by inducing secondary dormancy in seeds, which could be caused by modifying either the light quality by the canopy or the amplitude of soil temperature. Also in an intercropping system, available resources like water, nutrients and light are effectively used by two crops and therefore weeds do not access available resources for their growth. Intercropping finger millet with common bean could increase soil nitrogen content, suppress weeds and improve finger millet yield in Trans -Nzoia County.

2.5 Gaps identified in the literature review

In spite of the preference for finger millet grain in Kenya, its production however is constrained by weeds, pests and diseases among others (Ouma, 2016). Weed management is an important factor for enhancing the productivity of millet as weeds compete for nutrients, water, light and space; reduce crop yield and quality. As the weeds cause nearly 37% of the total loss, every attempt has to be made to contain the weed menace and uphold production.

Farmers in Trans-Nzoia County resolve to the problem of weeds through various traditional control methods such as hand weeding and uprooting the weeds. However, research findings indicate that these methods are insufficient to control weeds once they have well established on a field (Woomer *et al.*, 2004). Modern approaches to control weeds such as intercropping cereals with legumes has been developed.

One of the most reliable and less costly approach in controlling weeds in finger millet has been intercropping with common beans (*Phaseolus vulgaris*). Despite the competitive benefits associated with intercrops, the ability of beans to suppress weeds has still not been extensively studied. Although several studies of intercropping have been conducted, there is limited literature published on the effect of intercropping finger millet with common bean on weed management in Trans-Nzoia County.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

The field experiments were conducted at Kiminini Sub-County in Trans Nzoia County. The altitude of the site is 1900 metres above sea level and receives an average annual rainfall of 1300 mm with a mean temperature of 24°C. The site is located in the Upper Mid-land Agro –ecological Zone (UMZ) and is endowed with brown red and brown clay soils derived from volcanic ash. The soils are fertile and have high clay content. Kiminini lies on latitude 0°53'35"N and longitude 34°55'26" E.

The site receives a bimodal rainfall pattern with short rains falling between September and December, while the long rains start in March and end in August. The short rains contribute 25% of the total seasonal production. Long rains form the main season for cereal crops (Baltazari, 2014). Trans-Nzoia County was chosen for the study in the context of beans' production because beans are commonly grown by farmers in that area.

3.2 Experimental materials

The experimental materials comprised of three improved varieties of finger millet namely (Gulu-E, P-224 and U-15) and common bean variety (Rose coco).

Finger millet

Gulu-E; It is high yielding, easy to thresh and tolerant to lodging.

P-224; It is early maturing, high yielding and easy to harvest as it grows to knee high in cold areas and up to waist height in warm areas.

U-15; It is short, early maturing, high yielding and resistant to blast disease.

Beans Rose coco; It is early maturing and has a higher ability to adapt to the study site in terms of climate, soil type and soil fertility. This variety also has a restricted height and with fewer leaves. The other attributes considered when selecting this variety for intercropping included; market, nutritional and cooking qualities. This variety is also drought and pest resistant and has a high keeping quality.

This was action research focused on field practices relevant for farming communities.

3.3 Treatments

This study integrated components to give treatment combinations which were tested as an integrated entity considered as one unit, thus, the treatments were nine as presented below ;

- i. Finger millet sole crop (Gulu-E) -Weed free
- ii. Finger millet sole crop (P-224)- Weed free
- iii. Finger millet sole crop (U-15)- Weed free
- iv. Finger millet sole crop (Gulu-E) - Weedy
- v. Finger millet sole crop (P-224) - Weedy
- vi. Finger millet sole crop (U-15) – Weedy
- vii. Finger millet (Gulu-E) intercropped with beans
- viii. Finger millet (P-224) intercropped with beans
- ix. Finger millet (U-15) intercropped with beans

The intercropping pattern that was adopted is the additive series intercropping. The additive pattern holds the plant population of one species constant while varying the other species. In this case, the plant population of finger millet was held constant while that of beans was varied.

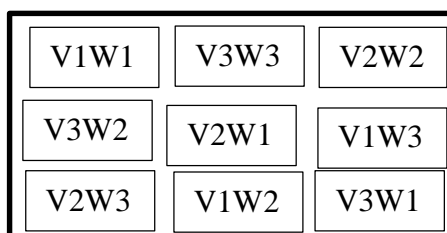
3.4 Experimental design

The nine treatments were laid out in a Randomized Complete Block Design (RCBD).

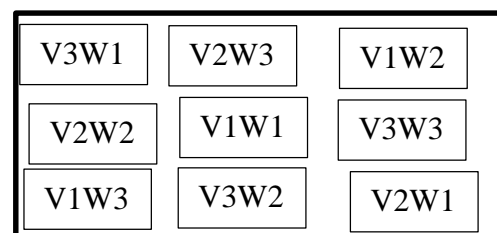
The treatments were replicated three times giving a total of 27 plots.

3.5 Experimental layout

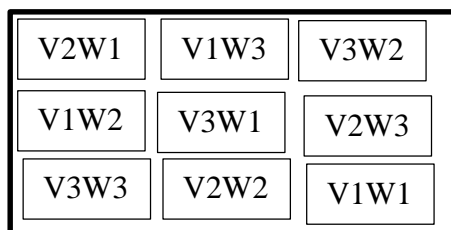
The plots measured 1.8 m x 1.5 m each and a path of 0.5 m was used to separate one plot from the other (Figure 1).



REP 1



REP 2



REP 3

Figure 1: Experimental layout

Key:

V 1= Gulu-E

V 2 = P -224

V 3 = U - 15

W 1= Weedy

W 2 = Weed free

W 3 = Intercropped

3.6 Field crop management practices

Before land preparation, all the experimental plots were laid out. The major dominant weed species and their number were recorded from all plots before land preparation. The plots were cultivated by a hand hoe to break the soil and then harrowed before planting. The finger millet was planted in furrows at a spacing of 60 cm x 15 cm. While in the intercrop plots, a row of common beans was planted at the mid of every two rows of finger millet and the seeds spaced at 15cm from plant to plant. Two seeds of beans were placed in each hole and then covered with the soil. Fertiliser was applied at planting at the rate of 20kg P₂O₅ per ha.

Hand weeding was done twice during the growing season, three weeks after emergence and three weeks later to reduce crop weed competition during finger millet's critical growing period. Weeding was done only in the weed free and intercropped treatments. The weedy check plots were left un weeded. After weeding 20kgN as a top dress for finger millet was applied. Other recommended agronomic practices for production of finger millet and beans were undertaken.

3.7 Data collection

Data was collected at the study site during the two cropping seasons; short rains (September 2020– January 2021) and long rains (February 2021 – July 2021) seasons. All data for finger millet was collected from plants in the middle rows of each experimental plot. Data collection commenced two weeks from germination and continued till plants matured and harvested.

3.7.1 Weed assessment parameters

Before land preparation, the major dominant weed species were determined by counting all the weeds and grouping them by their major groups; broad leaved and narrow leaved.

After planting, weeds were identified and counted by species in a marked area of 50 cm x 50 cm in each plot. The following weed variables were determined:

Weed type

Weed type was determined by counting the plants of each weed type in a marked area of 50 cm x 50 cm in each plot and the number of each weed type was recorded.

Weed count

Weed count was determined by counting and summing the number of plants in a marked area of 50 cm x 50 cm in each plot.

Total weed biomass

The weed biomass was determined by collecting the above and below ground part of weed species from a marked area of 50 cm x 50 cm in each plot. Then they were dried at 70⁰C for 3 days and weighed in grammes and expressed as weed dry weight per m².

3.7.2 Growth and yield parameters of finger millet

Plant height

Plant height was determined from 10 plants randomly selected from the middle rows in each plot. Finger millet plant height was determined by measuring the length of the plant from the base to the growing tip with the help of a tape measure and the average height was calculated in centimetres at maturity stage.

Number of productive tillers per plant

The number of productive tillers per plant was determined by counting the number of tillers from 10 plants selected at random and then the total number divided by 10 to get the average number of tillers per plant at maturity stage.

Panicle length

Panicle length was measured using a 30 cm ruler placed along the panicle from its base to the growing tip.

Days to 50% flowering

Days to 50 % flowering was established by counting the actual number of days taken for 50% of the plants in each plot to have flowers.

Days to 50% physiological maturity

Complete loss of green colour from the panicles was used as criteria for finger millet physiological maturity. Days to 50% physiological maturity of panicles was determined by counting the actual number of days taken for 50% of the plants to attain physiological maturity.

Dry grain yield

The dry grain yield (kg/ha) was recorded on per plot basis and then transformed into yield in kilogrammes per hectare.

3.7.3 Growth and yield parameters of beans**Plant height**

Bean plant height was measured by placing tape measure along the stem of the plant base to the growing tip. Plant height was recorded from 10 plants randomly selected from each of the experimental plots and the average height recorded in centimetres at maturity stage.

Leaf width

Leaf width was measured using a tape measure placed at the wider part of the fully expanded terminal leaflet of the third trifoliate leaf from the plant tip downward the stem.

Days to 50% flowering

The actual number of days taken for 50% of the plants in each plot to have flowered was counted.

Days to 50% physiological maturity

Complete loss of green colour from the bean pods was used as criteria for bean physiological maturity. Days to 50% physiological maturity of bean pods was determined by counting the actual number of days taken for 50% of the plants to attain physiological maturity.

Number of pods per plant

The number of pods per plant was determined by counting the number of pods containing one or more seeds from 10 plants selected at random. The total number of pods was divided by 10 to get the average number of pods per plant.

Number of seeds per pod

To determine the number of seeds per pod, seeds in each of the 10 randomly selected pods per plant were counted and an average recorded.

Dry grain yield

The dry grain yield was determined and recorded on per plot basis and then transformed into yield in kilogrammes per hectare.

100 - Grain weight

Three sets of 100 seeds were taken from the grain lot harvested from each plot then weighed and averaged to get 100-grain weight.

3.8 Data analysis

Data collected was subjected to analysis of variance (ANOVA) technique to determine the effects of seasons, treatments and their interaction using the mixed procedure of

SAS (Institute, 2012) software. The means of seasons, treatments and their interaction were compared by least significance difference at $P \leq 0.05$. The results were presented using tables and figures.

The following model was used for data analysis;

$$Y_{ijklmn} = \mu + C_j + R_k + S_m + CS_{ijlm} + \Sigma_{ijklmn}$$

Where:

Y_{ijklmn} =Finger millet yield

μ = General mean

C_j = Effect due to j^{th} level of cropping system.

R_k =Effect due to k^{th} level of replication.

S_m = Effect due to m^{th} level of season

$C S_{ijlm}$ =Effect due to interaction of cropping system and season.

Σ_{ijklmn} =Effect due to $ijklmn^{\text{th}}$ random error.

CHAPTER FOUR

RESULTS

4.1 Effect of intercropping finger millet and beans on weed management

The results on the effect of treatments on weed type, weed biomass and weed count were as follows:

a) Weed type and biomass

The results of analysis of variance showed that treatments significantly ($P \leq 0.05$) influenced weed type (Figure 2). The highest recorded values were of broad-leaved weeds while the lowest values were of narrow-leaved weeds across all the treatments. The highest values of broad-leaved weeds were recorded in Gulu –E sole weedy, U-15 sole weedy and P-224 sole weedy in a descending order. The broad-leaved weeds that were observed at the experimental site included: *Bidens pilosa*, *Commelina benglensis*, *Galinsoga parviflora*, *Oxalis latifolia*, among others. While narrow-leaved included weeds such as *Digitaria scalarum*, *Cynodon dactylon* and *Cyperus rotundus*.

The results also showed that treatments significantly ($P \leq 0.05$) influenced weed biomass with weedy finger millet recording highest biomass on broad-leaved weeds compared to weed free finger millet and finger millet-bean intercrop which recorded the lowest weed biomass on broad and narrow-leaved weeds (Figure 2).

