EFFECT OF MULCHING AS A WEED MANAGEMENT STRATEGY IN FIELD PRODUCTION OF FRENCH BEANS (*Phaseolus vulgaris* L.) IN KENYA.

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A THESIS SUBMITTED TO THE SCHOOL OF AGRICULTURE AND BIOTECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF SCIENCE IN PLANT PROTECTION, UNIVERSITY OF ELDORET, KENYA.

2025

DECLARATION

Declaration by the candidate

This thesis is my original work and has never been presented for the award of an academic degree in any other university and should not be copied, or reproduced in any format without written authority from the author and/or University of Eldoret.

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ACKNOWLEDGEMENT

I would like to acknowledge and thank the Director and staff at Kenya Agricultural and Livestock Research Organization (KALRO) Kitale for allowing me to conduct my research and providing any assistance requested. I would also like to thank my lecturers, supervisors, fellow students and generally the administrators in the Department of Seed, Crop and Horticultural Sciences, School of Agriculture (University of Eldoret, UoE) that assisted me with this project. Their eagerness and willingness to provide feedback made the completion of this research an enjoyable experience.

DEDICATION

This thesis work is dedicated to my family and many friends .Special gratitude to my late grandfather Mr Reuben Oluoch who always taught me that education is the key to success,my parents Dr. and Mrs. Okello and my siblings, I appreciate all they did by helping me develop this thesis throughout the entire study period. A special dedication also goes to my son Loch; may this be a lead to academic excellence for him.

ABSTRACT

There has been a 2% decrease on French bean (*Phaseolus vulgaris* L.) production in Kenya due to factors such as weeds, pests and diseases and the challenge of controlling them using chemicals that result in high rejection rate or interception in the export market because of chemical residues. The objectives of this study were to evaluate the effect of different mulching materials on the growth and yield of French bean cultivars and to determine the effect of different mulching materials on weed density. Field experiments were carried out in two seasons, long rain and short rain season of 2021 at KALRO Kitale, Trans Nzoia county. Season 1 was carried out during long rains of April and June 2021 and season two during the short rains of August and October 2021. Black polythene and grass mulch were compared with two hand weedings and no weeding in a Randomized Complete Block Design experiment with three replications. Data on growth and yield of French Beans were collected and subjected to ANOVA using GenStat to determine the significant differences between the treatments. The means were separated using Fisher's protected LSD at 5% significance level. Growth and yield of French Beans was significantly influenced by the treatments ($p \leq 0.05$). Plants grown under black polythene and grass mulch had the tallest height and the highest number of leaves and branches as well as number of pods and cumulative pod yield as compared to those that were hand weeded and unweeded. The highest pod yield of 2138 and 2597 kg/ ha was obtained under black polythene mulch in season 1 and 2 respectively. This was significantly higher than that obtained from grass mulch, hand weeding and unweeding. In conclusion polythene and grass mulch improved growth and yield of French beans and reduced weed density. It is therefore recommended that farmers should adopt mulching as a cultural weed management strategy.

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ABBREVIATIONS AND ACRONYMS

AFA – Agricultural and Food Authority

FAO – Food and Agriculture Organization of United Nation

GDP – Gross Domestic Production

GOK – Government of Kenya

HCD – Horticulture Crops Directorate

KALRO – Kenya Agricultural and Livestock Research Organization

MT – Metric Tonnes

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Horticulture is one of the most vital sub-sectors of agriculture in the Kenyan economy contributing 33% of the Agricultural Gross Domestic Product and 8% of the country's GDP (Kenya National Bureau of Statistics, 2022) , with vegetables, fruits, flowers and nuts being the major crops grown (GOK, 2020). The horticulture sub-sector has become an important source of income for rural farm households, traders and investors providing almost two million jobs to Kenyans, both directly and indirectly (FAO, 2020b).

French beans (*Phaseolus vulgaris* L.) is one of the major vegetables produced in the horticultural sub- sector for export market to the United Kingdom, France, Germany, Holland and Belgium (HCD, 2020). The crop accounts for 22 percent of vegetables produced in Kenya for export market and is one of the biggest source of foreign exchange earning the country revenue after cut flowers (AFA, 2020). It has economic and social potential in addressing food security, improving income and livelihoods and alleviating poverty (Wahome *et al.*, 2013). French bean value chain is important in the social economic systems and livelihoods as it contributes enormously to job creation for Kenyans working in the production value chain. Thousands of Kenyans earn a living either directly or indirectly by working in or with the vegetable-growing farms and the processing and packaging industries (HCD, 2020).

It is a leguminous vegetable in the Fabacaeae family in the genus Phaseolus native to Central and South America (Jatindra *et al.*, 2022). It has long edible pods that produce seeds when mature. In some countries it is known as field beans, garden beans, green beans or snap bean. French beans are used as vegetables in stir-fry, stews and grilled-salad. In the Asian region, French beans are used in curries, soups, stir-fry with rice and others. The leaves are also used as pot- herbs and the straws as forage (Ndegwa *et al.,* 2010).

Weed infestation is one of the major problems in French bean production. High weed infestation leads to increased competition for water, sunlight and nutrients and this in turn decreases crop yield. Proper weed management is therefore a key cultural crop management practice. Weed management in French beans is limited to cultural methods such as hand weeding which is safe but labour intensive. Chemical weed management is a great challenge due to the EU regulations on chemical residues and increased demand for chemical free produce by consumers (Ashu *et al.*, 2022).

1.2 Statement of the Problem

There has been a 2 percent decrease on French bean (*Phaseolus vulgaris* L.*)* production in Kenya. There has been a varying trend in production over time, with 66765 MT in 2017, 60013 MT in 2018, 83,530 MT in 2019 and 68905 MT in 2020. This variation in yield is attributed to several factors such as weeds, insect pests and diseases and the challenge of controlling them using chemicals that has resulted in high rejection rate or interception in the export market because of chemical residues (HCD, 2020).

Weeds are the most costly category of agricultural pests, causing more yield losses and added labor costs than either insect or diseases (Schonbeck 2011).Weeds account for 45 percent of losses experienced annually on agricultural produce, followed by insects 30 percent, diseases 20 percent and other pests 5 percent (Madukwe *et al.*, 2012). Weeds reduce crop yield and interfere with the use of water and land resources (Hamada *et al.*, 2009). French beans are extremely poor competitors against weeds in field conditions, the crop is highly susceptible to weed competition that affects the quality and ultimate yield during the early stages of growth and therefore should always be kept weed free (Charlker - Scott 2007).

Ultimate yield losses due to weed infestation depends on composition of weed flora and extent of infestation. It has been estimated that weeds alone can reduce the yield of French beans by up to 20-60 percent (Mukhtar 2012; Panotra and Kumar, 2016b). Uncontrolled weed growth reduces yield of crops by 50-100 percent, initial heavy infestation of weeds hinders overall growth and productivity of French beans since its initial growth rate is slow compared to the weeds (Mukhtar *et al.*, 2007).

Use of Hand weeding for weed control in in French bean is quite effective but costly and time consuming whereas the use of chemical weed control is expensive and limited due to high market demand for chemical free produce (Goud and Dikey, 2016).

Cultural weed management strategies such as mulching is therefore a promising option for weed control in French bean production systems however lack of access to knowledge abouttheir effectiveness is a significant in many production systems.

1.3 Justification

Although weed management is the most important cultural practice in crop production to ensure maximum yield and high quality crop produce, effective weed management is one of the main challenges in crop production (Colquhoun, 2007). Good weed management strategies results in higher yields and good quality produce (Abbasi *et al.*, 2013). It is therefore important for farmers to practice proper weed management measures to ensure they get maximum returns from inputs applied to the crop during production (Schonbeck 2008). Availability of alternative weed control methods is one of the factors that motivate farmers to choose weed control strategies that give them the best returns (FAO, 2020b). Mulching is an important component in crop production and very limited studies have been carried out on its use and effectiveness as a weed management strategy.

Considering the importance of French beans as a major horticultural export crop and providing a means of livelihood to farmers, the costs of weeds in terms of yield reduction, expenditure on their control, and the many options available for weed control, more information is needed about the effectiveness of mulch as weed management strategy in French beans to obtain maximum yield and profit. This study is therefore designed to investigate how the use of mulch for weed management influences growth and ultimate yield of French bean.

1.4 Objectives

1.4.1 General objective

- To increase production of French Bean in Kenya.

1.4.2 Specific objectives

1. To evaluate the effect of different mulching materials on the growth and yield of French bean cultivars.
2. To determine the effect of different mulching materials on weed density in French beans in French bean production fields.

1.5 Research Hypothesis

1. Mulching positively influences the growth and yield of French beans.
2. Mulching effectively control weeds in French Beans

CHAPTER TWO

LITERATURE REVIEW

2.1 Botanical Description of French beans

French bean is a herbaceous plant in the family Fabacaeae. It is an annual plant, with either a dwarf or climbing growth habit, however the dwarf type is common in Kenya. It has a tap root system and a branched herbaceous stem with alternate, compound, trifoliate and pulvinate leaves. It bears papilionaceous, zygomorphic hermaphrodite white or purple flowers. The long pods vary in color, depending on cultivar with 3-12 seeds in its interior that may be black, white or red colored, two colored or marbled (Romero-Arenas *et al.*, 2013). *Phaseolus* genus includes about 50 plant species, all native to America. It is commonly referred to as Snap beans, bush beans or string beans (Chi Christopher *et al.*, 2022).

2.2 Ecological conditions for growth of French beans.

In Kenya the crop performs well at an altitude of 1000-2100 m above sea level, with an average annual rainfall of 900-1200 mm and optimum temperature ranges from 16° C to 25° C. Extremely high rainfall during the growing season increases disease and insect pest incidences. To have continuous production of French bean pods, irrigation is required in areas that receive inadequate rainfall. French beans can be cultivated in soils ranging from light sandy loam to clay. However, they grow best on well drained medium loam soils with plenty of organic matter content. A pH ranging from 6.5 to 7.5 is the best for their growth and development, low pH of less than 4.5 impairs their growth (HCD, 2020; Wahome *et al.*, 2013).

2.3 Nutritional importance of French beans.

French beans are among the most highly nutritious leguminous vegetables. It has very high protein content, is a rich source of vitamins, minerals and dietary fiber and also has good digestibility (Agustina *et al.*, 2016). Immature pods which are widely used as food in most countries contain 1.7% protein while dry seeds contain 21.1% protein per 100 g of edible part (Prasad *et al.*, 2014). French beans are a source of nutritional factors that include flavonoids, vitamin A, carotenoids including beta-carotene, potassium, folate, iron, magnesium, thiamin, riboflavin, copper, calcium, phosphorous, omega-3 fatty acids and niacin (Stagnari and Pisante, 2011). French bean seeds contain 21.1% protein; 1.3% fat; 60.6% carbohydrate and minerals like calcium 260 mg per 100gm, phosphorus 410 mg and iron 5.8 mg (Panotra and Kumar, 2016a). The beans are a very rich source of dietary fiber that helps to protect colon mucosa by decreasing its exposure time to toxic substances as well as by binding to cancer-causing chemicals in the gut. Vitamin-A and antioxidants such as lutein, zeaxanthin, and β -carotene help act as protective scavengers against oxygen-derived free radicals that play a role in aging and various disease processes. Snap beans are an excellent source of folates with 100 g fresh beans providing 37 μg or 9% of folates. Folate along with vitamin B-$_{12}$ is one of the essential components of DNA synthesis and cell division. Healthy amounts of minerals like iron, calcium, magnesium, manganese, and potassium which are very essential for body metabolism are also cointained in French beans (FAO, 2020a).

