AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT

EFFECT OF WEED CONTROL REGIMES AND SPACING ON PRODUCTIVITY AND ECONOMIC BENEFIT OF GROUNDNUT (*Arachis hypogaea* L.) PRODUCTION

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BY

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A Thesis in the Department of Crop and Soil Sciences Education, Faculty of Agriculture Education submitted to the School of Graduate Studies, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development in partial fulfilment of the requirements for award of the Degree of Master of Philosophy degree in Crop Science (Agronomy)

MARCH, 2024

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree at this university or elsewhere.

Grace Nartey

Signature……………………………………   Date…………………………

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development.

Prof. Harrison K. Dapaah (Principal Supervisor)

Signature…………………………………..   Date……………………………

Prof. Stephen Labi- Koranteng (Co-supervisor)

Signature………………………………………   Date……………………………

ABSTRACT

Two field experiments were conducted at the Multi-purpose Nursery of the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED) in Mampong-Ashanti during the primary and secondary rainy seasons of 2022. The objective was to evaluate the influence of weed management and plant spacing on the phenology, growth, yield, and economic returns of groundnut cultivation. A split-plot design with four replications was employed, where the main plot factor was weed control (WC) with five levels: (i) weed-free (consistent weeding every two weeks), (ii) weeding once at 4 weeks after planting (WAP), (iii) weeding twice at 2 and 6 WAP, (iv) weeding twice at 4 and 8 WAP, and (v) no weeding (control). The subplot factor was plant spacing, tested at three levels: (i) 50 cm x 10 cm, (ii) 50 cm x 20 cm, and (iii) 50 cm x 30 cm. The findings revealed that the treatment of weeding twice at 4 and 8 WAP and a spacing of 50 cm x 20 cm resulted in the earliest 50% emergence and the highest plant establishment rates across both seasons. Regular weeding prompted the earliest 50% flowering and maturity during the primary season, while weeding twice at 4 and 8 WAP led to the earliest 50% flowering during the secondary season. The 50 cm x 10 cm spacing led to the earliest 50% pegging and podding in both seasons, whereas the 50 cm x 20 cm and 50 cm x 30 cm spacings had the shortest duration to pegging and podding. The interaction between weed control and spacing yielded the highest pod counts per plot and the heaviest hundred-seed weight in both seasons. Regular weeding and a spacing of 50 cm x 30 cm resulted in the tallest plants from 30 to 72 days after planting (DAP) in both seasons, while the combination of weeding twice at 4 and 8 WAP and 50 cm x 10 cm spacing produced the shortest plants. Weeding twice at 2 and 6 WAP led to a significantly higher number of branches per plant, and the 50 cm x 30 cm spacing significantly impacted pod weight per plot compared to the other spacings in both seasons. Weeding twice at 2 and 6 WAP and 50 cm x 10 cm spacing produced greater shoot dry weight from 58 to 86 DAP in the secondary season compared to regular weeding and 50 cm x 10 cm spacing. The unweeded control and 50 cm x 10 cm spacing resulted in higher fresh and dry weed weights at 72 DAP for both seasons. The interaction of weed control and spacing showed that the unweeded plot and 50 cm x 30 cm spacing led to greater shoot dry weight from 58 to 86 DAP in the primary season, while weeding once at 4 DAP and 50 cm x 30 cm spacing resulted in greater fresh and dry weed weights in the secondary season. Weeding once at 4 DAP also significantly increased canopy width. Seed yields ranged from 1,602 to 2,292 kg/ha in the primary season and from 1,458 to 2,167 kg/ha in the secondary season. The weed-free and weeding twice at 4 and 8 WAP treatments produced the highest seed yields, which were 43-47% and 34-49% higher than the unweeded treatment, respectively. For optimal profitability in groundnut production, regular weeding (weed-free) with 50 cm x 20 cm spacing is recommended, while weeding twice at 2 and 6 WAP is suitable for both seasons. The weeding twice at 4 and 8 WAP treatment recorded the highest total benefit-cost and net benefit-cost ratios, whereas the unweeded treatment yielded the lowest total benefits.