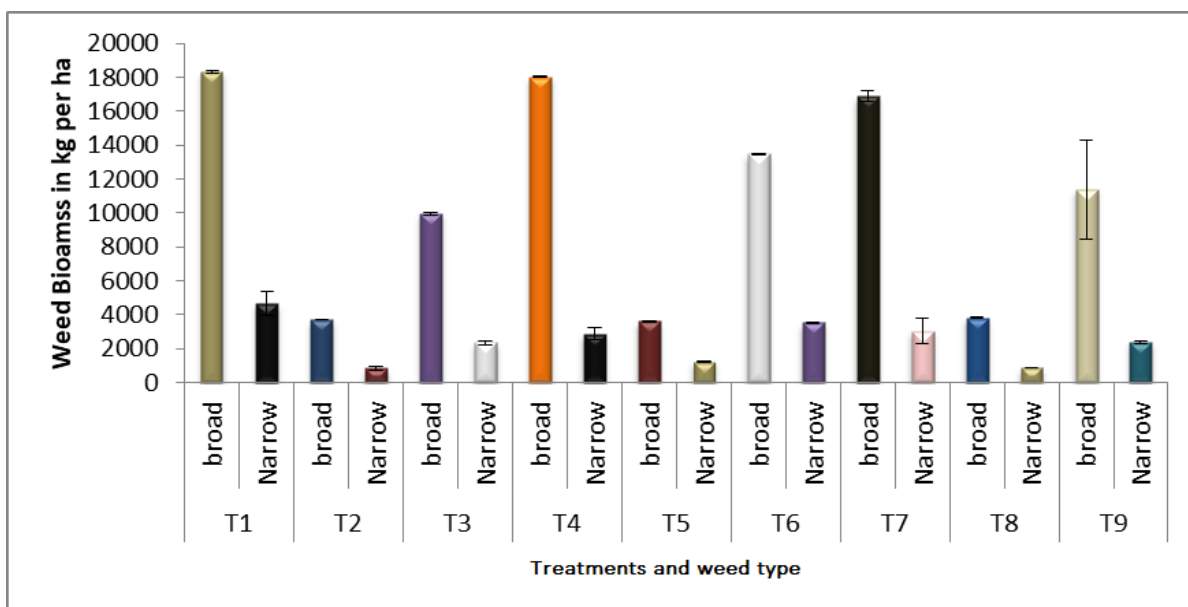


Figure 2: Effect of treatments on weed type and weed biomass

T1: Gulu -E sole (weedy), T2: U-15 + beans, T3: P-224 sole (weed free), T4: U-15 sole (weedy), T5: P-224 + beans, T6: Gulu-E (weed free), T7: P-224 sole (weedy), T8: Gulu-E + beans, T9: U-15 sole (weed free).

b) Weed count

Analysis of variance showed that intercropping finger millet with beans significantly ($P \leq 0.05$) influenced weed count as shown in Figure 3. Gulu-sole weedy finger millet recorded the highest weed count followed by P-224 sole weedy and U-15 sole weedy and they were statistically different. U-15 sole weed free, P-224 sole weed free, P-224 sole weed free and Gulu- sole weed free were also statistically different ($P \leq 0.05$) but recorded moderate weed count. Finger millet - bean intercrop recorded the lowest number of weeds, that is, U- 15, P-224 and Gulu- E all intercropped with beans.

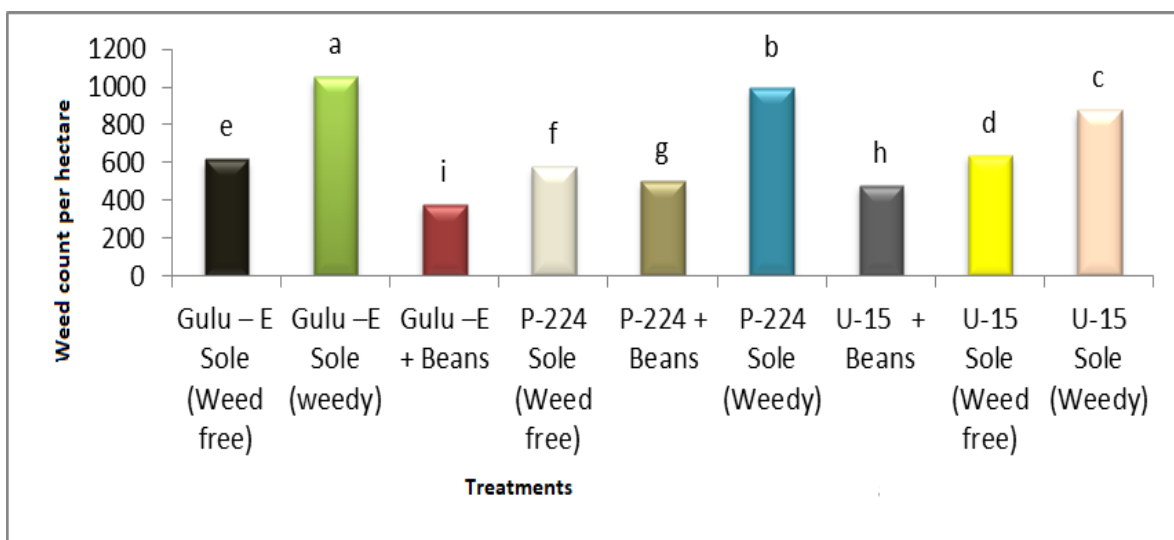


Figure 3: Effect of treatments on weed count

The small letters at the top of the bars denote levels of significance.

The results on the effect of season on weed type, weed biomass and weed count were as follows:

a) Weed type

The results of analysis of variance showed that season significantly ($P \leq 0.05$) influenced the weed type in both seasons (Figure 4). The highest value for broad-leaved weeds was recorded during the long rains season. While the lowest value of the broad-leaved weeds was recorded during the short rains season. Similarly, there were a higher number of broad-leaved weeds in both seasons as compared to narrow-leaved weeds.

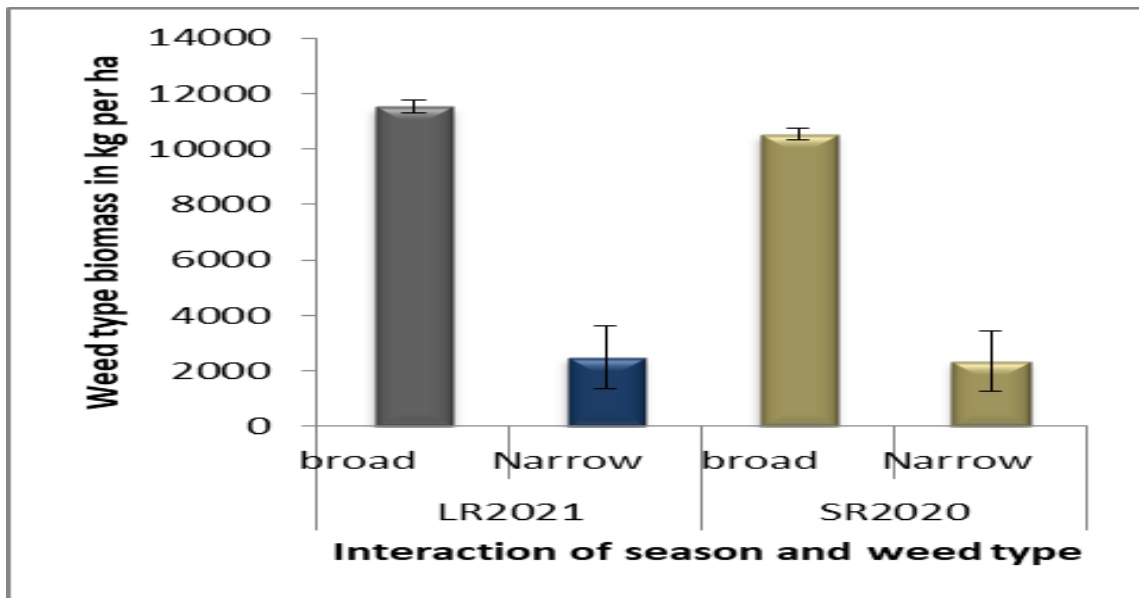


Figure 4: Effect of season on weed type

LR=Long rains

SR= Short rains

b) Weed count

Analysis of variance results showed that season significantly ($P \leq 0.05$) influenced weed count with long rains recording more weeds than short rains as shown in Figure

5.

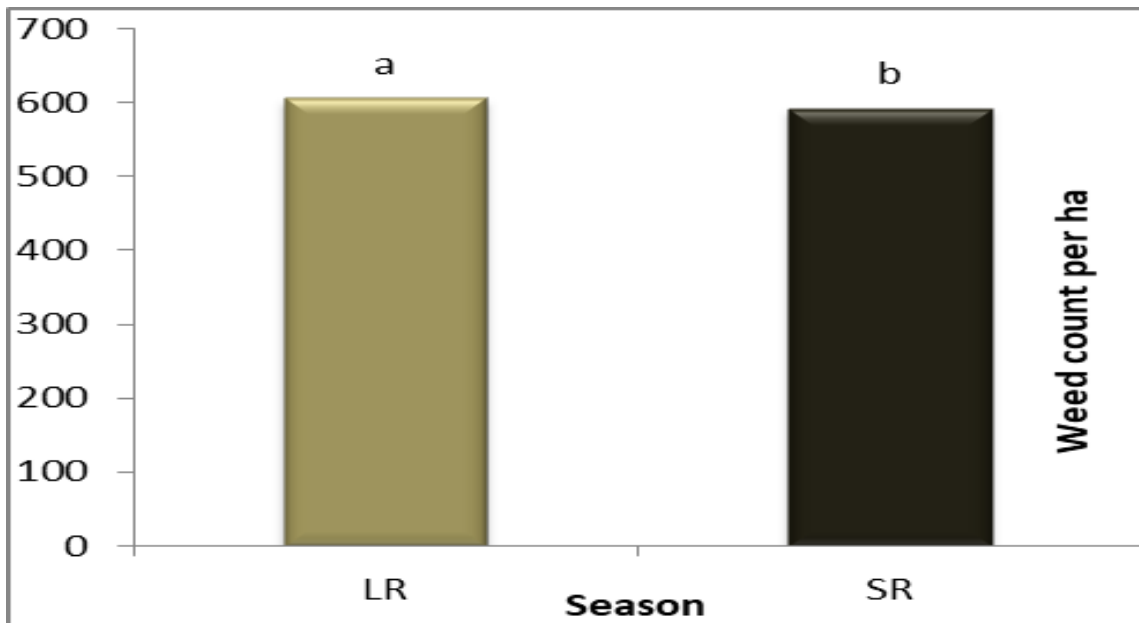


Figure 5: Effect of season on weed count

LR= Long rains

SR= Short rains

c) Weed biomass

The results of analysis of variance also showed that season significantly ($P \leq 0.05$) influenced weed biomass in that long rains recorded significantly higher weed biomass than short rains season as shown in Figure 6.

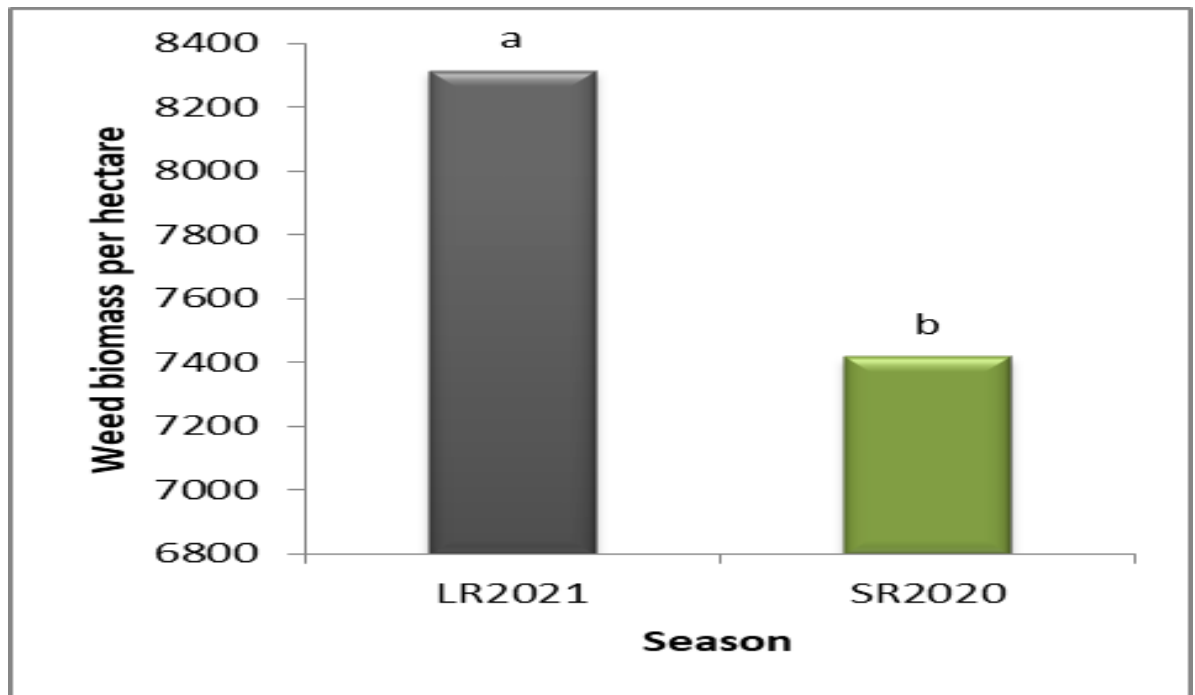


Figure 6: Effect of season on weed biomass

LR= Long rains

SR= Short rains

4.2 Effect of intercropping on growth, yield determining parameters and grain yield of finger millet

The results on the effect of intercropping on growth components and grain yield of finger millet are presented in Table 2 below.