French beans are nitrogen fixing legumes and can be used as an alternative to inorganic nitrogen fertilization. Some farmers also use French beans in crop rotation systems to improve soil conditions (Agustina *et al.*, 2016).

2.4 French bean production in Kenya

French beans *(Phaseolus vulgaris L.*) continue to be among the most important export vegetables in Kenya. It is the second largest vegetable for export in Kenya after cut flowers, in terms of volume and value. French beans contribute to over 60% of all exported vegetables and 21% by value of the horticultural export earnings (Ndegwa *et al.*, 2010). Kenya produced 45,263 metric tonnes of French beans from 5,682 hectares of land in 2017. The produce was valued at Kshs. 2.06 billion which accounted for 29% of foreign exchange earnings from vegetable exports of Kshs. 13.7 billion (FAO, 2020a)

In Europe, The United Kingdom, France, Germany, Netherlands and Belgium provide the main markets for Kenya's French beans at 59, 20, 7, and 3 percent respectively. Other markets include Middle East, South Africa, Norway, United States of America, Canada and Japan (HCD, 2020).

In Kenya, French beans were introduced from Europe and is cultivated mainly by smallholder farmers throughout the year using irrigation (Mwangi, 2015) in a wide variety of agro ecological zones in Kenya. The main growing areas include: Machakos, Murang'a, Kirinyaga and Meru counties. Other areas include Trans- Nzoia, Narok, Makueni, Laikipia, Nakuru and Nyeri counties, the commonly grown cultivars include Amy, Samantha, Julia and Vernadon (HCD, 2020).

Market preference is the key determinant of the French bean cultivars grown for export. Numerous cultivars are available in the Kenya both for fresh market and processing. Fresh market cultivars include: *Amy, Boston, Pekara, Teresa, Paulista, Rexas, Samantha, Belcampo and Cupver* while the processing cultivars include: *Julia, Ogandi, Vernandon and Sasa* (Ndegwa *et al.*, 2006).

2.4.1 Boston

Boston is a fine French bean cultivar with circular and straight pods, 14-15 cm long and glossy, dark green in color. The plant is a medium erect bush that grows 30- 45 cm tall and has a high yielding and good shelf life and has a maturity period of 56 days. Boston is tolerant to diseases such as Bean Anthracnose *(Colletotrichum lindemuthianum)* and Bean Common Mosaic Virus (*Potyvirus phaseovulgaris).*

Plate 1: Pods of *Boston* cultivar

2.4.2 Serengeti

Serengeti is a fine French bean cultivar with circular and straight pods, 14-16 cm long and glossy, dark green in color. The plant is a medium erect bush that grows 45-50 cm tall and is high yielding with a maturity period of 55 days. Serengeti is tolerant to diseases such as Bean Rust *(Uromyces appendiculatus)*, Bean Common Mosaic Virus (*Potyvirus phaseovulgaris)* and Bean Anthracnose .

Plate 2: Pods of *Serengeti* cultivar

2.5 Use of mulch in weed management in Vegetable Crop Production

Mulching is a cultural crop management practice that involves covering the soil surface around plants with different materials that create a favorable environment for increased crop growth and production. In commercial vegetable production, mulching can be done using organic or inorganic materials to help prevent growth and establishment of weeds, suppress weeds that have emerged, conserve soil moisture, protect the soil from being eroded and maximize biological activities in the soil (Rajiv and Saurabh, 2021; Schonbeck and Evanylo, 1998).

Organic mulching materials are those derived from plant and animal matter. They include residues and materials such as straw, hay, grass, compost, sawdust, wood chips and animal manures. Organic mulch should be applied immediately after germination of the crop or transplanting of the seedling to ensure optimum use and advantage (Sarolia and Bhardwaj, 2012).

Inorganic mulches are derived from synthetic materials such as polythene, landscape fabrics and woven polypropylene (McCraw and Motes, 2016). Polythene mulch account for the greatest volume of inorganic mulch used in commercial vegetable production and its use is slowly being adopted by small-scale farmers in vegetable production (Bhardwaj, 2011). Polythene mulch may be transparent, black, red, yellow or other colours depending on the purpose of the mulch (Raju and Krishi, 2013). Black polythene mulches are mostly used for weed control in a range of crops mostly under organic production systems (Bhardwaj, 2011; Raju *et al.*, 2013). The mulch is highly recommended for use in high value vegetable crops (Bakht *et al.*, 2014) as it controls most weeds and warms the soil, moderates soil temperature and conserves soil moisture enhancing crop maturity and in turn increasing total yields and significantly reducing losses caused by weeds (Ngouajio and Ernest, 2004). A good mulch layer can save many hours and cost of laborious weeding and increase crop productivity (Gordon *et al.*, 2008; Hooks and Johnson, 2003; Muhammad *et al.*, 2009; Sarolia *et al.*, 2012).

Mulch helps prevent the establishment of weeds in many vegetable crops (McCraw *et al.*, 2016) and reduce weed growth by making conditions unfavorable for germination of weed seeds, hampering emergence of weed, providing physical barrier for emerging weeds and reducing weed population as compared to bare soil (Gordon *et al.*, 2008; Hooks *et al.*, 2003; Muhammad *et al.*, 2009; Sarolia *et al.*, 2012). Well placed mulching materials control essentially all annual weeds except at planting holes and at the edges, where additional control measures such as hand plucing are needed (McCraw *et al.*, 2016).

2.6 Hand- weeding for weed management in Vegetable Crop Production

In most crop production systems, weed control is achieved through hand weeding using a hoe, which is laborious as it is mostly done two or three times for effective weed control. Hand weeding is expensive, time consuming and also requires proper timing which most farmers rarely follow leading to reduced yield (Sodangi *et al.*, 2013). Unavailability of labour required at the right time and the high wages makes hand weeding difficult, costly and less feasible during critical weed competition (Samant and Prusty, 2014). The inability to effectively manage weeds by hand, declining labour availability and the drudgery involved in weeding during wet and/or dry conditions encourage and increasingly justify the use of other weed management strategies (Khogali *et al.*, 2007).

2.7 Challenges and gaps in weed management in French bean production

Weed management is a key factor in French bean production. There is limited information on use of mulch as a cultural weed management stratergy in French bean production. This study was therefore intended to evaluate the effect of different mulching materials on growth and yield of French Beans and to determine the effect of different mulching materials on weed density in French bean production fields.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Experimental site

The field experiments were conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) Industrial Crop Research Centre demonstration farm in Kitale, Saboti Sub-county,Trans-Nzoia County.The demonstration farm lies on latitude 1°0´6.6´´N and longitude 34° 59´10´´E´ at an altitude of 1900 m above sea level. The annual mean precipitation is about 1000-2100 mm rainfall that starts in March to November with the peak in May and August and a dry spell from December to March. The research centre lies in upper midland 4 (UM4) Agro-ecological zone. The area is cool with average temperatures of 14°C and 25°C (GOK, 2020).

3.2 Experimental design and plot layout

The experiment was laid out in a randomized complete block design (RCBD) with the eight treatments replicated three times. Each block consisted of eight plots, giving a total of 24 exprimental units. The plots measured 2.1 m × 1.5 m and were separated by 0.5 m paths. Seeds of French beans variety *Boston* and *Serengeti* were sown at a spacing of 30 cm by 30 cm with one seed per hole. Season 1 of the experiment was done during the long rains between April and June 2021, and season 2 done during the short rains between August and October 2021.

3.3 Treatments and treatment combinations

The experiment was laid out in a randomized complete block design with treatments that consisted of :

a. French bean cultivar *Boston*
b. French bean cultivar *Serengeti*
c. Black polythene mulch applied between the rows at a thickness of 30 µm immediately after crop emergence
d. Grass mulch applied around the crops to a thickness of 10 cm immediately after crop emergence
e. Two hand weeding done at three weeks after emergence and two weeks later
f. Weedy check

Table 1: Treatment Combinations and plot layout

BLOCK 1		BLOCK 2		BLOCK 3	
V1M1	V2M3	V1M3	V2M3	V2M1	V1M3
V2M2	V1M4	V2M1	V1M1	V2M3	V1M2
V2M1	V1M2	V1M2	V2M2	V1M4	V2M3
V1M3	V2M4	V2M3	V2M3	V1M1	V2M2

V1 = *Boston* cultivar V2 = Se*rengeti* cultivar

M1= Black polythene mulch M2= Grass organic mulch

M3= Hand weeded check M4= Unweeded check

3.4 Crop Husbandry

Certified seeds of French beans variety *Boston* and *Serengeti* were acquired from Royal Seed Company and one seed per hole sown at a spacing of 30 cm by 30 cm in the 2.1 m by 1.5 m experimental units. Diammonium Phosphate (DAP) fertilizer was applied along the rows and mixed well with the soil before placing the seeds during sowing at a rate of 200 kg/ha. Calcium ammonium nitrate (CAN), was used as a top dressing at the rate of 150 kg/ha applied twice. First application was done when 2-3 leaves had appeared and the second at the beginning of flowering. Pest and disease management was done as per French bean production requirements. Black polythene and grass mulch were laid as treatments on the designated plots immediately after emergence at a thickness of 0.30 µm and 10 cm respectively. The black polythene mulch was cut into sizes that correspond to the plots and holes 5 cm cut on the polythene sheet for the protruding seedlings. For the handweeded treatment, the first weeding was done three weeks after emergence, followed by a second weeding two weeks later. French bean pods were harvested twice a week starting at 4 weeks after emergence of pods and continued at 5, 6 and 7 weeks after emergence.

3.5 Data collection and analysis

Data was collected on the following variables:

3.5.1 Weed flora

Weed flora was assessed using a 1 m by 1 m quadrant at the end of the experiment by determining species composition of the weeds.

3.5.1 Weed density

Weed collection on the experimental plots was done using a 1 m by 1 m quadrant at the end of the experiment for the mulched plots and the unweeded check and just before weeding for the hand weeded plots. Data on the number of weeds per sq. meter was recorded.

3.5.2 Growth and yield Parameters

The first data collection started at 4 weeks after emergence and continued at 5, 6, and 7 weeks after emergence. Three plants in the middle of the plot were randomly selected from each plot and tagged for the data collection. The plant growth parameters measured included: plant height, number of branches per plant and number of leaves per plant while the yield parameters include: number of pods per plant and cumulative pod yield.

a. Plant height per plant

The plant height (cm) of the selected plants were measured 4, 5, 6 and 7 weeks after emergence using a meter rule from ground level to the highest tip of the main stem for each of the three plants and the averages calculated.

b. Number of branches per plant

The number of branches per plant was obtained by counting the number of branches formed from the tagged plants at each harvesting interval and obtaining their average.

c. Number of leaves per plant

The number of leaves per plant was obtained by counting the mature leaves of the three tagged plants at each harvesting interval and obtaining their average.

d. Number of pods per plant

The number of pods per plant was obtained by counting the mature pods of the three tagged plants during each harvest and calculating their cumulative number.

e. Cumulative pod yield

The pods were harvested twice every week for 4 consequtive weeks. The total weights obtained were added and used to calculate the cumulative yield that was expressed in terms of kg per hectare.