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I deeply appreciate the support I received from my family, my grandpa Mr. Samuel Anim Nartey, my mum and all my siblings. I say God bless you all for your tremendous support throughout the work. You are indeed shareholders of this success story. God bless you all.

DEDICATION

This work is dedicated to my beloved grandfather Mr. Samuel Anim Nartey for seeing me through my education up to this level.

TABLE OF CONTENT

LIST OF TABLE

LIST OF FIGURES

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

The groundnut (Arachis hypogaea L.), believed to have originated in Brazil, is a vital crop across dry regions of Asia, Africa, Central and South America, Australia, and the Caribbean, prized for its economic, dietary, and nutritional value. This crop belongs to the Fabaceae family and the Papilionaceae subfamily, and is unique in agriculture due to its dual role as both an oilseed and a legume. Groundnuts are globally the fourth-largest source of edible oil and the third-largest source of vegetable protein (Mondal et al., 2018). They contain 44-50% edible oil, 25% protein, and are rich in vitamins B, E, and K, as well as thiamine and niacin, which are commonly lacking in cereals. The kernels are primarily used for oil extraction, while the shells and cakes are utilized as animal feed. Groundnuts are a key oilseed crop in tropical and subtropical areas, cultivated in 100 countries between 40°N and 40°S latitudes. Global production stands at 35.9 million tonnes from 25.2 million hectares, with an average yield of 1.42 tonnes per hectare (Popescu et al., 2019). India is the leading producer, accounting for 31.70% in the groundnut area and 37.50% of global cultivation. Groundnuts advance soil productiveness through a cooperative relationship with rhizobia bacteria in their root nodes, which add atmospheric N, thus benefiting subsequent crops. In return, the rhizobia receive carbohydrates and water from the groundnut plant, allowing it to thrive in nitrogen-poor soils compared to other plants. Agronomic practices such as plant spacing and soil fertility management impact groundnut cultivation. Farmers often plant in mounds, ridges, or without rows, which can lead to suboptimal outcomes. Achieving optimal plant density is crucial for maximizing yields, as it significantly affects canopy development and weed management (Onasanya et al., 2021).

Research on agronomic practices like plant spacing is important to enhance groundnut growth and yield, thus encouraging more farmers to cultivate it (Pandey et al., 2017). Proper plant space guarantees good aeration, decreases struggle for space and nutrients, lowers disease risk, facilitates weeding and farm movement, and prevents overcrowding, allowing for effective interception of light by plant canopies (Santo, 2015). Yield potential is closely tied to plant population, and optimizing plant density is a key non-monetary factor for increasing groundnut production.

Produce is affected by both inter-plant and intra-plant struggle, with significant potential for improvement through optimal plant population levels. Rokon et al. (2019) found that intermediate densities produce greater seed weight and more seeds per inflorescence due to the timing of these competitions. At the widest spacing (lowest plant density), these competitions are absent in early growth stages. In unfavorable conditions, narrowing crop rows does not necessarily enhance yield. Slattery et al. (2017) suggested that in years with limited water, soybeans in wide rows might yield as well as or better than those in narrow rows. During high-water seasons, soybeans in slim rows (25 cm) yielded 17% more than those in wider rows (100 cm). Rębilas et al. (2020) noted that 64% to 69% of pods did not mature in early sowings at high densities, regardless of ground site.

1.2 Problem Statement and Justification

Groundnuts are highly nutritious, containing around 45–50% oil, 27–33% protein, and essential minerals and vitamins. They are a crucial dietary component for resource-constrained women and children, and their haulms also serve as animal feed. However, groundnut production often suffers from poor cultivation practices and insufficient weed management (EL Naim et al., 2010). Weeds compete with groundnuts for nutrients, moisture, and sunlight, impede pegging and pod formation, and complicate harvesting. In the first six weeks of growth, groundnuts have a sparse canopy, which leads to intense competition with weeds and significant yield reductions (Shanwad et al., 2011). To optimize yield, effective and timely weed control during this vulnerable period is essential.