Table 2: Effect of intercropping finger millet and beans on growth components and yield of finger millet

Treatment	Plant height (cm)	Panicle Length (cm)	Productive tillers (numbers)	50% Flowering (days)	50%Physiological Maturity (days)	Grain yield (kg/ha)
T1	53.9d	3.8f	2.3g	79.2b	110.5c	1401.8f
T2	68.1b	5.9b	6.2b	78.3c	122.7a	2870.5e
T3	70.8a	5.5c	5.7c	88.2a	120.2b	2887.0e
T4	47.7f	3.3g	4.1f	78.3c	122.7a	1201.8h
T5	51.1e	5.4c	4.6e	88.2a	120.0b	2935.2d
T6	60.5c	6.1a	7.1a	79.2b	110.8c	3118.5b
T7	45.9g	3.7f	2.7g	88.2a	120.0b	1314.8g
T8	68.0b	5.2d	5.4d	79.2b	110.5c	2992.5c
T9	60.5c	5.0e	5.8c	78.3c	122.7a	3179.7a
LSD	1.36	0.16	0.16	0.48	0.91	41.6
CV%	1.98	2.68	2.7	0.49	0.65	1.46

Means followed by the same lowercase letter (s) within the column are not significantly different ($P \leq 0.05$)

T1: Gulu -E sole (weedy), T2: U-15 + beans, T3: P-224 sole (weed free), T4: U-15 sole (weedy), T5: P-224 + beans, T6: Gulu-E (weed free), T7: P-224 sole (weedy), T8: Gulu-E + beans, T9: U-15 sole (weed free)

a) Plant height

Treatments significantly ($P \leq 0.05$) influenced plant height across the two seasons (Table 2 and Appendix I). P-224 finger millet sole weed free was significantly higher than the other treatments as it recorded 70.8 cm. U- 15 intercropped with beans (68.1 cm) was statistically similar with Gulu- E (68.0 cm) intercropped with beans but statistically different from the rest of the treatments. This was followed by Gulu-E sole (60.5 cm) that was not significantly different from U-15 sole weed free, however, they were significantly different from the other treatments. Gulu- E sole weedy, P-224 with bean intercrop, U-15 weedy and P-224 sole weedy recorded the lowest plant height and were significantly different in descending order.

b) Panicle length

Treatments also significantly ($P \leq 0.05$) influenced panicle length of finger millet across the two seasons as shown in Table 2 and Appendix II. Gulu-E finger millet sole weed free (T6) was significantly higher than the other treatments as it recorded 6.1cm of panicle length This was followed by U-15 intercropped (T2) with beans (5.9 cm) which was statistically different with P-224 sole weed free (T3) (5.5 cm), however, it did not differ statistically with P-224 intercropped (T5) with beans (5.4 cm). Gulu- E intercropped with beans (T8) differed significantly with U-15 sole weed free (T9) with mean panicle length of 5.2 cm and 5.0 cm respectively. Panicle length was statistically same for Gulu-E sole weedy (T1) and P-224 (T7) sole weedy but differed significantly with U-15 sole weedy (T4) which recorded the lowest panicle length among all treatments (3.3 cm).

c) Productive tillers

Mixed model of analysis of variance results also showed that treatments significantly ($P \leq 0.05$) influenced productive tillers of finger millet across the two seasons as shown in Table 2 and Appendix III. Gulu- E finger millet sole weed free (T6) recorded more productive tillers (7) as compared to U-15 intercropped (T2) with beans (6.2) which was statistically different with U-15 sole weed free (T9) which had a mean of 5.8 productive tillers per millet plant, however, it did not differ statistically with P-224 sole weed free (T3) which had a mean of also 5.8 productive tillers per millet plant. Gulu- E intercropped with beans (T8) was significantly different with P-224 intercropped with beans (T5). The mean productive tillers (4.1) of U-15 sole weedy (T4) was statistically different with P224 (T7) sole weedy and Gulu- E sole weedy (T1), however, P-224 sole weedy (T7) was statistically same as Gulu-E sole weedy.

d) Days to 50% flowering

Analysis of variance results also showed that treatments significantly ($P \leq 0.05$) influenced days to 50% flowering period of finger millet across the two seasons (Table 2 and Appendix IV). P-224, Gulu- E and U-15 finger millet varieties differed significantly. P-224 finger millet variety took 88 days to reach 50 % flowering regardless of whether it was sole weed free, intercropped or sole weedy. Gulu-E finger millet variety took 79.2 days to reach 50% flowering and was statistically different ($P \leq 0.05$) from P-224. However, it was statistically same whether sole weed free, intercropped or weedy. The earliest finger millet was U-15, which reached 50% flowering at 78.3 days after planting and it statistically differed with Gulu-E and P-224 respectively.

e) Days to 50% physiological maturity

The results of analysis of variance also showed that treatments significantly ($P \leq 0.05$) influenced days to 50% physiological maturity of finger millet across the two seasons (Table 2 and Appendix V). P-224, Gulu- E and U- 15 finger millet varieties differed significantly ($P \leq 0.05$). U-15 finger millet variety took 122.7 days to reach 50 % physiological maturity regardless of whether it was sole weed free, intercropped or sole weedy. It was followed by P-224 finger millet in a descending order which took 120.0 days to reach 50% physiological maturity. P-224 was also statistically different ($P \leq 0.05$) from Gulu- E.

f) Grain yield

Analysis of variance results showed that treatments significantly ($P \leq 0.05$) influenced finger millet grain yield across the two seasons (Table 2 and Appendix VI). U-15 finger millet sole weed free (T9) recorded more grain yield (3179.7 kg/ha) when compared

with Gulu- E weed free (T6) intercropped with beans (3118.0 kg/ha). Gulu- E weed free (T6) was statistically different with Gulu-E (T8) intercropped with beans (2992.5 kg/ha) that was significantly higher than P224 intercropped with beans (2935.2 kg/ha). This was followed by P224 sole weed free (T3) which had a mean grain yield of 2887.0 kg/ha, however, P-224 sole weed free (T3) was statistically similar with U-15 intercropped with beans (T2) which had a mean grain yield of 2870.5 kg per ha. Generally, the mean grain yield for all the weedy treatments was lowest among and between treatments, with U-15 sole weedy recording the lowest mean yield of 1201.8 kg per hectare. This represents a yield loss of 264% when compared to U-15 sole weed free treatments.

The results on the effect of season on growth, yield determining parameters and grain yield of finger millet were as follows:

a) Plant height

Analysis of variance results showed that season significantly ($P \leq 0.05$) influenced plant height of finger millet as shown in Figure 7 and Appendix I. The highest values for plant height were recorded during the long rains season (78.0 cm) while the lowest values for plant height were recorded during the short rains season.

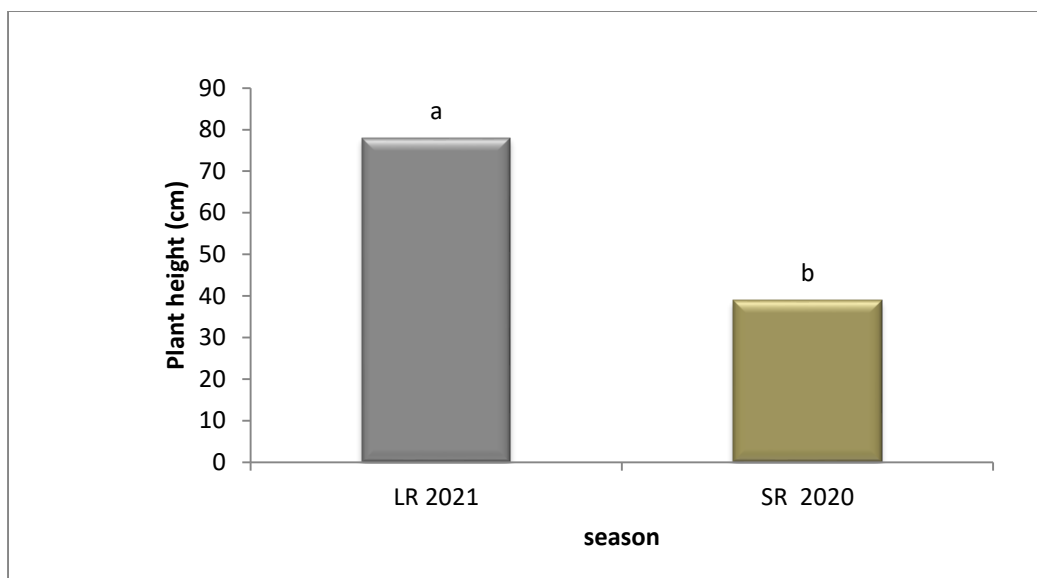


Figure 7: Effect of season on plan height

LR= Long rains

SR= Short rains

b) Panicle length

The analysis of variance results showed that the influence of season on the panicle length was higher during the long rains season than in the short rains season as shown in Figure 8 and Appendix II. In addition, the panicle length was 51% more in long rains than in the short rains season.

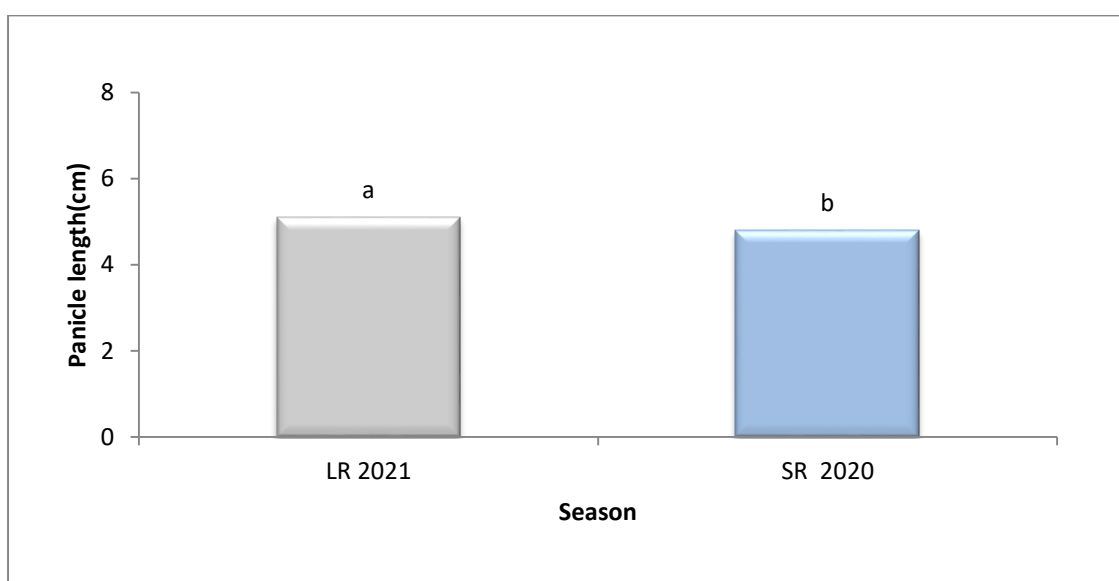


Figure 8: Effect of season on panicle length

LR= Long rains

SR= Short rains

c) Productive tillers

The number of productive tillers was not significantly ($P \geq 0.05$) affected by the season (Figure 9 and Appendix III). In this case, the number of productive tillers during both the long and short rains season was statistically similar.

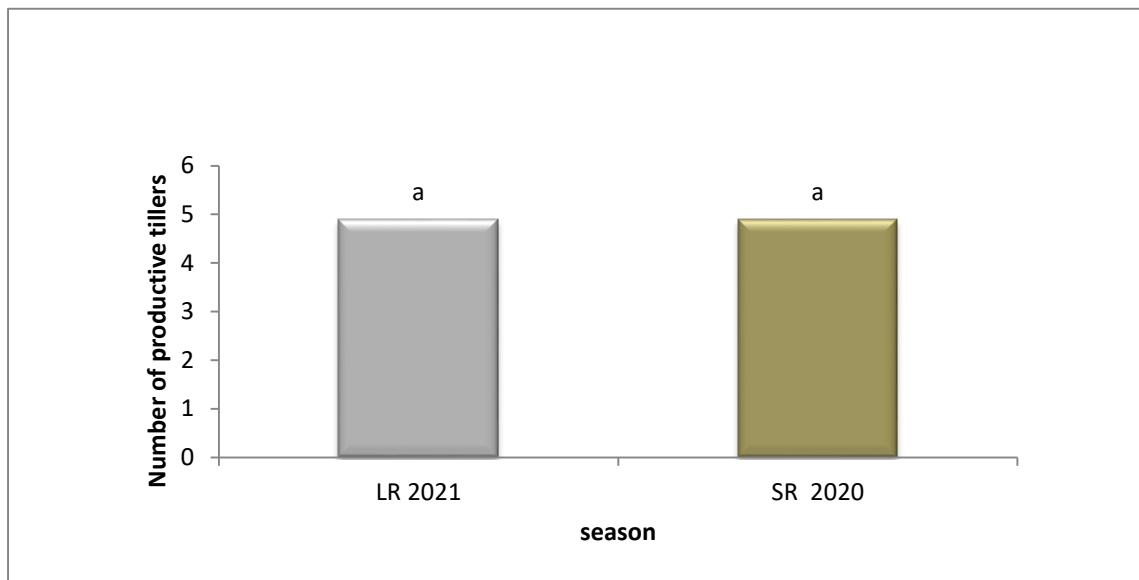


Figure 9: Effect of season on number of productive tillers

LR= Long rains

SR= Short rains

d) Days to 50% flowering

The analysis of variance results showed that season had a significant ($P \leq 0.05$) influence on days to 50% flowering as shown in Figure 10 and Appendix IV. The finger millet reached 50% flowering sixteen days (16) later in the long rains when compared to short rains season.