3.5.3 Data analysis

Data collected was subjected to analysis of variance (ANOVA) using GenStat Version 12.5 computer statistical and data management package. The treatment means were separated using the Least Significant Difference Test and comparison at probability $p \leq 0.05$.

3.5.4 Statistical Model

Data was analyzed based on the model below:

$$\mathbf{Y_{ijkl} = \mu + \beta_i + T_j + V_k + TV_{jk} + \square_{ijkl}}$$

Where:

Y_{ijkl} – Total yield

μ - Overall mean

β_i – Effect due to the i^{th} block

T_j – Effect due to the j^{th} mulch treatment

V_k – Effect due to the k^{th} variety

TV_{jk} – Effect due to interaction of j^{th} treatment and k^{th} variety

$\square_{ijkl}$ – Residual error term

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Effect of mulch and cultivar on growth and yield

The results of the experiment were as presented below:

4.1.1 Effect of mulch on plant height

The results of the experiment on the effect of the different mulching regimes on plant height in season 1 and 2 are shown in Figure 1 and 2 below.

The different mulching regimes used had different effects on plant height in both season 1 and 2. There was a significant difference in plant height on French beans grown under polythene mulch, grass mulch, handweeded and unweeded check at 4 and 5 weeks after emergence in season 1 ($p \geq 0.05$) *(Figure 1)* and at 4, 5, 6 and 7 weeks after emergence in season 2 *(Figure 2)*. However, at 6 and 7 weeks after emergence in season 1 there was no significant difference in plant height between hand weeding and unweeded and between grass mulch and polythene mulch *(Figure 1)*. Polythene mulch performed the best as compared to grass mulch, hand weeded and unweeded check in both season 1 and 2, producing the tallest plants at 53.3 and 56.3 cm tall in season 1 and 2 respectively. This was closely followed by grass mulch at 52.0 and 50.2 cm tall in season 1 and 2 respectively. Unweeded check produced the shortest plants at 44.0 and 43.3 cm in season 1 and 2 respectively. Hand weeding which is farmers' common practice produced 44.0 and 45.2 cm tall plants in season 1 and 2 respectively *(Figure 1, 2)*.

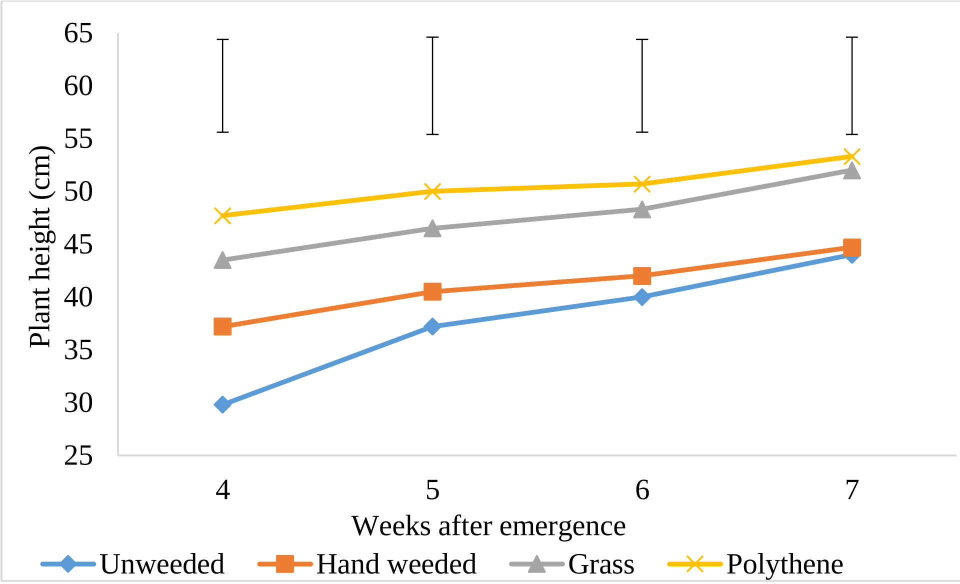


Figure 1: Effect of mulch on plant height (cm) of French Beans in season 1.

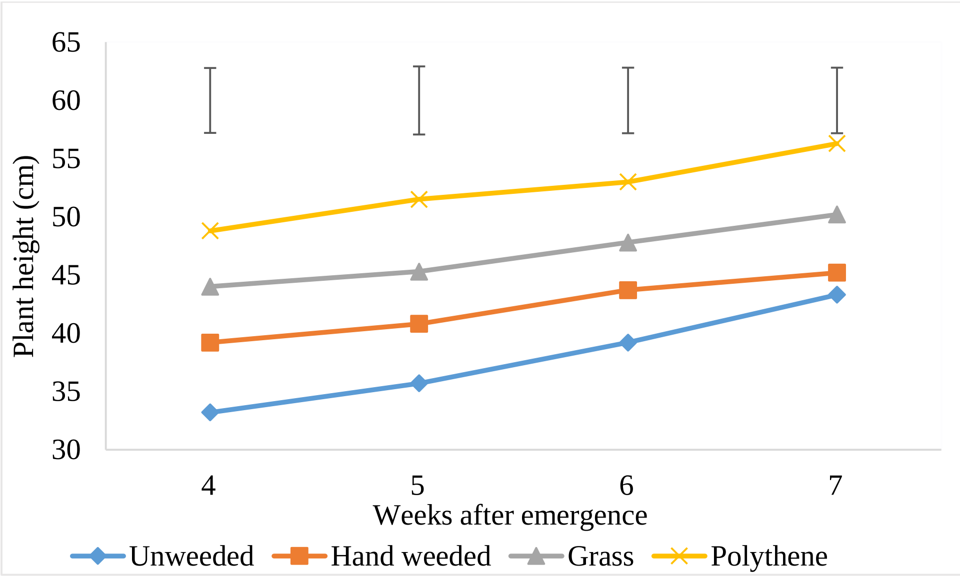


Figure 2: Effect of mulch on plant height (cm) of French Beans in season 2.

The difference in plant height could have been due to the different environmental conditions created by the mulches during the growth period. The tall plants produced by polythene mulch can be attributed to the fact that black polythene mulch conserve moisture better and increase soil temperature which provides favourable growth conditions for the plants (Kamarr *et al.*, 2010) nevertheless, the short plants in the unweeded plots could be attributed to competition between the plants and weeds for nutrients that aid in growth and development process in plants (Quamruzzaman *et al.*, 2021). Similar results were reported by Bhandari (2021) on broccoli and Prakash (2022) in cucumber.

4.1.2 Effect of cultivar on plant height

Results on the effect of cultivar on plant height are shown in Figures 3 and 4 below.

The was no significant difference on the effect of cultivar on plant height ($p \geq 0.05$) in both season 1 and 2 *(Figure 3 and 4).*

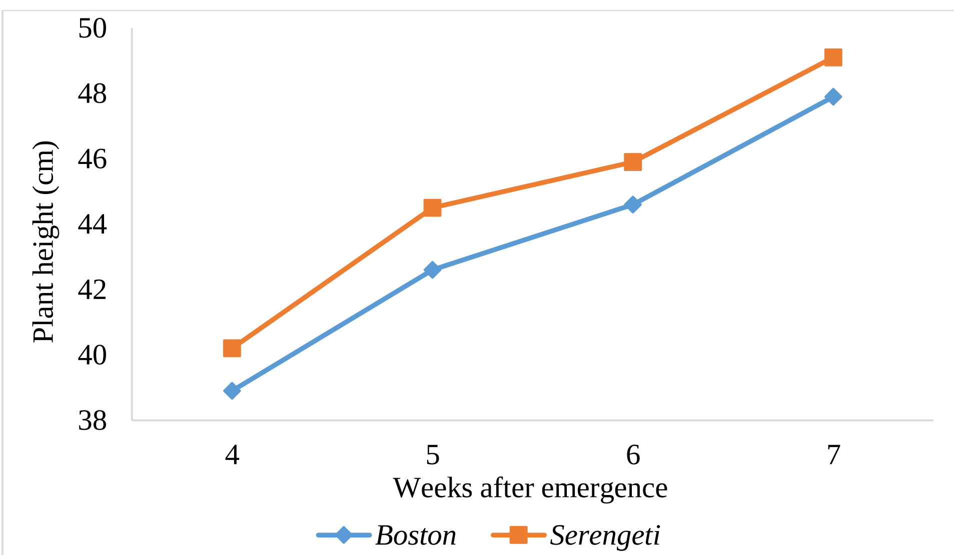


Figure 3: Effect of cultivar on height of French beans (cm) in season 1

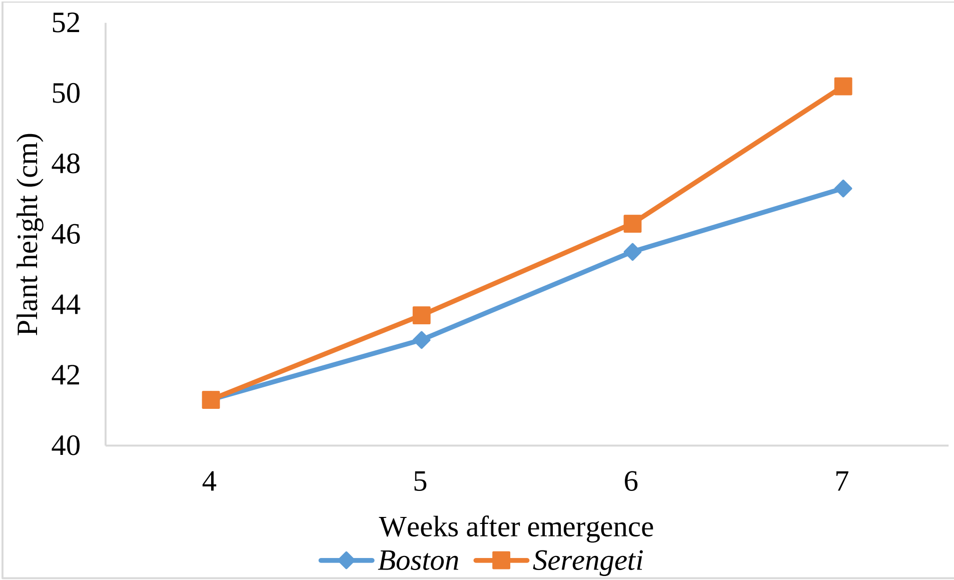


Figure 4: Effect of cultivar on height of French beans (cm) in season 2.

**Plant height (cm) were not significant between varieties in season 1 and 2.*

The variation in plant height between *Boston* and *Serengeti* might be due to genetic difference in their morphology (Naveed Ahmed *et al.*, 2016). *Serengeti* is a tall French bean cultivar growing up to 45-50 cm tall as compared to *Boston* which is a dwarf French bean cultivar and grows up to 40- 45 cm tall.