Onat et al. (2016) defined plant density as the number of main stems per unit area and noted that higher plant density increases competition for resources like nutrients, water, and light. Both Sreelatha et al. (2008) and Onat et al. (2016) highlighted that crop yield is influenced by how well the plant population exploits available environmental resources. The impact of planting patterns and densities on yield can be approached by maximizing leaf area to capture solar radiation during the reproductive phase or by maintaining uniform spacing to reduce competition between plants.

Managing plant population effectively can enhance crop yield by optimizing the use of resources such as light, nutrients, and water, and by minimizing soil surface evaporation (Naim et al., 2016). Groundnuts, like other legumes, form a symbiotic relationship with rhizobium bacteria to fix nitrogen in the soil (Tisdale and Nelson, 2015). As a cover crop, groundnuts help prevent soil degradation and control weeds (Akobundu, 2017; Doran, 2012). Ansa and Adesina (2018) found that increasing planting density through closer spacing can boost crop yield. Despite extensive research on spacing and weeding practices, there is limited information on how spacing affects weed control. Thus, this study aims to explore how weed management and plant population density influence groundnut growth and yield.

1.4 Objective of the Study

The main aim of the study was to assess the effects of weed control and plant spacing on the phenology, growth, yield, yield components, and economic benefits of groundnut cultivation.

The specific objectives were:

1. To examine the effects of different plant spacings and weed control methods on the phenology and growth of groundnuts.
2. To determine how plant spacing and weed control methods influence the produce and components of groundnuts.
3. To evaluate the economic benefits associated with various plant spacings and weed control methods in groundnut production.

CHAPTER TWO: LITERATURE REVIEW

2.1 Origin and Distribution

Groundnut (Arachis hypogaea L.) is an annual crop native to South America, specifically domesticated in regions including Brazil, Argentina, Paraguay, Peru, and Bolivia (Hamakareem et al., 2016). Before the arrival of Europeans in the Americas, groundnuts were unknown outside the New World. The Portuguese introduced them to the West Coast of Africa in the 16th century, while the Spanish brought them to the Philippines from Peru. All other Arachis species are wild and native to South America, where they are mainly used for forage (Smýkal et al., 2015). Most groundnut production is consumed locally. By the time Europeans arrived in South and Central America, groundnuts had been widely distributed, likely by the Arawak Indians. Archaeological findings in Mexico suggest their presence dates back to 1300-2200 BP. After European contact, groundnuts spread globally.

The Peruvian runner type was introduced to the Western Pacific, China, Southeast Asia, and Madagascar (Hammons et al., 2016). The Spanish likely brought the Virginia type to Mexico through the Philippines in the 16th century, and the Portuguese introduced it to Africa before bringing it to India from Brazil. Virginia types apparently reached the southeastern US through the slave trade. Dew (2017) observed notable subordinate variety in Africa and Asia, with various kinds and their positions supporting different theories about their dispersal. Groundnut is a key food crop cultivated throughout the tropics (Otieno, 2019).

2.2 Botan

Groundnut is classified within the family Fabaceae, sub-family Papilionoideae, tribe Aeschynomeneae, sub-tribe Stylosanthinae, genus Arachis, and species hypogaea (Shinde et al., 2019). The genus name Arachis derives from the Greek "a-rachis," meaning "without spine," referencing the lack of erect branches. The species name hypogaea comes from the Greek "hupo-gè," meaning "below earth," referring to the gynophore (flower stalk or peg) that grows downward into the soil, where the pod develops underground. Notably, A. hypogaea, the only cultivated species, is not known in its wild form. Groundnut varietal classifications are based on flower location on the plant, reproductive node patterns on branches, trichome density, and pod morphology (Reddy et al., 2016). Arachis hypogaea is a recent allotetraploid, likely formed from the hybridization of two wild species followed by natural chromosome duplication (Alix et al., 2017). There are two main genus of A. hypogaea, differentiated by their branching patterns: subspecies hypogaea, with alternate branching, and subspecies fastigiata, with sequential branching (Zhang et al., 2017). Within subspecies hypogaea, there are two botanic variations: var. hypogaea (Virginia and runner types) and var. hirsuta (Peruvian humpback and Chinese dragon). Subspecies fastigiata is also separated into botanical varieties: fastigiata (Valencia type) and vulgaris (Spanish type) (Ferguson et al., 2014).