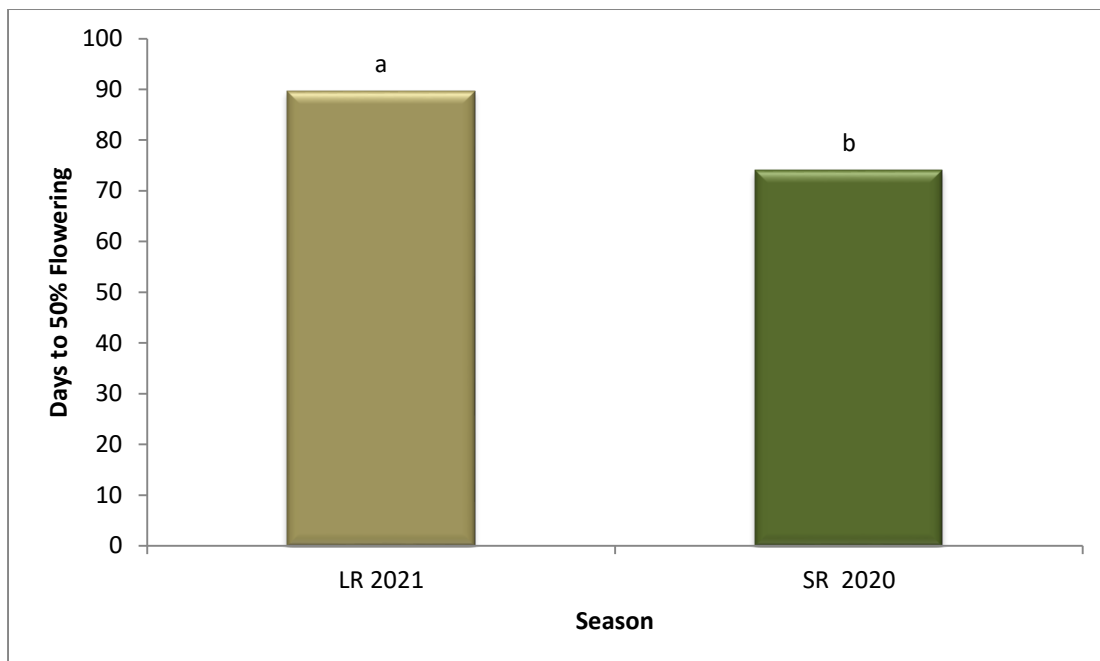


Figure 10: Effect of season on days to 50% flowering

LR= Long rains

SR= Short rains

e) Days to 50% physiological maturity

Analysis of variance results showed that season significantly ($P \leq 0.05$) influenced days to 50% physiological maturity as shown in Figure 11 and Appendix V. In this case, finger millet delayed by seven days to reach physiological maturity in long rains compared to short rains season.

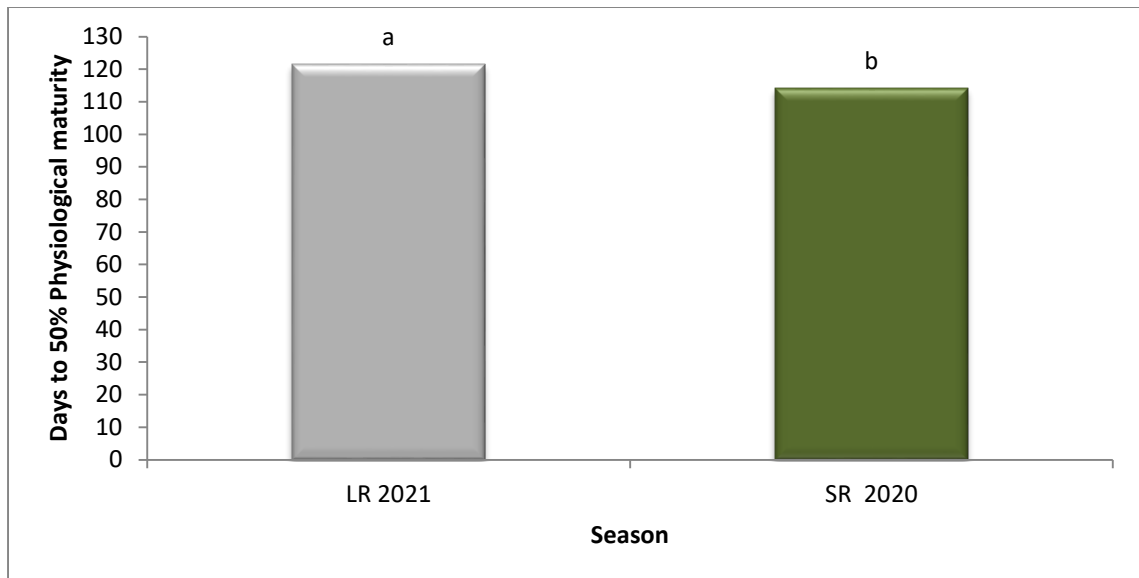


Figure 11: Effect of season on days to 50% physiological maturity

LR= Long rains

SR= Short rains

f) Dry grain yield

The results of analysis of variance showed that there was a significant ($P < 0.05$) difference in dry grain yield between the long and short rains season (Figure 12 and Appendix VI). The highest grain yield of finger millet (2755.9 kg/ha) was recorded during the long rains season while the lowest dry grain yield (2111.2 kg /ha) was recorded during the short rains season.

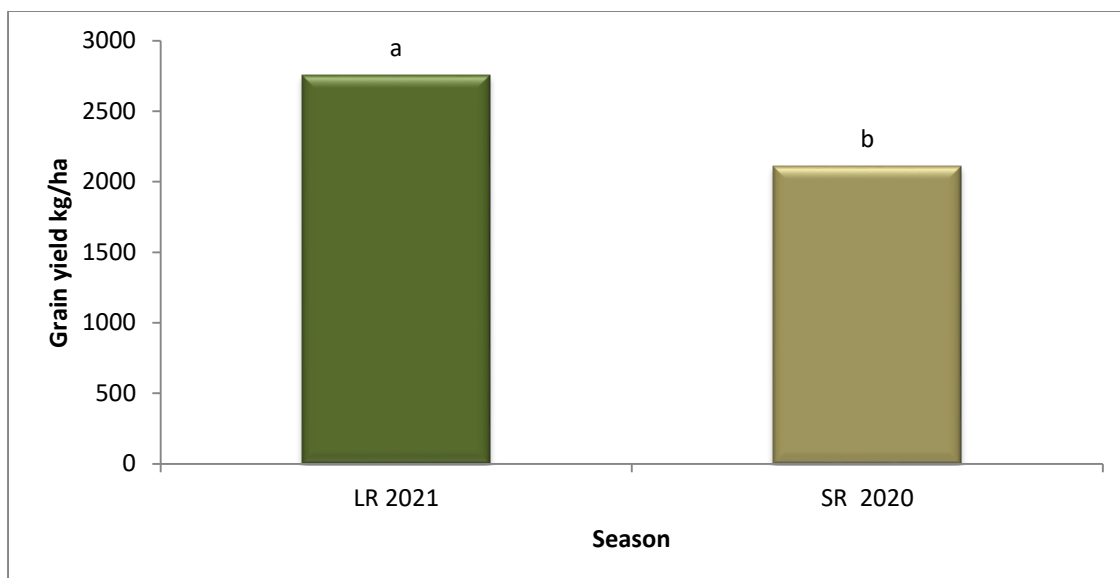


Figure 12: Effect of season on grain yield

LR= Long rains

SR= Short rains

4.3 Effect of intercropping on finger millet grain yield

The results on the effect of treatments on finger millet grain yield are as follows:

Analysis of variance results showed that treatments significantly ($P \leq 0.05$) influenced finger millet grain yield across the two seasons (Table 2). U-15 finger millet sole weed free (T9) recorded more grain yield (3179.7 kg/ha) when compared with Gulu- E weed free (T6) intercropped with beans (3118.0 kg/ha). Gulu- E weed free (T6) was statistically different with Gulu-E (T8) intercropped with beans (2992.5 kg/ha) that was significantly higher than P-224 intercropped with beans (2935.2 kg/ha). This was followed by P-224 sole weed free (T3) which had a mean grain yield of 2887.0 kg/ha, however, P-224 sole weed free (T3) was statistically similar with U-15 intercropped with beans (T2) which had a mean grain yield of 2870.5 kg per ha. Generally, the mean grain yield for all the weedy treatments was lowest among and between treatments, with U-15 sole weedy recording the lowest mean yield of 1201.8 kg per hectare. This represents a yield loss of 264% when compared to U-15 sole weed free treatments.

The results on the effect of season on finger millet dry grain yield were as follows:

The effect of season significantly ($P \leq 0.05$) influenced grain yield of finger millet at $P \leq 0.05$. Finger millet during long rains had a grain yield advantage of 31% compared to short rains as shown in Figure 12.

4.3.1 Effect of treatments on growth, yield parameters and grain yield of common bean

The results on the effect of treatments on growth, yield parameters and grain yield of common bean are presented in Table 3.

Table 3: Effect of intercropping finger millet and beans on growth components and grain yield of beans

Treatments	Plant height (cm)	Leaf Width (cm)	No. of pods/plant (numbers)	No of per pod/Plant (numbers)	Seeds	Grain yield (kg/ha)
U-15 +Beans	57.9b	8.7c	11.5c	7.4b		2702.6b
P-224+Beans	58.9c	7.6a	9.6b	7.2b		2342.5a
Gulu-E+ Beans	56.4a	8.1b	10.7a	5.8a		2042.5a
LSD	0.34	0.20	0.92	0.25		291.02
CV%	25.3	1.9	6.7	8.5		10.2

Means followed by the same lowercase letter (s) within the column are not significantly different ($P \leq 0.05$).

a) Plant height

The effect of treatments on plant height of common bean differed significantly ($P \leq 0.05$) among the treatments as shown in Table 3. The common bean intercropped with the finger millet variety P-224 was significantly higher than all other treatments as it recorded 58.9 cm while the common bean intercropped with the finger millet variety Gulu – E recorded the lowest plant height (56.4 cm).

b) Leaf width

The results from this study indicated that treatments significantly ($P \leq 0.05$) influenced the leaf width of common bean (Table 3). The longest value for leaf width was recorded in the common bean intercropped with finger millet variety U-15. The shortest value for leaf width was recorded in the common bean intercropped with finger millet variety P-224.

c) Number of pods per plant

The results have revealed that treatments significantly ($P \leq 0.05$) influenced the number of pods per plant as shown in Table 3. The highest value for number of pods was recorded in the common bean intercropped with the finger millet variety U-15 followed by Gulu – E and P-224 in a descending order.

d) Number of seeds per pod

The results from this study indicated that treatments significantly ($P \leq 0.05$) influenced the number of seed per pod (Table 3). The highest recorded values for number of seeds per pod were recorded in the common bean intercropped with the finger millet variety U-15. The lowest values for the number of seeds per pod were recorded in the common bean intercropped with the finger millet variety Gulu – E.

e) Dry grain yield

According to the results of the study, treatments significantly ($P < 0.05$) influenced grain yield of the common bean as shown in Table 3. The highest grain yield was recorded in the common bean intercropped with the finger millet variety U-15. The lowest value for the grain yield was recorded in the common bean intercropped with the finger millet variety Gulu – E.

f) 100 – grain weight

The results indicated that treatments significantly ($P \leq 0.05$) influenced 100 – grain weight of common bean (Table 3). The common bean intercropped with the finger millet variety U-15 recorded the highest 100 – grain weight while the bean intercropped with the finger millet variety Gulu E recorded the lowest 100 – grain weight.

4.3.2 Effect of season on growth components and grain yield of common bean

The results on the effect of season on growth components and grain yield of common bean were as follows:

a) Plant height

The results from this study indicated that season significantly ($P \leq 0.05$) influenced plant height of common bean as shown in Figure 13. In this case, plant height differed across the seasons whereby the highest values were recorded during the long rains season (61.0 cm) while the lowest values were recorded during the short rains season (53.9 cm).