4.1.3 Effect of mulch on number of branches per plant

Effect of the different mulching regimes on the number of branches per plant is shown in figure 5 and 6 below.

The different mulching regimes had different effects on the number of branches per plant at 4, 5, 6 and 7 weeks after emergence in season 1 and 2. Mulching had a significant effect on the number of branches per plant throughout the experiment in both season 1 and 2 *(Figure 5,6 Appendix V-VIII, XXVII-XXX)*. There was a significant difference between mulching with polythene or grass mulch as compared to hand weeding and unweeded check at 4, 5, 6 and 7 weeks in season 1, while in season 2 there was a significant difference in number of branches per plant for black polythene mulch, grass mulch, handweeding and unweeded check at 5 and 6 weeks. However, there was no significant difference between handweeding and unweeded check at 7 weeks after emergence in season 2. In both season 1 and 2, mulching with black polythene or grass increased the number of branches per plant significantly as compared to handweeded and unweeded check. Plants mulched with the black polythene roll had consistently higher number of branches compared to the absolute control and the rest of the weed management techniques during both seasons. It was further observed that the plastic mulch increased branch numbers by 10 – 12 over the control between week 5 and 7 at both seasons *(Figure 5,6)*

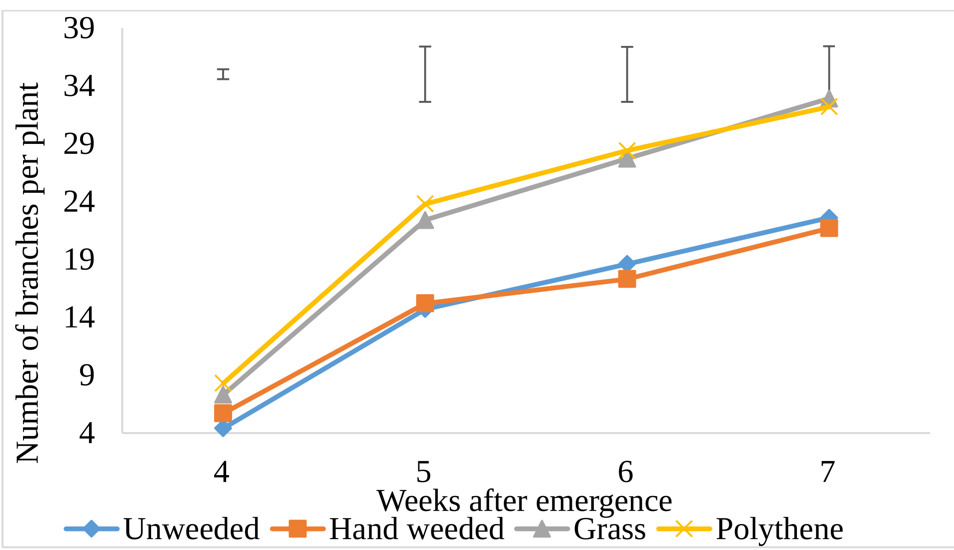


Figure 5: Effect of mulch on number of branches per plant in season 1

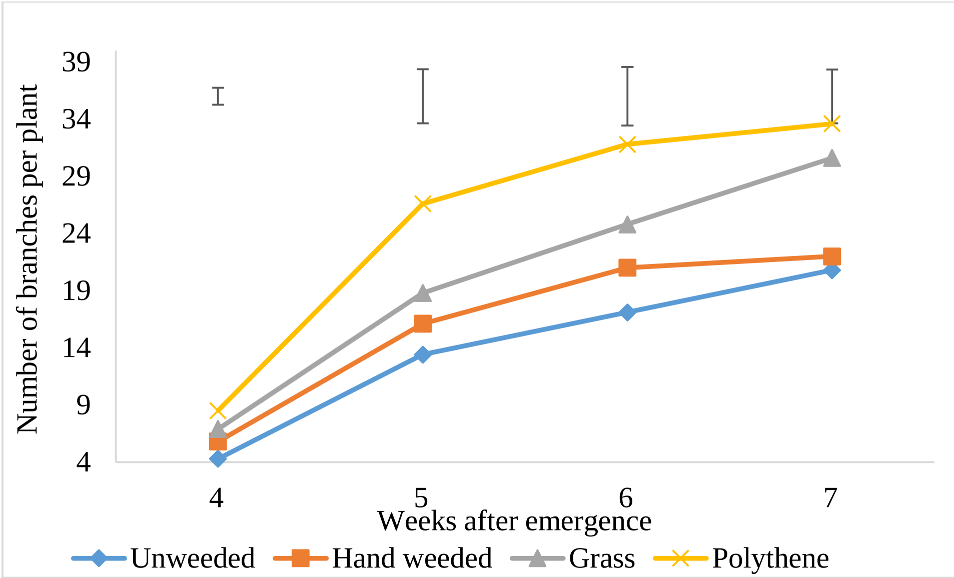


Figure 6: Effect of mulch on number of branches per plant in season 2

The different trends in the number of branches in season 1 and 2 can be attributed to the fact that Season 1 was a long rain season while season 2 was short rain season. Polythene mulch produced plants with the highest number of branches while those that were in the control plot had the least throughout season 1 and 2 *(Figure 5, 6).* The high number of branches on the plots mulched with polythene and grass could be due to the favorable microclimate created by mulch that increase the growth and development process of the plants that organic and inorganic mulching increased plant height and number of branches (Bhardwaj, 2013). These results were in agreement with those obtained by Ashrafuzzaman *et al.*, (2011) in Chilli and Ramesh (2021) in French beans.

4.1.4 Correlation between final plant height and final number of branches per plant

The correlation between plant height and number of branches per plant showed that there was a positive and significant relationship between plant height (cm) of and number of branches per plant in season 1 and 2 at r=0.68 and 0.61 respectively .

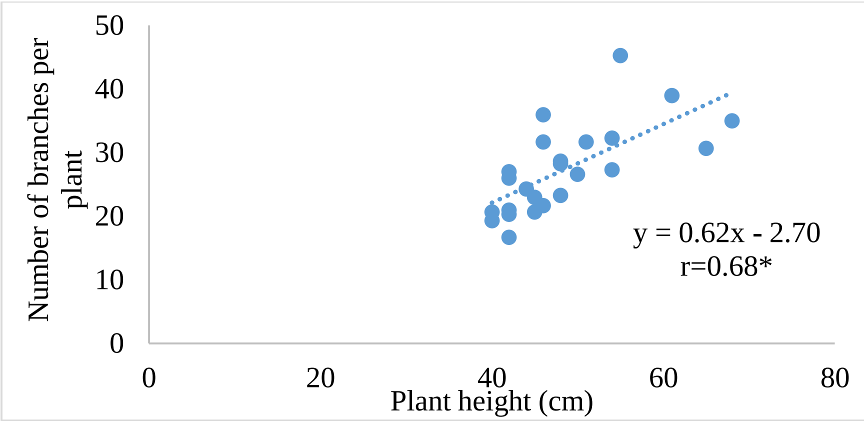


Figure 7: Correlation between number of branches per plant and plant height in season 1

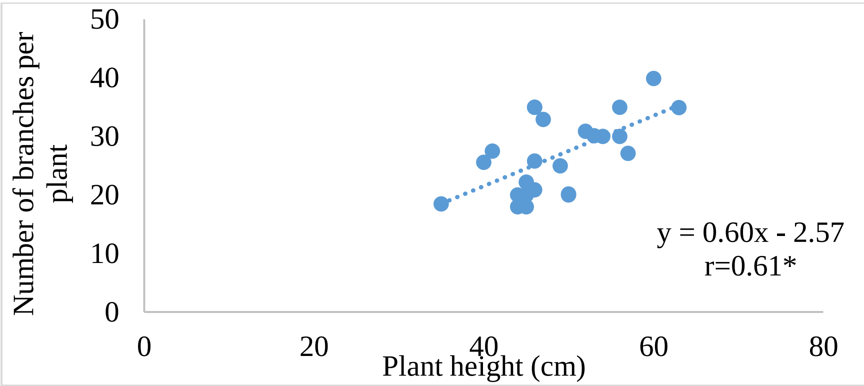
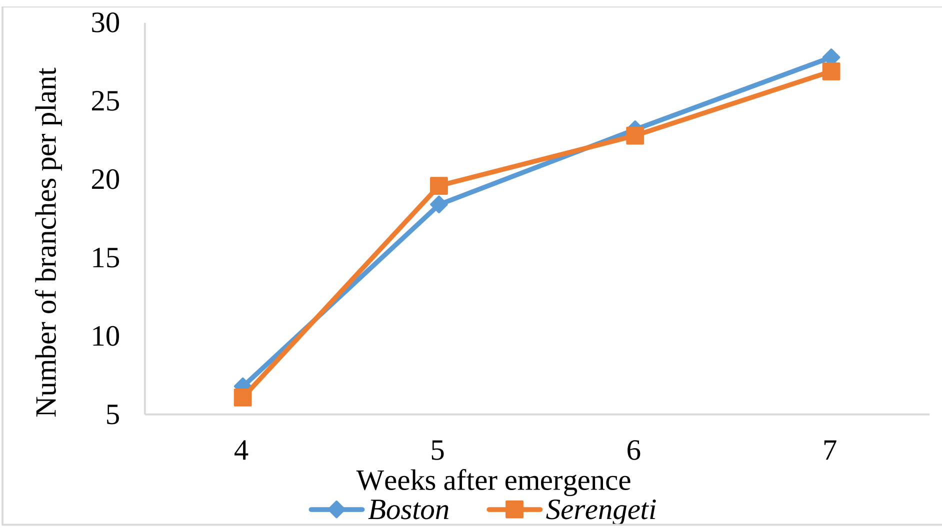


Figure 8: Correlation between number of branches per plant and plant height in season 2

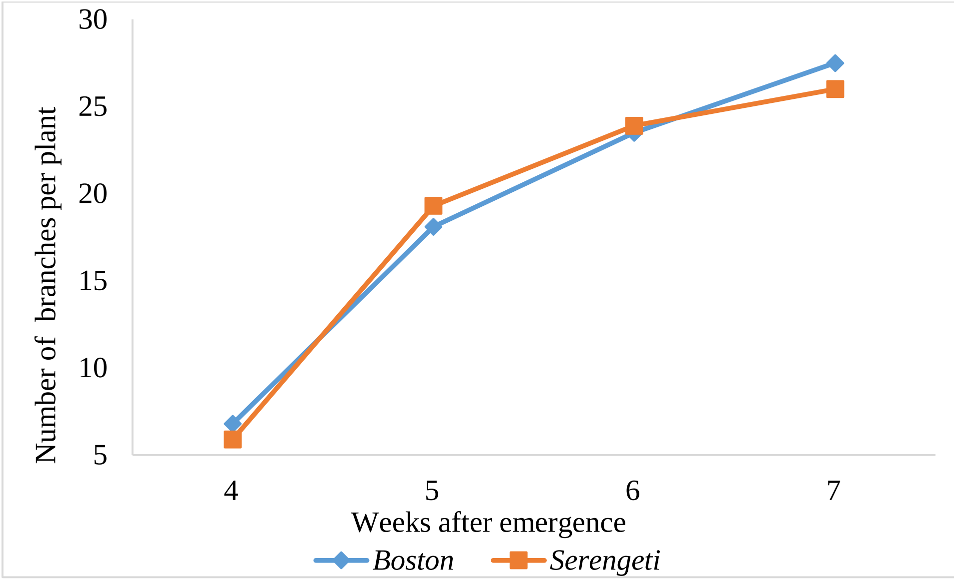
4.1.5 Effect of cultivar on number of branches per plant of French bean

The results on the effect of the two cultivars used on the the number of branches per plant in season 1 and 2 are shown below in figures 9 and 10 respectively.There was no significant difference between *Boston and Serengeti* in terms of the number of branches per plant in both season 1 and 2 *(Figure 9, 10, Appendix V-VIII, XXVII-XXX).*



**Number of branches per plant were not significant between varieties in season 1*

Figure 9: Effect of cultivar on number of branches per plant of French beans in season 1



**Number of branches per plant were not significant between varieties in season 2*

Figure 10: Effect of cultivar on number of branches per plant of French beans in season 2

4.1.6 Effect of mulch on number of leaves per plant

Effect of mulch on number of leaves per plant is shown in Figure 11 and 12 below.