Table 2.1: Subspecies of groundnut *Arachis hypogea*

Subspecies	*Fastigiata*	*Hypogea*
Site of flowering and pod production	Main stem	Lateral Branches
Growth Habit	Erect	Spreading Bunching
Botanical variety and market type	*Fastigiata* Valencia	*Hypogea* Runner *Hypogea* Virginia
Seed Dormancy	Low or Absent	Present
Maturation Time	Short 90-120 days	Long 145-165 days

Source: Shokes & Melouk, (2015).

2.3 Uses and Nutritional value

In modern societies, groundnuts are mainly grown for their kernels and edible oil. Various by-products of groundnuts, such as groundnut cake (Desire et al., 2021) and vegetative residue, are commonly used in many African villages. Groundnut kernels, which have 10-15% carbohydrates, are rich in phosphorus and provide significant amounts of vitamins B and E (Koushki et al., 2015). Groundnuts are processed into several products; their oil, being the most affordable of vegetable oils, is widely used for cooking, making margarine, and preparing salads (Hashempour-Baltork et al., 2016). Groundnut paste is a popular soup thickener across Africa (Ene-Obong et al., 2013). The cake is utilized as animal feed and fertilizer. Groundnut shells, the dry outer layer of mature pods, contain cellulose, carbohydrates, protein, minerals, and lipids (Figueroa et al., 2020). They are used in various ways, including as a source of activated carbon (Jain et al., 2016).

Additionally, groundnut shells can be pelletized and used as fuel in the form of smokeless briquettes (Balraj et al., 2020). They also serve as soil conditioners, fillers in fertilizers and feeds, and substitutes for cork and hardboard, or can be composted with lignin-decomposing bacteria (Malliga et al., 2020). The foliage of groundnut plants is used as silage and forage for livestock, especially during the rainy season (Kebede et al., 2017). Groundnut shell ash, which contains approximately 8.66% calcium oxide (CaO), 1.93% iron oxide (Fe2O3), 6.12% magnesium oxide (MgO), 15.92% silicon oxide (SiO2), and 6.73% aluminum oxide (Al2O3), has been classified as pozzolana (Grandawa, 2014). This composition makes it effective as a partial replacement for cement in concrete, showing notable success (Grandawa, 2014).

2.4 Varieties

Various groundnut varieties have been introduced globally. In Ghana, the CSIR-SARI and CSIR-CRI have developed high-yielding commercial varieties that are cultivated throughout the country. A list of some of these groundnut varieties released by CSIR-SARI and CSIR-CRI is provided in Table 2.2 (Danso-Abbeam et al., 2017).

2.5 Production Estimate

2.5.1 Global Groundnut Production

In 2017, the global area for groundnut cultivation was 23.91 million hectares, yielding approximately 37.95 million tonnes (unshelled), with an average yield of 1.58 tonnes per hectare (Amoah, 2016). The top producers of groundnuts are Nigeria, China, India, , the USA, Indonesia, and Sudan. However, smallholder farmers in Africa face persistent low yields, resulting in a significant yield gap compared to other regions. For instance, in 2010, the global average yield was 1580.7 kg/ha, while Africa averaged only 902.1 kg/ha, compared to 3086.2 kg/ha in the Americas (Amoah, 2016).