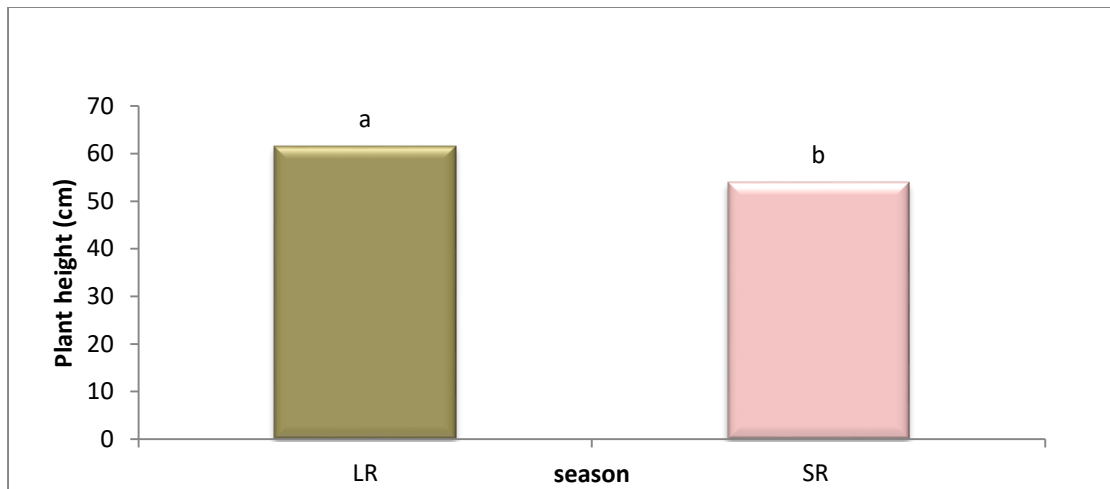


Figure 13: Effect of season on plant height

LR= Long rains

SR= Short rains

b) Leaf width

The analysis of variance results showed that season significantly ($P \leq 0.05$) influenced leaf width of the common bean (Figure 14). The longest values for leaf width were recorded during the long rains season while the shortest values were recorded during the short rains season.

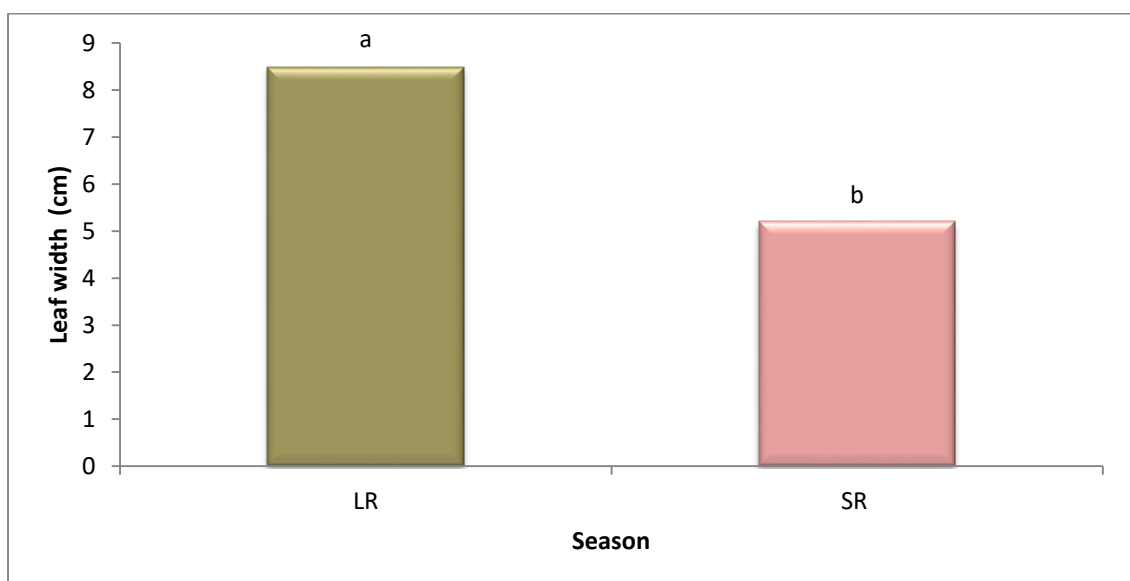


Figure 14: Effect of season on leaf width

LR= Long rains

SR= Short rains

c) Number of pods per plant

The results from the study indicated that the number of pods per plant was significantly ($P \leq 0.05$) influenced by season as shown in Figure 15. In this case, the highest values for the number of pods were recorded during long rains season while the lowest values were recorded during the short rains season.

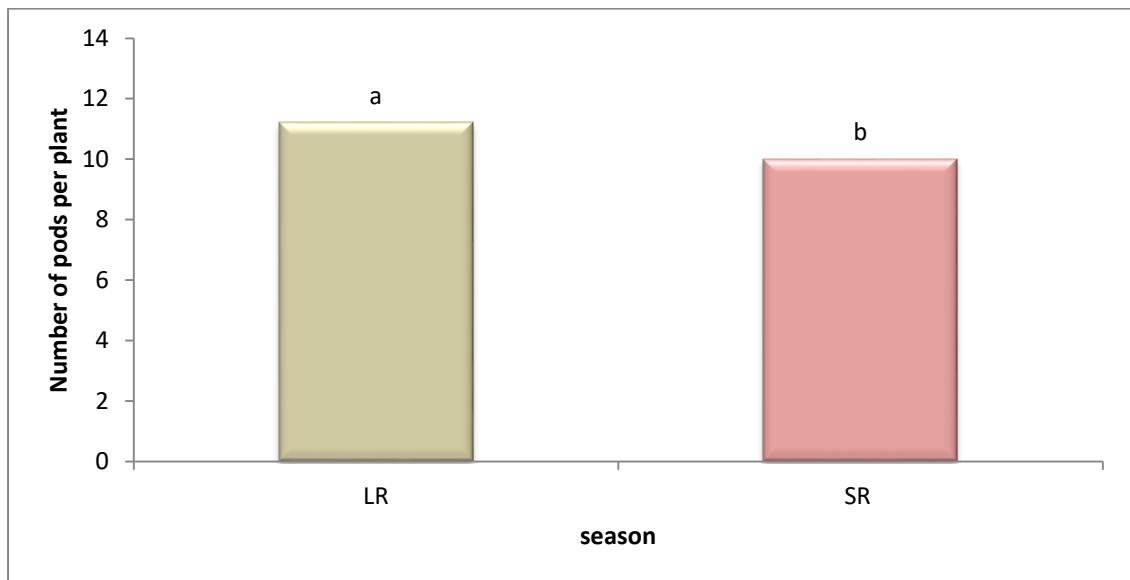


Figure 15: Effect of season on number of pods per plant

LR= Long rains

SR= Short rains

d) Number of seeds per pod

The results from the study revealed that season significantly ($P \leq 0.05$) influenced the number of seeds per pod as shown in Figure 16. The highest values for the number of seeds per pod were recorded during the long rains season. The lowest values for the number of seeds per pod were recorded during the short rains season.

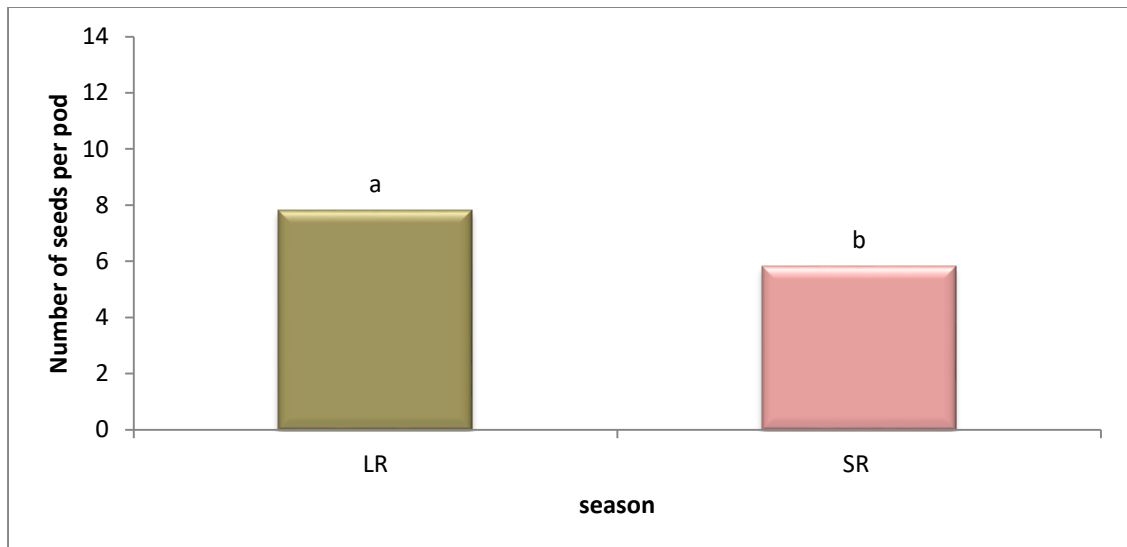


Figure 16: Effect of season on number of seeds per pod

LR= Long rains

SR= Short rains

e) Dry grain yield

The analysis of variance results indicated that season significantly ($P \leq 0.05$) influenced dry grain yield (Figure 17). The grain yield of beans varied by seasons with the long rains season recording the highest yield compared to the short rains season.

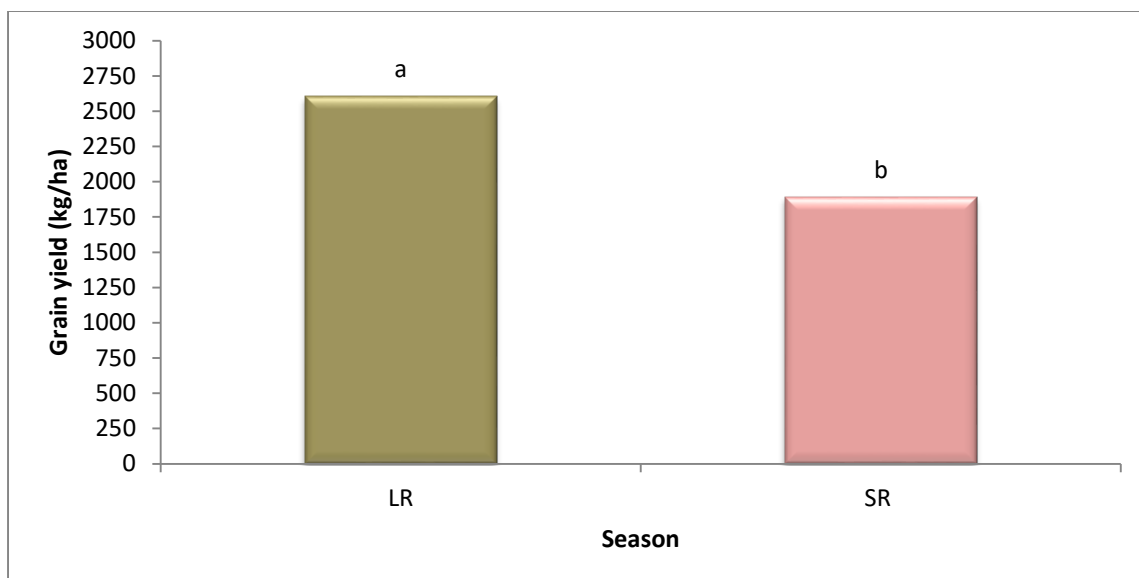


Figure 17: Effect of season on grain yield

LR= Long rains

SR= Short rains

f) 100 – grain weight

The results from the study showed that 100 - grain weight was significantly ($P \leq 0.05$) affected by season. The highest 100 - grain weight was recorded during the long rains season while the lowest value was recorded during the short rains season.

g) Days to 50% flowering

The results of the study revealed that season had a significant ($P \leq 0.05$) influence on days to 50% flowering. The common bean reached 50% flowering thirty-two days later in the long rains when compared to the short rains season. This indicated that the crop plants in the long rains season took the longest time to flowering while in the short rains the plants took the shortest time to flowering.

h) Days to 50% physiological maturity

According to the results, season had a significant ($P \leq 0.05$) influence on days to 50% physiological maturity. The common bean plants delayed by thirty-three days to reach 50% physiological maturity in the long rains compared to short rains season. Hence, the common bean attained maturity earlier during the short rains season as compared to the long rains season.