The different mulching regimes had different effects on the number of leaves per plant. Effect of the different mulching regimes on number of leaves per plant was significant at 4, 5, 6 and 7 weeeks after emergence in both season 1 and 2 (*Figure 11, 12*).

The effect of polythene mulch on number of leaves per plant was highly significant as compared to grass mulch, Hand weeding and unweeded control through out season 1 and season 2. Polythene mulch produced French beans with the highest number of leaves per plant throughout season 1 and 2 at 73.8 and 78.7 respectively 7 weeks after emergence, while unweeded check produced plants with the lowest number of leaves per plant throughout season 1 and 2 at 32.9 and 46.0 respectively 7 weeks after emergence (*Figure 11*, *12*).

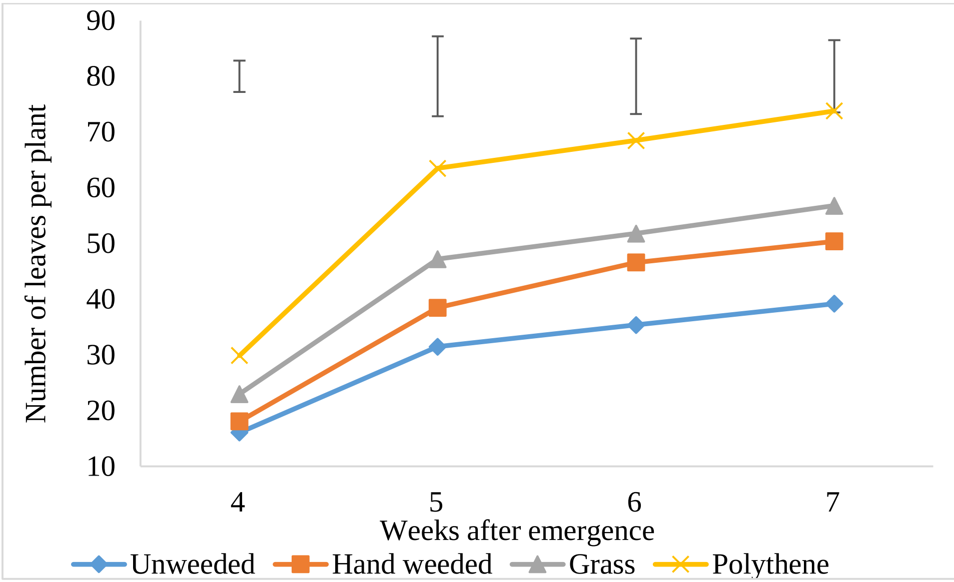


Figure 11: Effect of mulch on number of leaves per plant in season 1

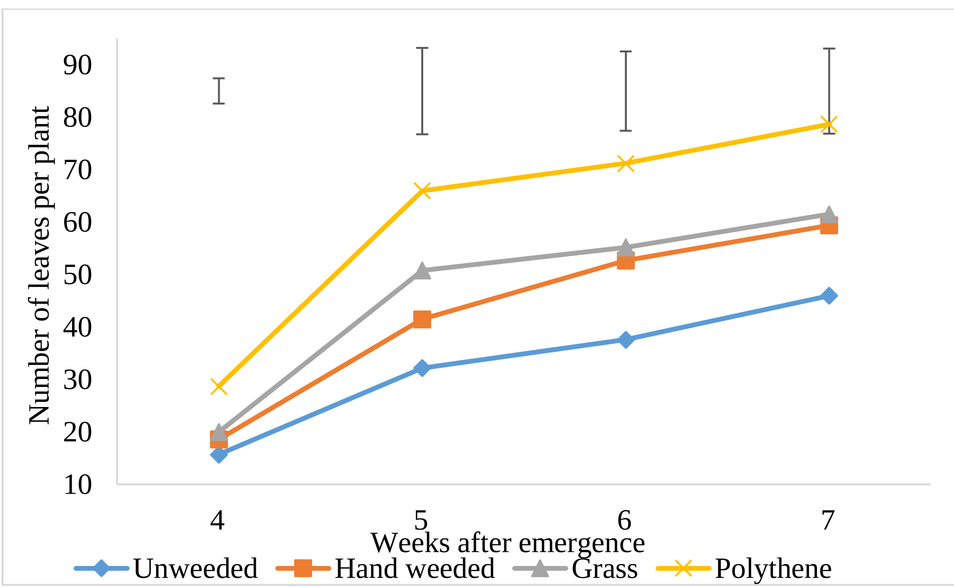
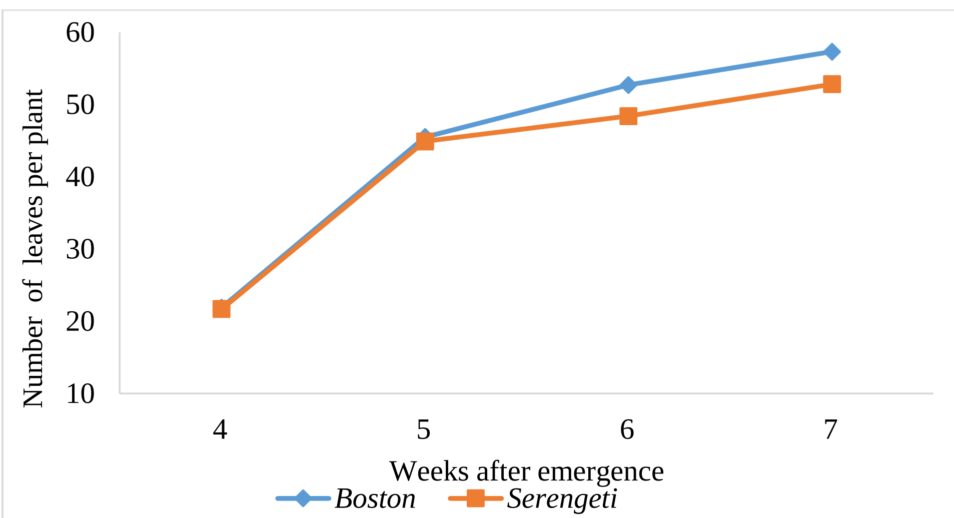


Figure 12: Effect of mulch on number of leaves per plant in season 2

Similar results were reported by Chi Christopher *et al.* (2021) on Effect of Different Mulching Materials on the Growth and Yield of Green Beans (*Phaseolus vulgaris L.)* in Nfonta the Western Highlands of Cameroon. The microclimate condition improved by the mulches might have provided a suitable condition for producing higher number of leaves in the plants (Ashrafuzzaman *et al*., 2011)

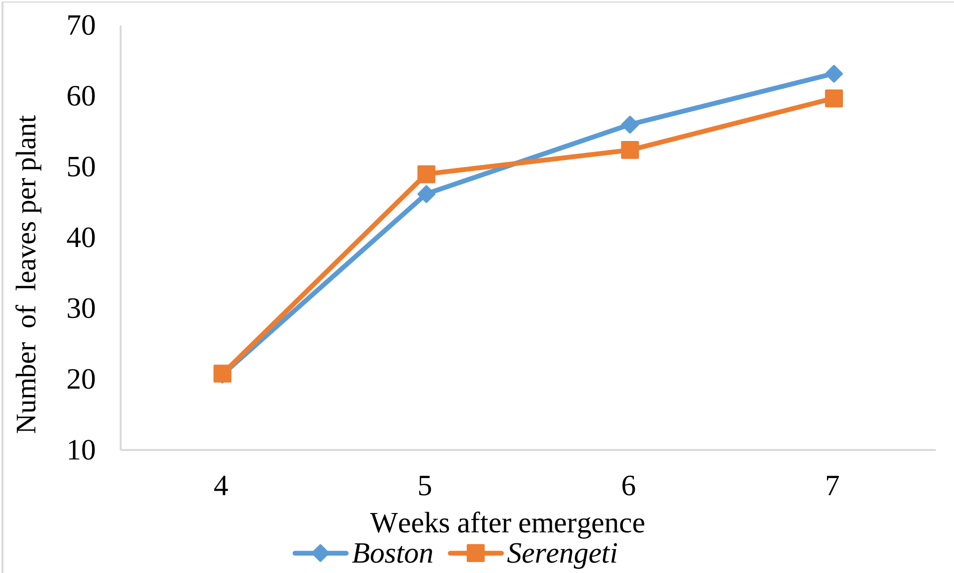
4.1.7 Effect of cultivar on number of leaves per plant

The effect of cultivar on the number of leaves is shown in Figure 13 and 14 below. Effect of cultivar on the number of leaves per plant was not significant both in season 1 and season 2 *(Figure 13, 14)*. However, Variety *Boston* performed better as compared to Variety *Serengeti*. Variety *Boston* produced the highest number of leaves at 57.3 and 63.2 in season 1 and 2 respectively.



**Number of leaves per plant were not significant between varieties in season 1*

Figure 13: Effect of cultivar on number of leaves per plant in season 1



**Number of leaves per plant were not significant between varieties in season 2*

Figure 14: Effect of cultivar on number of leaves per plant in season 2

4.1.8 Effect of mulch on number of pods per plant

Effect of mulch on number of pods per plant is shown in figure 15 and 16 below.

The different mulching regimes had different effects on the number of pods per plant. The effect of mulch on the number of pods per plant was significant ($p \geq 0.01$) in season 1 *(Figure 15, Appendix 13-16)* and in season 2 *(Figure 16, Appendix XXII-XXXIV).* Polythene mulch differed significantly from unweeded check in both season 1 and 2. Polythene mulch produced plants with the highest number of pods per plant throughout season 1 and 2. Number of pods produced by plants that were hand weeded and those that were not mulched did not differ significantly.