In 2010, the harvested area for groundnuts (in shell) was 23.4 million hectares, producing 34.9 million metric tonnes (Mt) (Amoah, 2016). This marked an increase of 3.7 million hectares in harvested area and an 11.7 million Mt rise in production from the year 2000. The average global productivity in 2010 was around 1490 kg/ha. Groundnuts are cultivated in about 90 countries and thrive in climates that support optimal production (Wani et al., 2017). Approximately 90% of global production originates from regions where about 60% comes from the semi-arid tropics (SAT). Groundnuts are primarily used for oil, accounting for two-thirds of the production, making it a major source of vegetable oil alongside soybean, sunflower, and palm oil. The crop is predominantly grown in developing countries, particularly in Asia and Africa (Ortega & Tschirley, 2017).

2.5.2 Soil Requirements for Groundnut Cultivation

Groundnuts thrive in well-drained sandy loam or sandy clay loam soils with a pH between 6.5 and 7.0 and high fertility. Runner and Spanish varieties are more suited to heavier soils, while Virginia types have less tolerance (Coyle et al., 2017). Heavier soils can result in increased pod loss. Groundnuts grow best in loose, friable soils that are well-drained, with many productive groundnut soils being sandy and categorized within the Alfisols, Entisols, Inceptisols, and Ultisols orders. Light-textured soils facilitate planting and establishment. However, Hall et al. (2020) noted a moderately large stem width of groundnut seedlings helps them emerge through most surface crusts. The sub-surface soil must be wabbly and permeable; even slight decreases in penetrability can significantly impact development. Fousová et al. (2017) found that reducing soil porosity from 44% to 38% led to a decrease in root yields from 1000 to 100 kg/ha in the 10-20 cm layer. Loose, friable soils support peg infiltration and growth and ease harvesting. Nanduri & Dakheel (2015) observed that while pegs can exert considerable force, a surface crust of 1.5 cm can obstruct peg penetration and pod development. Hefty clay soils complicate harvesting and reduce yields due to peg fractures and clay staining (Marais et al., 2017). Additionally, Turner (2019) demonstrated that light-textured soils are less prone to waterlogging, that can adversely affect groundnut seedlings within just 24 hours. Waterlogging impacts rhizobia growth when nitrogen demand is high (Allito et al., 2015).

Diallo et al. (2019) reported that groundnuts can be grown successfully on heavier soils, often using raised beds. While groundnuts can tolerate both acid and basic soils, a pH range of 6 to 7 is optimal for production. Tittonell & Giller (2013) also found that a pH range of 5.3 to 7 is suitable. Groundnuts grow best in well-drained sandy loam soils, which facilitate peg penetration, development, and harvesting (Lin et al., 2018). The ideal soil provides a balanced mix of air, water, and nutrients, allowing plant roots to access these resources easily for rapid growth. Light-textured soils aid in planting and establishment (Phogat et al., 2020). Nonetheless, the sub-surface soil must remain loose and permeable, as even minor decreases in porosity can significantly impact development.

2.6 Crop Propagation

Commercial groundnut propagation predominantly relies on seeds, although stem cuttings are occasionally used for research purposes (Bisi et al., 2020). Shelled seeds are preferred for planting because, nuts in shell are prone to rot in the pods and might harbor pests and diseases that aren't detectable before planting (Latham & Ku Mbuta, 2011). Seeds generally germinate within 5-7 days. Bigger seeds particularly are susceptible to wetness stress. Traditionally, seeds are sown by hand, with 2 or 3 seeds per hill. Cotton and maize planters can be adapted for groundnuts by using specialized groundnut plates. Only healthy, disease-free seeds should be planted. Treatments with fungicide/insecticide dressings, such as Fernasan D, Apron Plus, or Apron Star (1 sachet/5 kg of seeds), are recommended to ensure good crop establishment and protection against pests like squirrels, mice, rats, lizards, termites, and birds (Flinn & Patel, 2016).

For planting, Fernandes (2011) recommends 30 x 30 cm or 30 x 45 cm spacing for bunch types on even or higher beds. In commercial cultivation, a density of at least 120,000 plants per hectare is suggested. Santo (2011) proposes wider spacing for local runner varieties, with ridges of 30 cm between holes and 60-120 cm between ridges for varieties like Mani pintar and other semi-erect types in Northern Ghana. Generally, spacings of 90 cm x 20 cm for spreading types and 60 cm x 10 cm for bunch types are advised (Rees et al., 2016).