CHAPTER FIVE

DISCUSSION

5.1 Effect of intercropping finger millet with common bean on weed management

The discussion of the results on the effect of treatments on weed type, weed count, and weed biomass is as follows:

a) Weed type

The results from this study indicated that treatments significantly influenced weed type. In this case, the highest recorded values were of broad-leaved weeds while the lowest values were of narrow-leaved weeds across all the treatments. Broad-leaved weeds had a fast initial growth and vigorous canopy which enhanced interspecific and intraspecific competition thus making them dominant. The highest values of broad-leaved weeds were recorded in Gulu- E weedy, U-15 sole weedy and P-224 sole weedy in a descending order. Gulu- E had the highest value of broad-leaved weeds which could be due to its lower performance in the competition with broad-leaved weeds compared to P-224 sole weedy and U-15 sole weedy.

The finger millet variety U-15 and Gulu- E with beans recorded the lowest value of narrow-leaved weeds. These results indicate that the Gulu- E and U-15 had a superior ability of suppressing narrow-leaved weeds when intercropped with beans. These results are similar to those of Nielson *et al.*, (2003) who observed that less weed count under intercropping system may be due to higher inter-specific competition combined with complementarity between intercrop species that improved the crop stand competitive ability towards weeds.

b) Weed count

The results indicated that intercropping finger millet with beans significantly influenced weed count. Gulu- E sole weedy finger millet recorded the highest weed count followed by P-224 sole weedy and U-15 sole weedy and they were statistically different. The highest weed count in Gulu- E sole might be because of the lower performance of Gulu- E sole in the competition with weeds compared to P-224 sole weedy and U-15 sole weedy. On the other hand, high growth rate, faster canopy, and covering soil surface for a long time might be good reason for lower weed count in the P-224 sole weedy and U-15 sole weedy.

In fact, obstruction of light is the most important effect that could inhibit weed seed germination by a rapid occupation of the open space between the main crop rows and reducing weed seedling growth and development (Steinmaus *et al.*, 2008). U-15 sole weed free, P-224 sole weed free and Gulu- E sole weed free were also statistically different but recorded moderate weed count. These results showed that these treatments had a moderate ability of suppressing the weeds at the site.

The finger millet bean intercrop recorded the lowest weed count, that is, U-15, P-224 and Gulu- E all intercropped with bean. The less weed count under intercropping system maybe was due to higher inter-specific competition combined with complementarity between the intercrop species that improved the crop stand competitive ability towards weeds (Nielson *et al.*, 2008). These results were similar to those of Szumigalski and Van Acker (2005) who reported that intercrop treatment tended to provide greater weed suppression compared to sole finger millet.

The intercrops that are effective at suppressing weeds capture a greater share of available resources than sole crop and can be more effective in pre-emptying resources

by weeds and suppressing weed growth. Other suppressive effects of finger millet intercrop have been reported. Midega *et al.*, (2010) reported that intercropping of finger millet with desmodium significantly reduced the striga population in the field. Generally, finger millet sole had significantly higher number of weed count compared with intercrop indicating that intercropping was more effective in suppressing the weeds thereby reducing their numbers. Niche differentiation between component crop species is regarded as a major mechanism that enhances a better weed suppression in intercrops as compared to sole treatments. This is because the combination of species in an intercrop treatment occupies a broader niche, hence leaving less empty space for weeds.

c) Weed biomass

The results from the study showed a positive influence on weed biomass with weedy finger millet recording higher biomass on broad-leaved weeds compared to weed free finger millet and finger millet bean intercrop which recorded lower weed biomass on broad and narrow –leaved weeds. The higher weed biomass in sole weedy finger millet could be due to the intraspecific competition for growth resources.

These results are similar to those of Chandra *et al.*, (2013) who reported that the weed biomass was higher in sole finger millet plots (250 kg/ha) compared to intercropping. The weed biomass was the lowest in intercropping because the finger millet had greater growth rate than beans when they were grown in mixture together. However, on the other hand finger millet occupied the upper part of the canopy and cast shadow on bean and on the other hand beans in the lower part of the canopy cast shadow on the soil and led to suppression of weeds in this system. Similarly, finger millet (*Eleusine coracana*) intercropped with green leaf desmodium (*Desmodium intortum*) reduced *Striga hermonthica* biomass in the intercrop than in the monocrop (Midega *et al.*, 2010).

In addition, reduction of weed incidence was also observed in intercropping system with high coverage compared to monocropping (Daryanto *et al.*, 2020). Hence, recent studies have addressed intercropping as an option for an integrated weed management particularly in farming systems with low external inputs (Agegnehu *et al.*, 2006). If the crops grown together differ in the way they utilize environmental resources they can complement each other and make better combined use of resources than when they are grown separately (Gomes *et al.* 2005).

Other similar results showed that intercropping of maize and soy bean, maize and cowpea significantly reduced weed growth than sole cropping (Kiwia *et al.*, 2019). The morphological and physiological differences among intercrop components resulted in their ability to occupy different niches. Thus, environmental resources could be more efficiently utilized and converted to biomass by mixed stands of crops than by pure stands (Amar *et al.*, 2015). Also, reduction in weed biomass in intercropped treatments could be due to shading effect brought about by the canopy by finger millet having suppressive impact on the available weeds. Therefore, in the present study, more PAR interception and also greater water and nutrient extraction by intercrops could be the major reason for the lower weed biomass observed for intercropping over sole cropping. The following is the discussion of the results on the effect of season on weed type, weed count, and weed biomass:

a) Weed type

According to the results, season significantly influenced the weed type in both seasons. The highest value for broad-leaved weeds was recorded during the long rains season. While the lowest value of the broad-leaved weeds was recorded during the short rains season. Similarly, there was a higher number of broad-leaved weeds in both seasons as compared to narrow leaved weeds. The long rains resulted in good germination of

broad-leaved weeds. Furthermore, the broad-leaved weeds absorbed a lot of water from the soil than the narrow-leaved weeds.

b) Weed count

The results revealed that season significantly influenced weed count with long rains recording more weeds than short rains season. In this case, during the long rains season, the weed count was higher than that of the short rains season. This could be due to the fact that cumulative rainfall in the rain season, combined with other factors such as increased frequency and amplitude of wetting stimulated more weeds to germinate. Furthermore, additive weed emergence as the long rain season progresses is dependent on adequate soil moisture (Benech-Arnold *et al.*, 2000).

Indeed, the importance of soil water potential (rainfall) in determining weed germination and emergence is recognized in the release of hydrothermal weed emergence empirical models which integrate soil water potential and soil temperature (Werle *et al.*, 2014). This is contrary to Rodenberg *et al.*, (2010) who postulated that under prolonged drought spells, C4 and parasitic weeds like *S. hermonthica* will thrive better.

c) Weed biomass

According to the results of the study, season significantly influenced weed biomass in that long rains recorded significantly higher weed biomass than short rains season. The highest biomass product of weeds was observed in long rains 2021 because of the high rainfall that favoured the increase of weed biomass. The conditions created by higher rainfall led to availability of soil water which favoured the increase of weed biomass and community. The low rainfall during the short rains season affected the weed germination hence lower weed biomass.

These results further emphasized that the very low rainfall coinciding with the germination period of the crop and associated weeds, reduced significantly the weed biomass (Maria and Juan, 2021). The results from this study further suggest that in short rains season soil moisture was not adequate at the beginning of the season to stimulate major flushes of weed germination. In the short rains season, the accumulation of adequate hydrothermal units for most weed species at the site to germinate and emerge was delayed by a high frequency of days when there was lack of moisture in the soil as a result of the low and erratic rainfall. Hence, this explains the increase in weed biomass that was recorded during the long rain season in this particular study.

5.1.1 Dominant weed species composition before and after treatment application

The major weed flora of the experimental field consisted of grass weeds: *Digitaria scalarum*, *Cynodon dactylon*, sedges: *Cyperus rotundus* and broad – leaved weeds: *Conyza banariensis*, *Bidens pilosa*, *Commelina benglensis*, *Galinsoga parviflora*, *Datura stramonium*, *Oxygonum sinuatum*, *Oxalis latifolia* and *Leonitis nepetifolia*. The population of broad – leaved weeds was greater than narrow – leaved weeds.

The results of weed species composition in this study showed that weed seed bank is dynamic because species changed from those observed before land preparation in both seasons. The most dominant weeds species were annual weeds. The presence of annual weeds could be due to soil disturbances during tillage operation such as seedbed preparation and weeding. The annual weeds are well adapted to succeed in environments which are highly unstable and unpredictable brought about by frequent tillage.

Tillage operations influenced weed seed reserves by inverting the soil along with uprooting weed seedlings and deep burying of the mature seeds (Atkinson *et al.*, 2007). Alongside this, the previously buried seeds were also returned to the soil surface (Streit

et al., 2003). Seeds returned to the soil surface as a result of tillage operations germinated and infested the field. However, diversity of weed seeds returning to shallow depths owing to frequent soil disturbance hindered the domination of a few problematic weed species (Maqsood *et al.*, 2020).

Deep tillage helped in achieving weed control goal by burying the weed seeds deeper or by destroying the roots of perennial weeds. Tillage is often necessary for removing established weeds especially perennial weeds emerging from storage roots, rhizomes or other underground vegetative propagules. Refsell and Hartzler (2009) reported that tillage operations might have positive or negative effects on weed seeds in the soil seed bank as some weed seeds are buried in the soil. In contrast, tillage was reported to work efficiently after the weed seeds had germinated as the weed seeds which had escaped deep burial were eliminated by subsequent tillage (Buhler, 2002).

Some weed species such as *Commelina benglensis*, *Galinsoga parviflora*, *Oxygonum sinuatum* and *Cyprus rotundus* were not present before land preparation appeared during the cropping seasons. On the other hand, some weed species such as *Digitaria scalarum*, *Conyza banariensis* and *Datura stramonium* which were observed before land preparation disappeared during the cropping seasons. These results showed that some seeds which were below the soil profile were moved up the profile by tillage and vice versa is true for the emerged weed species. Begum *et al.*, (2008) reported weed emergence to be influenced by soil disturbance, temperature, rainfall, soil moisture and radiant energy. Weed seeds stimulated by tillage to either emerge or die depends on depth to which germination occurs and whether current growing conditions are favourable. Generally, tillage hastens the decline in numbers of viable dormant weed seeds remaining in the soil.

5.2 Effect of intercropping on growth, yield determining parameters and grain yield of finger millet

The discussion of the results on the effect of treatments on growth, yield determining parameters and grain yield of finger millet is as follows:

a) Plant height

According to the results, treatments significantly influenced plant height of finger millet across the two seasons. The finger millet variety P-224 sole weed free was significantly higher than all other treatments as it recorded 70.8 cm. The taller plants were found in weed-free treatments while weedy treatments resulted in shorter plants. Weed competition for nutrients and water with crop plants was absent in weed free treatments resulting in increased plant height. These results are in accordance with the previous research where taller rice plants were found in all weed-free treatments (Begum *et al.*, 2008).

The enhancement of crop growth attributes could be due to the less competition by the weeds and crop for these factors throughout the crop growth period due to control of early emerged weeds. In addition, increase in the height of crop plant in the variety P-224 sole weed free might be attributed to the reduction in weed competitiveness with the crop which ultimately favoured better environment for growth and development of the crop. The varieties finger millet U-15 and Gulu- E intercropped with beans had a lower plant height compared to P-224 sole weedy. This could be due to the vigorous growth of beans which led to slender and shorter finger miller crop plant. Furthermore, the common bean shaded the finger millet thus curtailing its photosynthetic potential, as a result the finger millet plant was shorter.

Other studies have indicated that intercropped plants may decrease, increase or maintain their normal height depending on the nature of interference of the component crops (Sarita *et al.*, 2017). Similarly, Singh and Khan (2000) observed that intercropping did not affect the crop growth negatively. Yadav, *et al.*, (2015) noted that the main crops (moth bean and cluster bean) and the intercrop (pearl millet) recorded the maximum plant height under 5:1 planting system.

b) Panicle length

The results have revealed that treatments also significantly influenced panicle length of millet across the seasons. Gulu-E finger millet sole weed free was significantly higher than the other treatments as it recorded 6.1 cm of panicle length. This could be due to the reduction in weed competitiveness with the crop which favoured better nutrition and increased nutrient uptake which resulted in better growth and development of the panicles.

The U-15 intercropped with beans (5.9 cm) was statistically different with P-224 sole weed free (5.5 cm), however, it did not differ statistically with U-15 sole weed free with mean panicle length of 5.2 cm and 5.0 cm respectively. These treatments recorded a lower value compared to Gulu-E finger millet sole. This is because maybe they had a moderate ability to compete with the weeds for growth resources such as light, water and nutrients.