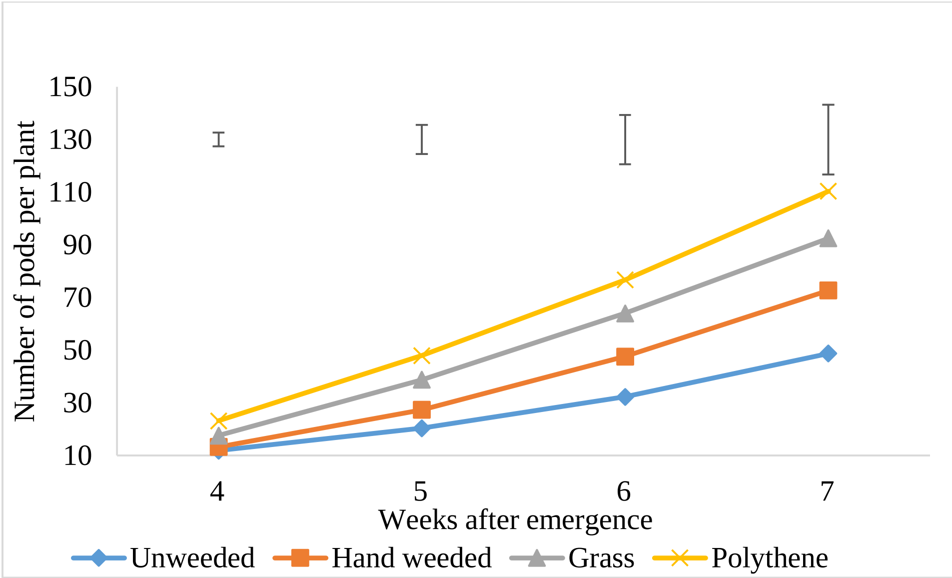


Figure 15: Effect of mulch on number of pods per plant in season 1

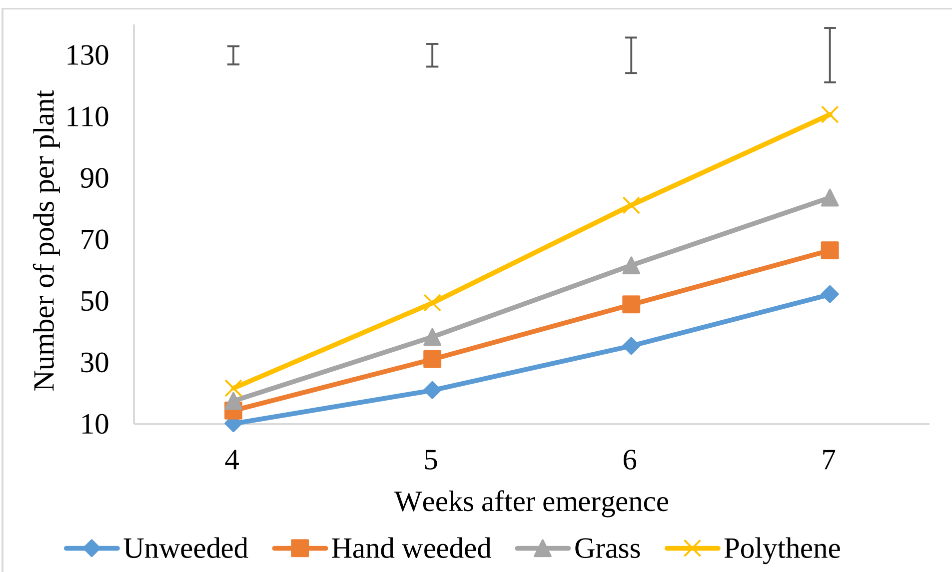


Figure 16: Effect of mulch on number of pods per plant in season 2

A previous study on the effect of different mulching materials on growth and yield of green beans (*Phaseolus vulgaris L.*), indicated a significant difference in pod yield per plant due to the favorable growth and development conditions created by mulch (Chi Christopher *et al.*, 2022).

Higher number of pods per plant was obtained from black polythene mulch while those that were grown in control had the least number of pods per plant (Kamarr *et al.*, 2010).

4.1.9 Effect of cultivar on number of pods per plant

Results on the effect of cultivar on the number of pods per plant is shown in figures 17 and 18 below.

The results of the effect of cultivar on the number of French bean pods showed no significant difference in both season 1 and season 2. Variety Boston produced the highest number of pods per plant with 89 pods per plant at 7 weeks after emergence in season 1, while variety Serengeti had 73 pods per plant at 7 weeks after emergence.

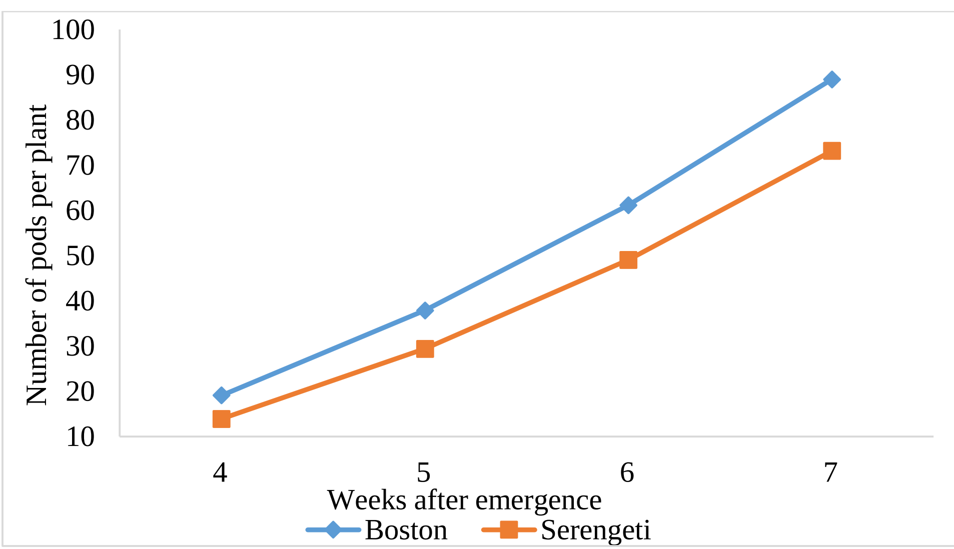


Figure 17: Effect of cultivar on number of pods per plant in season 1

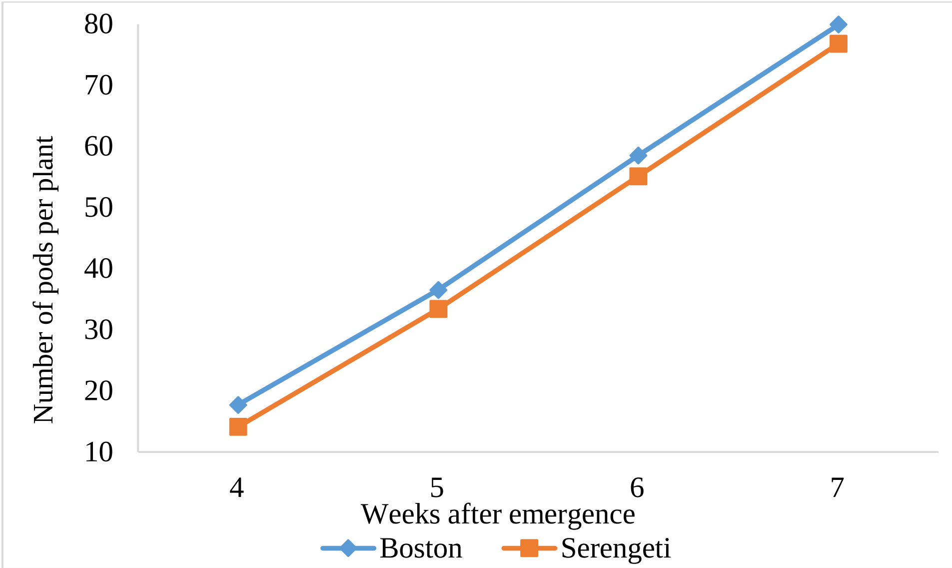


Figure 18: Effect of cultivar on number of pods per plant in season 2

**Number of pods per plant were not significant between varieties in season 1 and 2*

4.1.10 Effect of mulch and cultivar on pod yield

The data on the effect of mulch on pod yield are shown in Tables 3 and 4 below.

The results showed that there was a high significance ($p \leq 0.001$) on the effect of mulch on cumulative pod yield in season 1 *(Appendix XVII)* and season 2 *(Appendix XXXV)*. Plots mulched with polythene produced the highest pod yield of 2138 and 2598 kg/ha in season 1 and 2 respectively. Grass mulch, hand weeding and unweeded followed with 1582, 1171 and 888 kg/ha respectively in season 1 and 1934, 1419 and 953 kg/hectare respectively in season 2 (Table 3, 4).

Table 2: Effect of mulch and cultivar on cumulative pod yield (kg/ha) in season 1

Cultivar	Mulching regime				
	Unweeded	Hand- weeded	Grass	Polythene	Mean (Cultivar)
Boston	968	1227	1607	2199	1500 a
Serengeti	807	1115	1557	2078	1389 b
Mean (Mulch)	888 d	1171 c	1582 b	2138 a	

LSD $_{0.05}$ Mulch=113.8 LSD $_{0.05}$ Cultivar=80.5 CV (%) = 6.4

Table 3: Effect of mulch and cultivar on cumulative pod yield (kg/ha) in season 2

Cultivar	Mulching regime				
	Unweeded	Hand weeded	Grass	Polythene	Mean (Cultivar)
Boston	1232	1569	2263	3058	20301 a
Serengeti	673	1268	1605	2137	1421 b
Mean (Mulch)	953 d	1419 c	1934 b	2598 a	

LSD $_{0.05}$ Mulch=262.0 LSD $_{0.05}$ Cultivar=185.3 CV (%) = 12.3

**Means with the same letters within the rows or the columns are not significantly different at p≤0.05*

Application of plastic mulches increased the yields compared to non-mulched plots *(Table 3)*. Higher yields in mulch treatments might be due to its effects on soil temperature, soil moisture and weed suppression. These findings are in unison with Quamruzzaman *et al*, 2021 who reported plastic mulch to have boosted the yields of both fruit and vegetables in an experiment.

The significant difference in yield between the mulched and non-mulched plots can be attributed to the fact that mulching improves crop stands and increases yield as it provides favorable microclimate for optimum plant growth (Kumar and Dey, 2011; Prasad *et al.*, 2014) and improves soil properties by moderating soil temperature, reducing rate of evaporation, runoff and soil erosion (Arora *et al.*, 2011; Vanlalhluana and Sahoo, 2011).

Harmanjeet et al. (2017) reported that black synthetic mulch significantly increased the growth and yield of Tomatoes (Harmanjeet *et al.*, 2017).

Cultivar had a significant effect on the cumulative pod yied in season 1 ($p \leq 0.01$) *(Appendix XVII)* and in season 2 ($p \leq 0.001$) *(Appendix XXXV)*. Boston performed better that Serengeti *(Table 3, 4)*.

4.1.11 Correlation between cumulative pod yield and final plant height

Correlation between cumulative pod yield and final plant height are shown in Figure 19 and 20 below.

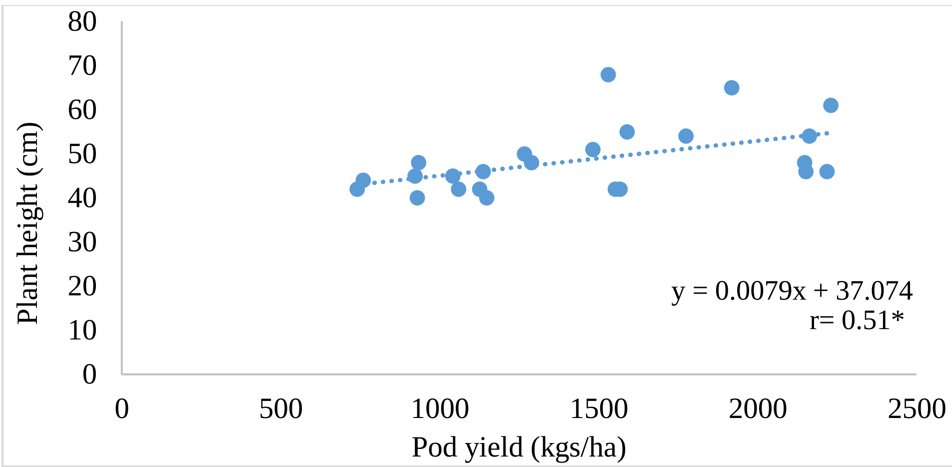


Figure 19: Correlation between cumulative pod yield (kg/ha) and final plant height (cm) in season 1

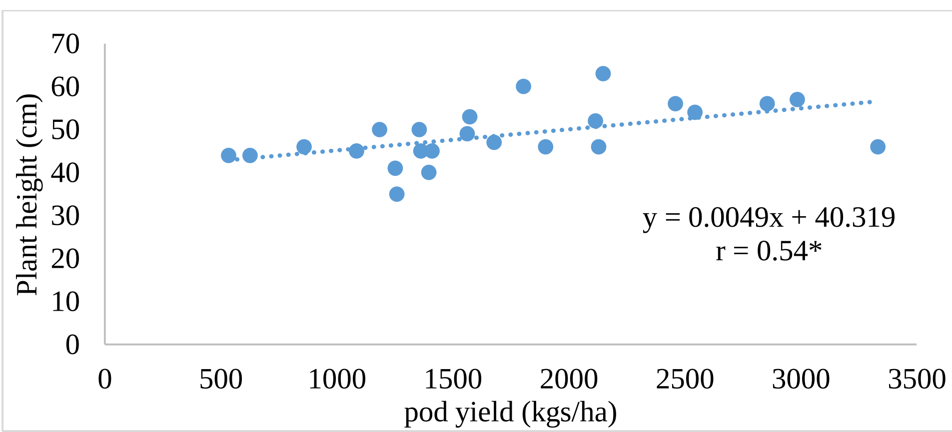


Figure 20: Correlation between cumulative pod yield (kg/ha) and final plant height (cm) in season 2

The correlation between plant height and pod yield showed that there was a positive and there was a significant linear relationship between plant height (cm) of and pod yield (kg/ha) of French beans in both season 1 and 2 at r=0.51 and 0.54 for season 1 and 2 respectively. The linear relationship could be because the taller plants had more branches and in turn more number of pods.

4.2 Effect of mulch and cultivar on weeds

4.2.1 Weed flora

The weed flora in the experimental site consisted of grass and broad-leaved weeds. The dominant weed species were: *Echinochloa crus-galli (*L) P. Beauv *, Cynodon dactylon (*L.*), Galinsoga parviflora Cav, Amaranthus retroflexus L., Portulaca oleracea* and *Chenopodium album.* Plots thet were unweeded had the greatest number of weed species while those that were mulched with polythene had the least number of weed species.

4.2.2 Effect of mulch on weed density

Results of the effect of mulch on weed density in season 1 and 2 is shown in Tables 5 and 6 below.

Effect of mulch on weed density was highly significant in season 1 and 2 ($p \leq 0.001$) as shown in the *Appendix XVIII* and *XXXVI* respectively. Polythene mulch, grass mulch, hand weeding and unweeded check all differed significantly in season 1. However hand weeding and grass mulch did not differ significantly in season 2.

The highest weed density was that of unweeded check at 35.5 and 32.5 weeds per m^2 in season 1 and 2 respectively, while the lowest weed density was that of polythene mulched plots at 10 and 9 weeds per m^2 in season 1 and 2 respectively . This was followed by grass mulch and hand weeding with 14.5 and 23.5 weeds per m^2 respectively in season 1 and 15 and 20 weeds per m^2 respectively in season 2 (Table 5, 6).

Effect of cultivar on weed density on French beans was not significant in both season 1 and 2 *(Appendix XVIII, XXXVI).*

Table 4: Effect of mulch and cultivar on weed density (number per sq metre) in Freanch beans in season 1

Cultivar	Mulching regime				
	Unweeded check	Hand weeded check	Grass mulch	Polythene mulch	Mean (Cultivar)
Boston	36	24	15	10	21
Serengeti	35	23	14	10	21
Mean (Mulch)	35.5 a	23.5 b	14.5 c	10 d	

LSD $_{0.05}$ Mulch=2.7 LSD $_{0.05}$ Cultivar=1.9 CV (%) = 10.3

Table 5: Effect of mulch and cultivar on weed density 9number per sq metre) in French Beans in season 2

Cultivar	Mulching regime				
	Unweeded check	Hand weeded check	Grass mulch	Polythene mulch	Mean (Cultivar)
Boston	32	22	14	10	19.6
Serengeti	33	18	16	8	18.7
Mean (Mulch)	32.5 a	20 b	15 b	9 c	

LSD $_{0.05}$ Mulch=6.0 LSD $_{0.05}$ Cultivar=4.2 CV (%) = 25.0

**Means with the same letters within the rows or the columns are not significantly different at p≤0.05*

The variation in weed density in the different mulch treatments was due to the fact that some treatments were more effective for weed control as compared to others. Similar research by Usman *et al*. (2005) reported maximum weed density in control plots while the lowest density was found in mulched plots of Okra (Usman *et al.*, 2005). Weed control between mulched and non-mulched plots of eggplant also showed significant differences as reported by Ossom (Ossom, 2001).

Low weed densities in plots mulched with grass and polythene mulch can be attributed to the fact that mulching generally creates a physical barrier reducing the emergence, germination and growth of weed seeds keeping them in control (Bhardwaj, 2013) thereby reducing weed growth and in turn results in low weed densities. Black polythene mulch was the most effective mulch for weed control as it prevents penetration of light to the soil inhibiting weed seed germination and smothering emerged weeds (Jalendhar *et al.*, 2016).

Black polythene mulch suppressed the weed growth and thereby, increased the fruits yield (Ashrafuzzaman *et al.*, 2011), indicating black polythene mulch was more effective than the other mulches in suppressing weed growth. Black polythene mulch also blocked the emergence of weeds, except a few, which emerged through the planting holes (Schonbeck *et al.*, 1998). Mukhtar *et al.* (2007) reported that black polythene film mulch resulted in 100% control of all the weeds in maize that supported the present experimental result.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. Polythene and grass mulch both influenced growth and yield of French Bean cultivars with polythene mulch producing best results in terms of growth and yield.
2. Polythene and grass mulch led to better weed control compared to hand weeding and unweeded plots.

5.2 Recommendations

1. There is need for farmers to adopt polythene and grass mulch as cultural weed management practice so as to increase growth and yield of French beans.
2. Further research should also be carried out to determine the profitability of polythene and grass mulch as cultural weed management stratergy in commercial French bean production

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APPENDICES

Appendix I: ANOVA table for Plant height at 4 WAE in season 1

Source of variation	d. f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0633	0.0317	0.06	
Rep.*Units* stratum					
Mulching Technique	3	10.8946	3.6315	7.29	0.004**
Variety	1	0.0938	0.0938	0.19	0.671
Mulching Technique. Variety	3	0.9712	0.3237	0.65	0.596
Residual	14	6.9767	0.4983		
Total	23	18.9996			

Appendix II: ANOVA table for Plant height at 5 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0533	0.0267	0.05	
Rep.*Units* stratum					
Mulching Technique	3	6.0213	2.0071	3.67	0.039**
Variety	1	0.2204	0.2204	0.40	0.536
Mulching_Technique.Variety	3	1.1979	0.3993	0.73	0.551
Residual	14	7.6667	0.5476		
Total	23	15.1596			

Appendix III: ANOVA table for Plant height at 6 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0475	0.0237	0.05	
Rep.*Units* stratum					
Mulching Technique	3	4.6183	1.5394	3.09	0.062
Variety	1	0.1067	0.1067	0.21	0.651
Mulching_Technique.Variety	3	1.0533	0.3511	0.70	0.565
Residual	14	6.9792	0.4985		
Total	23	12.8050			

Appendix IV: ANOVA table for Plant height at 7 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.3700	0.1850	0.33	
Rep.*Units* stratum					
Mulching Technique	3	4.2333	1.4111	2.52	0.100
Variety	1	0.0817	0.0817	0.15	0.708
Mulching_Technique.Variety	3	0.8717	0.2906	0.52	0.676
Residual	14	7.8433	0.5602		
Total	23	13.4000			

Appendix V: ANOVA table for Number of branches per plant at 4 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	10.1458	5.0729	10.59	
Rep.*Units* stratum					
Mulching Technique	3	52.0746	17.3582	36.23	<.001***
Variety	1	3.6037	3.6037	7.52	0.600
Mulching_Technique.Variety	3	0.4279	0.1426	0.30	0.826
Residual	14	6.7075	0.4791		
Total	23	72.9596			

Appendix VI: ANOVA table for Number of branches per plant at 5 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	53.38	26.69	1.79	
Rep.*Units* stratum					
Mulching Technique	3	408.43	136.14	9.11	0.001***
Variety	1	8.88	8.88	0.59	0.454
Mulching_Technique.Variety	3	45.39	15.13	1.01	0.417
Residual	14	209.28	14.95		
Total	23	725.35			

Appendix VII: ANOVA table for Number of branches per plant at 6 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	87.75	43.88	3.00	
Rep.*Units* stratum					
Mulching Technique	3	614.31	204.77	13.98	<.001***
Variety	1	0.88	0.88	0.06	0.810
Mulching_Technique.Variety	3	89.66	29.89	2.04	0.154
Residual	14	205.00	14.64		
Total	23	997.60			

Appendix VIII: ANOVA table for Number of branches per plant at 7 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	142.48	71.24	4.69	
Rep.*Units* stratum					
Mulching Technique	3	653.13	217.71	14.33	<.001***
Variety	1	5.23	5.23	0.34	0.567
Mulching_Technique.Variety	3	89.74	29.91	1.97	0.165
Residual	14	212.74	15.20		
Total	23	1103.32			

Appendix IX: ANOVA table for Number of leaves per plant at 4 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	12.91	6.46	0.32	
Rep.*Units* stratum					
Mulching Technique	3	679.37	226.46	11.23	<.001***
Variety	1	0.24	0.24	0.01	0.915
Mulching_Technique.Variety	3	19.05	6.35	0.31	0.814
Residual	14	282.40	20.17		
Total	23	993.96			