Panicle length was statistically same for Gulu-E sole weedy and P-224 sole weedy but differed significantly with U-15 weedy which recorded the lowest panicle length among all treatments (3.3 cm). The U-15 sole weedy had the lowest panicle length probably due to the stiff competition by weeds posed to the millet crop plants. This ultimately

led to poor growth and development of the panicles in U-15 sole weedy. Generally, the panicle length was higher in weed free and intercropped treatments and lowest in weedy (control) treatments in both seasons.

c) Productive tillers

The results from this study have indicated that treatments significantly influenced productive tillers of finger millet across the two seasons. The variety Gulu-E of finger millet sole weed free recorded more productive tillers as compared to all other treatments. These results may be due quick growth of Gulu-E hence producing more tillers. This growth habit gave it an early start towards forming a closed canopy which in turn suppressed weed growth.

The higher number of productive tillers in Gulu-E sole weed free may also be due to the lower finger millet population and wider space available for more growth and development of finger millet. Also, increase in the production of more tillers in weed free treatments could be due to better access to growth resources which enabled plants to produce more tillers. In the intercropped treatments, the number of productive tillers was lower as compared to the weed free treatments. This was may be due to the interspecific competition between the finger millet and bean plants.

Other studies have indicated that sole pearl millet recorded significantly a greater number of tillers per plant than the intercropping systems of pearl millet+green grams, pearl millet +cluster beans and pearl millet +cowpea (Baldev *et al.*, 2005). Similarly, Ansari *et al.*, (2012) reported an average increase of 9.62 cm in plant height and 1.9 in number of tillers per metre row length in sole stand of pearl millet than intercropping system at maturity stage. The lowest number of productive tillers was recorded in the

weedy treatments. This could be due to the stiff competition between the crop and weeds hence poor growth and development of finger millet.

d) Days to 50% flowering

According to the results, treatments significantly influenced days to 50% flowering period of finger millet across the two seasons. P-224, Gulu-E and U-15 finger millet varieties differed significantly may be because of their different growth and development attributes. The finger millet variety P-224 took 88 days to reach 50% flowering regardless of being sole weed free, intercropped or sole weedy. The late flowering of P-224 could be attributed to its slow growth habits. The Gulu-E finger millet variety took 79.2 days to reach 50% flowering and was statistically different from P-224. However, it was statistically same whether sole weed free, intercropped or weedy.

The earliest finger millet was U-15, which reached 50% flowering at 78.3 days after planting and it statistically differed with Gulu-E and P-224 respectively. The finger millet variety U-15 was the earliest to reach 50% flowering probably because of its fast growth rate compared to the other varieties. The earlier flowering has been observed and documented in crop plants and this is often associated with warmer temperatures.

In Germany, the phenology of 78 agricultural and horticultural events between 1951 and 2004 were on average 1.1-1.3 days earlier per decade (Estrella *et al.*, 2007). Likewise, winter wheat c. v, Kharkof grown in U.S.A Great plains has flowered 0.8-1.8 days earlier depending on location (Hu *et al.*, 2005). Other studies have associated the changes in phenology with warmer season temperatures. Earlier flowering in crop species may be related more to the earlier onset of farming activities than to temperature (Cranford and Wheeler,2009).

e) Days to 50% physiological maturity

The results from the study have indicated that treatments significantly influenced days to 50% physiological maturity of finger millet across the two seasons. The P-224, Gulu-E and U-15 finger millet varieties differed significantly and this could be due to their differential growth attributes. U-15 finger millet variety took 122.7 days to reach 50% physiological maturity regardless of whether it was sole weed free, intercropped or sole weedy. This could have been caused by the relatively slow growth rate.

The P-224 finger millet variety in a descending order took 120.0 days to reach 50% physiological maturity. P-224 was also statistically different from Gulu-E while Gulu-E finger millet variety whether sole weedy or intercropped with beans took 110.5 days to attain days to 50% physiological maturity. The Gulu-E finger millet variety was the earliest to reach days to 50% physiological maturity probably because of its accelerated crop growth and development habits.

Earlier crop maturity has been observed and documented in recent decades and this is often associated with warmer temperatures. The warmer temperatures tend to shorten developmental stages of plant crops (Estrella *et al.*, 2007). Similarly, Sennhenn *et al.*, (2017) reported that an increase in the dry spell might have a more severe impact on crop production as it accelerates crop development and ripening processes.

f) Dry grain yield

The results from this study indicated that treatments had a significant influence on finger millet grain yield across the two seasons. The finger millet variety U-15 sole weed free recorded the highest value of grain yield (3179.7 kg/ha) when compared to other treatments. The increase in grain yield was mainly due to maintenance of weed free environment especially during the critical growth stages of the crop which reduced

crop weed competition hence helped in better growth and development of finger millet resulting in higher grain yield. The increase in the yields of finger millet in weed free treatments was due to increased production and translocation of photosynthates to the grains, due to availability of growth resources which resulted to less competition offered by weeds.

The finger millet varieties P-224, U-15 and Gulu- E intercropped with beans also gave a higher yield but less than that of U-15 sole weed free and Gulu- E weed free. These intercropped treatments produced higher yield by effective use of more resources (light, moisture and nutrients) and also prevented weed's growth. The legume – based intercropping aims to produce higher yield from a unit area by making optimal use of all available resources that could not be utilized by a single crop (Meena, 2015).

The discussion of the results on the effect of season on growth, yield determining parameters and grain yield of finger millet is as follows:

a) Plant height

The results of this study showed that season significantly influenced plant height of finger millet. The highest values for plant height were recorded during the long rains season (78.0 cm) while the lowest values were recorded during the short rains season. In this case, the mean plant height for finger millet was higher in long rains (67%) more than short rains.

During the long rains season, rainfall was more abundant and more evenly distributed throughout the growing period hence increase in the height of finger millet crop plants. On the other hand, during the short rains season, plant height was more severely depressed by rainfall shortage.

b) Panicle length

The results from the study revealed that the influence of season on the panicle length was higher during the long rains season than in the short rains season. In addition, the panicle length was 51% more in long rains than in the short rains season. Other studies found grain yield per plant to be significantly influenced by finger length and finger width among finger millet genotypes from diverse regions of India (Bondale *et al.*, 2002).

c) Productive tillers

The results of the study showed that the number of productive tillers was not significantly affected by the season. In this case, the number productive tillers during both the long and short rains season were statistically similar. This indicated that the climatic factors during both seasons equally influenced the growth and development of the productive tillers.

d) Days to 50% flowering

According to the results, season had a significant influence on days to 50% flowering. The finger millet reached 50% flowering sixteen days (16) later in the long rains when compared to short rains season. In this case, the finger millet matured earlier during the short rains as compared to the long rains season. The crop plants in the long rains took the longest time to flowering (121.4 days) while in the short rains the plants took the shortest time to flowering (74.1 days).

The earlier flowering has been observed and documented in crop plants and this is often associated with warmer temperatures. In Germany, the phenology of 78 agricultural and horticultural events between 1951 and 2004 were on average 1.1 – 1.3 days earlier per decade (Estrella *et al.*, 2007). Likewise winter wheat c.v. Kharkof grown in U.S.A

Great plains had flowered 0.8 – 1.8 days earlier depending on location (Hu *et al.*, 2005). Other studies have associated the changes in phenology with warmer seasonal temperatures, earlier flowering in crop species may be related more to the earliest onset of farming activities than to temperature (Cranford and Wheeler, 2009).

e) Days to 50% physiological maturity

The results of the study revealed that season significantly influenced days to 50% physiological maturity. In this case, finger millet delayed by seven days to reach physiological maturity in long rains compared to short rains season. Hence, the finger millet attained maturity earlier during the short rains as compared to the long rains season.

During the short rains season, the phenological developments decreased so that days to 50% physiological maturity was shorter compared to the long rains season. The results also indicated that the available crop varieties including the short season grain legume varieties may not be able to exhaust their physiological potential due to the shortened development time aligned with the increased heat stress (Sennhenn *et al.*, 2017).

The earlier crop maturity has been observed and documented in recent decades and this is often associated with warmer temperatures. The warmer temperatures tend to shorten development stages of plant crop (Estrella *et al.*, 2007). Similarly, Sennhenn *et al.*, (2017) noted that an increase in the dry spell might have a more severe impact on crop production as it accelerates crop development and ripening processes.

f) Dry grain yield

The results of the study indicated that there was a significant difference in dry grain yield between the long and short rains seasons. The highest grain yield of finger millet (2755.9 kg/ha) was recorded during the long rains season while the lowest dry grain

yield (2111.2 kg/ha) was recorded during the short rains season. The yield difference across the seasons in the present study is likely to be as a result of more rainfall during the long rains season compared to the short rains season.

The yield levels during the long rains were higher compared to short rains because during the long rains season, there were continuous rains at flowering stage resulting to higher yields. As demonstrated by several authors, rainfall plays a critical role in crop growth and yields under rain fed agriculture (Biazin *et al.*, 2012). Periods of drought, however, short during some stages of growth markedly reduced the yield during the short rains season.

The results further revealed that fluctuation in weather parameters affected the grain yield during the short rains season. From the other studies, it appears that drought occurring during the growth of legumes may result in a reduction of the number of pods per plant by 65% and in a decrease of seed yield as much as 70% (Janusz and Anna, 2011). Similarly, Bondale *et al.*, (2002) found grain yield per plant to be significantly influenced by finger length and finger width among finger millet genotypes from diverse regions of India.

Other studies have showed that biological yield is the complementarity effect of increase of growth parameters, viz, increased number of branches per plant and dry matter accumulation per plant. The increased root biomass, leaf area index and crop growth rate might have positively affected the total biological yield of soy bean in sole cropping. The increased biological yield further had a positive influence on the conversion of photosynthates into economic yield, that is, seed yield (Layek, 2018).

5.3 Effect of intercropping on finger millet grain yield

The following is the discussion on the effect of treatments on finger millet dry grain yield:

The results from this study indicated that treatments significantly influenced finger millet grain yield across the two seasons. The finger millet variety U-15 sole weed free recorded the highest value of grain yield when compared to other treatments. The higher grain yield of U-15 sole weed free might be attributed to the reduction in weed competitiveness with the crop plants which ultimately favoured better environment for the growth and development of the crop. The increase in grain yield mainly due to maintenance of weed free environment especially during the critical growth stages of the crop reduced crop weed competition which helped in better growth and development of finger millet resulting in higher grain yield.

The higher yield under the U-15 sole weed free treatment was due to the fact that this treatment controlled early as well as late flushes of weeds and provided weed free environment to the crop during critical period of crop- weed competition. These results are in conformity with the findings of Pajput and Kushwah (2004).

The finger millet varieties P-224, U-15 and Gulu- E intercropped beans also gave a higher yield but less than that of U-15 sole weed free and Gulu- E weed free. These intercropped treatments produced higher yield by effective use of more resources (light, moisture and nutrients) and also prevented weed's growth. The legume – based intercropping aims to produce higher yield from a unit area by making optimal use of all available resources that could not be utilized by a single crop (Meena, 2015).

In an ideal intercropping system, most of the available natural resources are effectively utilized to enhance productivity from a unit area of land in unit time and minimize the

risk of crop failure (Seran and Brintha, 2010). Furthermore, intercropping increases availability of applied nutrients and improves nutrient use efficiency by associated cereals and thereby increases the total land output yield (Kiwia *et al.*, 2019).

Furthermore, a mixture of two or more crops often gives a better coverage of the soil and reduces the growth of weeds, runoff, and loss of soil and nutrients (Banik *et al.*, 2006). As component crops in an intercropping system differed in their competitive ability, they can use the available resources of water, nutrients and solar radiation more efficiently (Hauggard – Nielson *et al.*, 2009) and convert them regarding crop biomass or productivity (Lithourgidis *et al.*, 2011).

Similarly, Maitra *et al.*, 2000 reported that finger millet produced more yield under intercropping with pigeon pea compared to grown as sole cropping. Naresh *et al.*, (2017) reported a greater yield of millet and mung bean under intercropping compared to monocropping and attributed it to beneficial interactions between millet and legumes. However, Ghilotia *et al.*, (2015) by contrast reported a decrease in combined grain yields compared to millet grown alone due to competition of associated crop for soil nutrients and environmental resources.

Generally, the mean grain yield for all weedy treatments was lowest among and between treatments with U-15 sole weedy recording the lowest mean yield of 1201.8 kg per hectare. This represents a yield loss of 26.4% when compared to U-15 sole weed free treatments. The weedy treatments produced lowest grain yield probably due stiff competition by the weeds. In these treatments, there was maximum density and dry matter of weeds which competed with the crop plants. The severe competition exerted by the weeds on finger millet crop led to the reduction in grain yield. Reduction in grain yield of finger millet due to weed competition was also reported by Prithi *et al.*, (2015).

The crop yield losses due to weeds depend on the cultivar grown, species and number of weeds per area, competition period, and crop development stage.

The discussion of the results on the effect of season on finger millet grain yield is as follows:

According to the results of the study, there was a significant difference in dry grain yield between the long and short rains season. The finger millet during the long rains had a dry grain yield advantage of 31% compared to short rains season. The results further indicated that the highest grain yield of finger millet was recorded during the long rains season, while the lowest dry grain yield was recorded during the short rains season. The yield differences across the seasons in the present study are likely as a result of more rainfall during the long rains as compared to the short rain season.