Appendix X: ANOVA table for Number of leaves per plant at 5 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	198.8	99.4	0.75	
Rep.*Units* stratum					
Mulching Technique	3	3435.8	1145.3	8.62	0.002***
Variety	1	2.8	2.8	0.02	0.887
Mulching_Technique.Variety	3	274.5	91.5	0.69	0.574
Residual	14	1860.9	132.9		
Total	23	5772.8			

Appendix XI: ANOVA table for Number of leaves per plant at 6 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	322.4	161.2	1.35	
Rep.*Units* stratum					
Mulching Technique	3	3402.0	1134.0	9.49	0.001***
Variety	1	108.8	108.8	0.91	0.356
Mulching_Technique.Variety	3	353.2	117.7	0.99	0.428
Residual	14	1672.4	119.5		
Total	23	5858.9			

Appendix XII: ANOVA table for Number of leaves per plant at 7 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	235.7	117.9	1.08	
Rep.*Units* stratum					
Mulching Technique	3	3766.3	1255.4	11.48	<.001***
Variety	1	124.7	124.7	1.14	0.304
Mulching_Technique.Variety	3	409.4	136.5	1.25	0.330
Residual	14	1531.4	109.4		
Total	23	6067.4			

Appendix XIII: ANOVA table for Number of pods per plant at 4 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	51.90	25.95	1.46	
Rep.*Units* stratum					
Mulching Technique	3	462.41	154.14	8.66	0.002***
Variety	1	160.68	160.68	9.03	0.900
Mulching_Technique.Variety	3	32.65	10.88	0.61	0.619
Residual	14	249.13	17.80		
Total	23	956.79			

Appendix XIV: ANOVA table for Number of pods per plant at 5 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	91.92	45.96	1.40	
Rep.*Units* stratum					
Mulching Technique	3	956.70	318.90	9.74	<.001***
Variety	1	68.68	68.68	2.10	0.170
Mulching_Technique.Variety	3	75.52	25.17	0.77	0.531
Residual	14	760.88	20.02		
Total	23	1651.41			

Appendix XV: ANOVA table for Number of pods per plant at 6 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	80.94	40.47	0.99	
Rep.*Units* stratum					
Mulching Technique	3	961.68	320.56	7.86	0.003**
Variety	1	73.85	73.85	1.81	0.200
Mulching_Technique.Variety	3	67.95	22.65	0.56	0.653
Residual	14	571.03	40.79		
Total	23	1755.46			

Appendix XVI: ANOVA table for Number of pods per plant at 7 WAE in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	67.22	33.61	0.78	
Rep.*Units* stratum					
Mulching Technique	3	930.62	310.21	7.16	0.004**
Variety	1	81.40	81.40	1.88	0.192
Mulching_Technique.Variety	3	79.98	26.66	0.62	0.616
Residual	14	606.58	43.33		
Total	23	1765.80			

Appendix XVII: ANOVA table of cumulative pod yield in season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	19076.0	9538.0	1.13	
Rep.*Units* stratum					
Mulching Technique	3	5310973.0	1770324.0	209.57	<.001***
Variety	1	74059.0	74059.0	8.77	0.010**
Mulching_Technique.Variety	3	9287.0	3096.0	0.37	0.778
Residual	14	118264.0	8447.0		
Total	23	5531660.0			

Appendix XVIII: ANOVA table of Weed density per m^2 season 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	87.750	43.875	9.46	
Rep.*Units* stratum					
Mulching Technique	3	2278.125	759.375	163.77	<.001***
Variety	1	3.375	3.375	0.73	0.408
Mulching_Technique.Variety	3	0.458	0.153	0.03	0.992
Residual	14	64.917	4.637		
Total	23	2434.625			

Appendix XIX: ANOVA table for Plant height at 4 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.2758	0.1379	0.69	
Rep.*Units* stratum					
Mulching Technique	3	8.0846	2.6949	13.39	<.001***
Variety	1	0.0004	0.0004	0.00	0.964
Mulching Technique.Variety	3	0.8312	0.2771	1.38	0.291
Residual	14	2.8175	0.2013		
Total	23	12.0096			

Appendix XX: ANOVA table for Plant height at 5 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.2758	0.1379	0.61	
Rep.*Units* stratum					
Mulching Technique	3	8.1433	2.7144	12.09	<.001***
Variety	1	0.0267	0.0267	0.12	0.736
Mulching_Technique.Variety	3	0.7233	0.2411	1.07	0.392
Residual	14	3.1442	0.2246		
Total	23	12.3133			

Appendix XX1: ANOVA table for Plant height at 6 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.3433	0.1717	0.91	
Rep.*Units* stratum					
Mulching Technique	3	6.2683	2.0894	11.04	<.001***
Variety	1	0.0417	0.0417	0.22	0.646
Mulching_Technique.Variety	3	0.7150	0.2383	1.26	0.326
Residual	14	2.6500	0.1893		
Total	23	10.0183			

Appendix XXII: ANOVA table for Plant height at 7 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.1525	0.0762	0.37	
Rep.*Units* stratum					
Mulching Technique	3	6.1017	2.0339	9.79	<.001***
Variety	1	0.4817	0.4817	2.32	0.150
Mulching_Technique.Variety	3	0.4417	0.1472	0.71	0.563
Residual	14	2.9075	0.2077		
Total	23	10.0850			

Appendix XXIII: ANOVA table for Number of leaves per plant at 4 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.21	0.61	0.04	
Rep.*Units* stratum					
Mulching Technique	3	565.79	188.60	12.64	<.001***
Variety	1	0.02	0.02	0.00	0.971
Mulching_Technique.Variety	3	35.09	11.70	0.78	0.522
Residual	14	208.92	14.92		
Total	23	811.04			

Appendix XXIV: ANOVA table for Number of leaves per plant at 5 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	545.9	272.9	1.53	
Rep.*Units* stratum					
Mulching Technique	3	3731.6	1243.9	6.98	0.004**
Variety	1	49.0	49.0	0.28	0.608
Mulching_Technique.Variety	3	183.1	61.0	0.34	0.795
Residual	14	2494.0	178.1		
Total	23	7003.6			

Appendix XXV: ANOVA table for Number of leaves per plant at 6 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	612.2	306.1	2.05	
Rep.*Units* stratum					
Mulching_Technique	3	3414.8	1138.3	7.62	0.003***
Variety	1	79.9	79.9	0.54	0.477
Mulching_Technique.Variety	3	291.9	97.3	0.65	0.595
Residual	14	2091.1	149.4		
Total	23	6489.9			

Appendix XXVI: ANOVA table for Number of leaves per plant at 7 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	730.2	365.1	2.14	
Rep.*Units* stratum					
Mulching_Technique	3	3242.8	1080.9	6.34	0.006***
Variety	1	76.3	76.3	0.45	0.514
Mulching_Technique.Variety	3	404.6	134.9	0.79	0.519
Residual	14	2385.6	170.4		
Total	23	6839.5			

Appendix XXVII: ANOVA table for Number of branches per plant at 4 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	12.716	6.358	4.41	
Rep.*Units* stratum					
Mulching_Technique	3	56.125	18.708	12.97	<.001***
Variety	1	4.167	4.167	2.89	0.111
Mulching_Technique.Variety	3	8.713	2.904	2.01	0.158
Residual	14	20.197	1.443		
Total	23	101.918			

Appendix XXVIII: ANOVA table for Number of branches per plant at 5 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	11.03	5.52	0.38	
Rep.*Units* stratum					
Mulching_Technique	3	579.90	193.30	13.30	<.001***
Variety	1	8.88	8.88	0.61	0.447
Mulching_Technique.Variety	3	14.35	4.78	0.33	0.804
Residual	14	203.52	14.54		
Total	23	817.68			

Appendix XXIX: ANOVA table for Number of branches per plant at 6 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	56.76	28.38	1.68	
Rep.*Units* stratum					
Mulching_Technique	3	702.09	234.03	13.82	<.001***
Variety	1	1.00	1.00	0.06	0.811
Mulching_Technique.Variety	3	30.23	10.08	0.60	0.628
Residual	14	237.03	16.93		
Total	23	1027.11			

Appendix XXX: ANOVA table for Number of branches per plant at 7 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	16.61	8.31	0.58	
Rep.*Units* stratum					
Mulching_Technique	3	725.42	241.81	16.78	<.001***
Variety	1	13.95	13.95	0.97	0.342
Mulching_Technique.Variety	3	34.90	11.63	0.81	0.511
Residual	14	201.71	14.41		
Total	23	992.59			

Appendix XXXI: ANOVA table for Number of pods per plant at 4 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	86.76	43.38	1.91	
Rep.*Units* stratum					
Mulching_Technique	3	428.67	142.89	6.30	0.006**
Variety	1	76.86	76.86	3.39	0.087
Mulching_Technique.Variety	3	43.21	14.40	0.64	0.605
Residual	14	317.45	22.68		
Total	23	956.79			

Appendix XXXII: ANOVA table for Number of pods per plant at 5 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	63.269	31.634	4.10	
Rep.*Units* stratum					
Mulching_Technique	3	906.394	302.131	39.13	<.001***
Variety	1	1.426	1.426	0.18	0.674
Mulching_Technique.Variety	3	156.234	52.078	6.74	0.005
Residual	14	108.109	7.722		
Total	23	1235.432			

Appendix XXXIII: ANOVA table for Number of pods per plant at 6 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	30.20	15.10	0.83	
Rep.*Units* stratum					
Mulching_Technique	3	1034.27	344.76	18.92	<.001***
Variety	1	0.77	0.77	0.04	0.840
Mulching_Technique.Variety	3	177.65	59.22	3.25	0.054
Residual	14	255.17	18.23		
Total	23	1498.06			

Appendix XXXIV: ANOVA table for Number of pods per plant at 7 WAE in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	29.34	14.67	0.47	
Rep.*Units* stratum					
Mulching_Technique	3	613.99	204.66	6.57	0.005**
Variety	1	0.74	0.74	0.02	0.880
Mulching_Technique.Variety	3	101.74	33.91	1.09	0.386
Residual	14	435.84	31.13		
Total	23	1181.64			

Appendix XXXV: ANOVA table for cumulative pod yield in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	110867.0	55434.0	1.24	
Rep.*Units* stratum					
Mulching_Technique	3	8975927.0	2991976.0	66.82	<.001***
Variety	1	2231136.0	2231136.0	49.83	<.001***
Mulching_Technique.Variety	3	295052.0	98351.0	2.20	0.134
Residual	14	626855.0	44775.0		
Total	23	12239838.0			

Appendix XXXVI: ANOVA table of Weed density per m^2 in season 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	12.25	6.12	0.27	
Rep.*Units* stratum					
Mulching_Technique	3	1852.79	617.60	26.98	<.001***
Variety	1	5.04	5.04	0.22	0.646
Mulching_Technique.Variety	3	28.13	9.38	0.41	0.749
Residual	14	320.42	22.89		
Total 23 2218.62					

Appendix XXXVII: Similarity Report

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