The yield levels during the long rains season were higher compared to short rains because during the long rains season there were continuous rains at flowering stage resulting to higher yields. As demonstrated by several authors, rainfall plays a critical role in crop growth and yields under rainfed agriculture (Biazin *et al.*, 2012). Periods of drought, however short during some stage of growth markedly reduced the yield during the short rains season.

The results further revealed that fluctuations in weather parameters affected the grain yield during the short rains season. From other studies, it appears that drought occurring during the growth of legumes may result in a reduction of the number of pods per plant by 65% and in a decrease of seed yield as much as 70% (Janusz and Anna, 2011). Similarly, Bondale *et al.*, (2002) found grain yield per plant to be significantly influenced by finger length and finger width among finger millet genotype from diverse regions of India.

Other studies have revealed that biological yield is the complementary effect of increased growth parameters, viz, increased number of branches per plant. The increased root biomass, leaf area index, crop growth rate might have positively affected the total biological yield of soybean in sole cropping. The increased biological yield further had a positive influence on the conversion of photosynthates into economic yield, that is, seed yield (Layek, 2018).

5.3.1 Growth components and yield of common bean

The following is the discussion of the results on the effect of treatments on growth, yield parameters and grain yield of common bean:

a) Plant height

According to the results, treatments significantly influenced the plant height of common bean. The common bean intercropped with the finger millet variety P-224 was significantly higher than all other treatments. The higher plant height might be attributed to the reduction in weed competition with the crop which ultimately favoured better environment for growth and development of common bean plants.

Yadav *et al.*, (2015) observed that the main crop (moth bean and cluster bean) and the intercrop (pearl millet) recorded the maximum plant height under 85 planting system.

b) Leaf width

The results from this study indicated that treatments significantly influenced the leaf width of common bean. The longest value for leaf width was recorded in the common bean intercropped with U-15 finger millet variety while the shortest value for leaf width was recorded in the common bean intercropped with P-224 finger millet variety. The leaf width of the common bean intercropped with U-15 finger millet variety was the longest due to better growth of common bean due to poor competition from the

intercropped finger millet. Also, longest value of leaf width was due to the satisfactory control of weeds during the vegetative growth period.

c) Number of pods per plant

The results have revealed that treatments significantly influenced the number of pods per plant. The highest values for number of pods were recorded in the beans intercropped with finger millet variety U-15 followed by finger millet variety Gulu-E and P-224 intercropped with common bean in a descending order. The number of pods per plant of common bean directly influences the grain in common bean. In the present study, different intercropping treatments caused a significant variation in pods per plant of common bean. Also, the development of wider leaves under low weed infestation might have enhanced the photosynthetic efficiency of the crop that resulted in increase in the number of pods per plant.

d) Number of seeds per pod

The results from this study indicated that treatments significantly influenced the number of seeds per pod. The highest values for number of seeds per pod were recorded in the common bean intercropped with finger millet variety U-15 while the lowest values for the number of seeds per pod were recorded in the beans intercropped with finger millet variety Gulu-E. The grain yield of common bean directly depends on the seeds per pod of common bean. In the present study, different intercropping treatments of common bean with finger millet significantly affected the number of seeds per pod of common bean. In addition, the increase in suppression of weeds led to better crop growth hence more grain formation.

e) Dry grain yield

According to the results of the study, treatments positively influenced grain yield of the common bean. The common bean dry grain yield varied significantly in different intercropping treatments whereby the highest grain yield was recorded in the common bean intercropped with finger millet variety U-15. This might be attributed to increased growth and yield parameters such as leaf width, number of pods per plant and number of seeds per pod. The lowest value for the grain yield was recorded in the beans intercropped with finger millet variety Gulu -E. Also, better translocation of photosynthates under less competition among plants could be one of the reasons for obtaining higher yields of beans.

f) 100- Grain weight

The results indicated that treatments significantly influenced 100-grain weight of common bean. In the present study, different intercropping treatments of common bean with finger millet significantly affected 100-grain weight of common bean. 100-grain weight is an important yield contributing parameter which positively affect the final yield of common bean.

The discussion of the results on the effect of season on growth, yield parameters and grain yield of common bean is as follows:

a) Plant height

The results from this study indicated that season significantly influenced plant height of common bean. In this case, plant height differed across the seasons whereby the highest values were recorded during the long rains season (61.6 cm) while the lowest values were recorded during the short rains season (53.9 cm). The common bean plants

were significantly tall during the long rains season than in the short rains season probably due to the adequate and well distributed rainfall throughout the growing period.

b) Leaf width

The analysis of variance showed that season significantly influenced leaf width of the common bean. The longest values for leaf width were recorded during the long rains season while the shortest values were recorded during the short rains season. The abundant rains led to increase in the leaf width while shortage of water in the soil caused a decline in the leaf width. Decrease in leaf area caused by deficit of water in the soil was also found by Barrios *et al.*, (2005) for another legume bean.

c) Number of pods per plant

The results for the study indicated that the number of pods per plant was influenced by season. In this case, the highest values for the number of pods were recorded during the short rains season. The highest number of pods during the long rains season was due to favourable weather conditions. While during the short rains season unfavourable weather conditions led to the reduction in the number of pods.

d) Number of seeds per pod

The results from the study revealed that season significantly influenced the number of seeds per pod. The highest values for the number of seeds per pod were recorded during the long rains season. While the lowest values for the number of seeds per pod were recorded during the short rains season.

The abundant rains during the long rains season created favourable weather conditions which led to the increase in number of seeds per pod. While during the short rains

season weather conditions did not favour the formation of seeds hence reduction of the number of seeds per pod.

e) Dry grain yield

The analysis of variance indicated that season significantly influenced dry grain yield. The grain yield of beans varied by seasons with the long rains season recording the highest yields compared to the short rains season. This could be explained by the fact that favourable climatic conditions prevailed during the long rains season. The yield levels during the long rains were higher compared to the short rains season because during the long rains season there were continuous rains at flowering season resulting to higher yields.

As demonstrated by several authors, rainfall plays a critical role in crop growth and yields under rain fed agriculture (Biazin *et al.*, 2012). The abundant rains allowed the seed yields to be higher than those in short rains season which was characterized by shortage of rainfall throughout the growth of common bean.

f) 100 -Grain weight

The results for the study showed that 100-grain height was significantly affected by season. The highest 100- grain weight was recorded during the long rains season while the lowest value was recorded during the short rains season. The highest 100-grain weight recorded value during the long rains season was due to favourable weather conditions.

g) Days to 50% flowering

The results of the study showed that season had a significant influence on days to 50% flowering. The common bean reached 50% flowering thirty-two days later in the long

rains season when compared to the short rains season. In this case, the crop plants in the long rains season took the longest time to flowering while in the short rains the plants took the shortest time to flowering. The earlier flowering during the short rains season was attributed to warm temperatures.

h) Days to 50% physiological maturity

According to the results, season had a positive influence on days to 50% physiological maturity. The common bean plants delayed by thirty-three days to reach 50% physiological maturity in long rains compared to short rains season. Hence, the common bean attained maturity earlier during the short rains season as compared to the long rains season. During the short rains season, the physiological developments decreased so that days to 50% physiological maturity was short compared to the long rains season.

5.3.2 Resource utilization in intercropping

The main advantage of intercropping is the more efficient utilization of the available resources and increased productivity with each of the mixture (Agegnehu *et al.*, 2008). Currently there is increased interest in intercropping because resources may be used more efficiently than in the corresponding monoculture. The most important growth resources used by crops are light, water and nutrients (Brisson *et al.*, 2004). Above ground parts of plants compete for light while below ground for water and nutrients (Malezieux *et al.*, 2009).

Intercropping can conserve soil water by providing shade, reducing speed and increasing infiltration with mulch layers and improved soil structure (Tsubo *et al.*, 2001). Intercropping maize with cow pea has been reported to increase light interception in the intercropping, reduce water evaporation and improve conservation of soil moisture compared to maize alone (Gahanbari *et al.*, 2010). Water is the most

limiting factor for plant production and water is the medium that transport all other soil – based resources (Malezieux *et al.*, 2009). Compared to sole cropping system, intercropping system use less water to produce more grains and show complementarity effect in utilizing the available water (Raza *et al.*, 2021).

Overall, these results suggest that intercropping system is more profitable in obtaining a higher net income with fewer inputs. The considerably high LER values of intercropping system indicate the efficient use of available land (Gitari *et al.*, 2020), water and nutrient resources (Raza *et al.*, 2020). The observed higher production under intercropping system than pure stand could further be attributed to increased radiation use efficiency as it was followed by a high LAI. This is consistent with the previous findings in which they observed increased crop yield under intercropping and associated it with an increased light interception (Liu, *et al.*, 2018).

Agreeing with the results of other studies (Li *et al.*, 2020), the overall results of this study exhibit yield stability, resource use advantages and net profit of the intercropping system. Yield improvement by intercropping is attributed mainly to complementary effects, better resource efficiency of intercrop and buffering effects of the intercrop against weeds and diseases (Deksen *et al.*, 2002). Intercropping positively helps in the soil conservation by improving soil fertility (Jarenyama *et al.*, 2000).

In the present study, the ability of the common bean to suppress the weeds emanates from its growth habit like most of leguminous plants having high leaf area index due to massive forage that precludes light from reaching the ground where weeds are growing.

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CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. Intercropping finger millet with common bean is an effective approach of weed management than sole cropping.
2. Intercropping finger millet with common bean enhances better growth and development of finger millet.
3. Intercropping finger millet with common bean produces higher finger millet grain yield.

6.2 Recommendations

1. Small holder farmers should be encouraged to grow finger millet varieties intercropped with common bean to assist in weed suppression and improve finger millet yield.
2. There is need for farmers to grow finger millet intercropped with common bean for different ecological zones for Kenya.
3. A wide study should be done on the mechanisms by which common bean promotes growth and development of finger millet.

6.3 Further research

1. The field experiments should be carried out over a longer period of time and in multiple sites to further investigate the potential of common bean for weed suppression in finger millet varieties.
2. There is also a need to intercrop finger millet with different varieties of leguminous crops.

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APPENDICES

Appendix I: Analysis of variance on finger millet plant height

Source of variation	DF	Mean square	F-Value	Pr>F
Season	1	20576.42241	15382.7	<.0001
Treatment	8	519.89824	388.67	<.0001
Replicate	2	0.25685	0.19	0.8262
season*treatment	8	400.34491	299.29	<.0001
Error	34			
Total	53			
CV %		1.977468		

Significant levels at $P \leq 0.05$

Appendix II: Analysis of variance on panicle length

Source of variation	DF	Mean square	F-Value	Pr>F
Season	1	1.245185	71.13	<.0001
Treatment	8	6.018796	343.82	<.0001
Replicate	2	0.012407	0.71	0.4994
Season*Treatment	8	2.485185	141.97	<.0001
Error	34			
Total	53			
CV%		2.696091		

Significant levels at $P \leq 0.05$

Appendix III: Analysis of variance on number of productive tillers

Source of variation	DF	Mean square	F-Value	Pr>F
Season	1	0	0	1
Treatment	8	15.265	865.02	<.0001
Replicate	2	0.086667	4.91	0.0134
Season*Treatment	8	0	0	1
Error	34			
Total	53			
CV%		2.717227		

Significant levels at $P \leq 0.05$

Appendix IV: Analysis of variance on days to 50% flowering

Source of variation	DF	Mean square	F-Value	Pr>F
Season	1	3266.666667	19600.0	<.0001
Treatment	8	133.791667	802.75	<.0001
Replicate	2	0.166667	1.00	0.3784
Season*Treatment	8	5.291667	31.75	<.0001
Error	34			
Total	53			
CV%		0.498539		

Significant levels at $P \leq 0.05$

Appendix V: Analysis of variance on 50% physiological maturity

Source of variation	DF	Mean square	F-Value	Pr>F
Season	1	726.000000	1213.97	<.0001
Treatment	8	181.083333	302.80	<.0001
Replicate	2	5.166667	8.64	0.0009
Season*Treatment	8	82.250000	137.53	<.0001
Error	34			
Total	53			
CV%		0.656601		

Significant levels at $P \leq 0.05$

Appendix VI: Analysis of variance on grain yield

Source of variation	DF	Mean square	F-Value	Pr>F
Season	1	5612468.17	4461.19	<.0001
Treatment	8	4364644.03	3469.33	<.0001
Replicate	2	164.24	0.13	0.8781
Season*Treatment	8	271360.29	215.70	<.0001
Error	34			
Total	53			
CV%		1.457516		

Significant levels at $P \leq 0.05$

Appendix VII: Similarity Report



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