2.7 Cultural Practices

2.7.1 Weed Control

Wang et al. (2013) noted that legumes, including groundnuts, are particularly vulnerable to weed competition during their early growth stages due to their limited competitive ability. Factors influencing crop-weed competition include the type of crop, cultivating scheme, planting period, plant density, moisture accessibility, and soil productiveness. Harding & Raizada (2015) highlighted that weeds can harbor pests and diseases, including fungal, viral, and bacterial pathogens. The International Institute of Tropical Agriculture (Weerarathne, 2014) reported that weed growth can reduce yields by 68% and 78%, of semi-prostrate and erect crops respectively. In many tropical regions, including Ghana, weeding is often neglected. Although small-scale farmers recognize the importance of weeding, it is frequently delayed until weeds become heavily infested (Tippe et al., 2017). This delay in weeding is a hidden cause of yield loss, rooted in traditional practices where weeding is postponed until weeds are problematic (Taylor, 2015). Taylor (2015) emphasizes the sensitivity of crops to early weed competition and advises weeding within the first two to three weeks after planting.

2.7.2 Fertilizer Application

Groundnuts benefit from phosphorus fertilizers, which enhance nitrogen fixation (Asante et al., 2020). Elrys et al. (2018) found that single superphosphate (50-100 kg/ha) provides superior results compared to other phosphatic fertilizers due to its high calcium and sulfur content, which are essential for groundnut nutrition. Applying a small dose of nitrogen-bearing fertilizer (50 kg/ha of sulfate of ammonia, equivalent to around 10 kg/ha N) on poor soils helps seedlings establish before they develop a strong root system for nodulation

(Elrys et al., 2018). Martínez-Hidalgo et al. (2014) observed that poorly developed plants fail to form well-structured nodules and do not fix sufficient nitrogen.

2.7.3 Planting Date

In South Africa, groundnuts are typically planted from mid-October to mid-November, though the timing depends on several factors, with rainfall being the most critical. Planting immediately after the first rains in September is not advisable (Son et al., 2020) because this period often brings cooler soil temperatures (below 18°C), which can hinder germination. Farmers should aim to plant early in the season when the risk of cold spells is lower (Jones, 2016). Delayed planting generally results in reduced yields and increased need for foliar disease management (Ajeigbe et al., 2014).

2.7.4 Crop Rotation

Implementing a well-planned crop rotation system can improve groundnut yields and quality. Rotating groundnuts with other crops, especially grass crops, reduces risks in the farming system (Ajeigbe et al., 2014). Groundnuts can enhance the yields of subsequent maize and other grains by up to 20% (Zhang et al., 2015). An effective rotation typically involves a grass fallow followed by groundnuts, leading to fewer disease issues. Groundnuts perform best on fields that have been fallowed and should follow main crops like maize, small grains, sorghum, or millet (Egada-Lizarazu & Monti, 2011). It is advisable to avoid planting groundnuts after cotton or soybeans due to disease risks and to exercise caution when planting after tobacco (Akhtar et al., 2014). Continuous planting of groundnuts may lead to disease problems, particularly with leaf and pod diseases, though deep ploughing can help alleviate these issues. Monoculture is generally not recommended (Crews et al., 2018).

2.8 Pests and Disease Control

2.8.1 **Disease Management**

Groundnuts in West Africa face a variety of diseases and pest challenges that can significantly impact yields. Key diseases affecting groundnuts include:

2.8.2 Viral and Fungal Infections:

Groundnuts are prone to several viral and fungal diseases. Common fungal infections include leaf spot, stem rot, pod rot, and southern blight. Viral diseases such as groundnut rosette disease are also prevalent (Boudreau, 2013; Jayalakshmi et al., 2020).

2.8.3 Bacterial Wilt and Nematodes:

These can cause significant damage in some regions (Boudreau, 2013).

2.9 Control Measures:

2.9.1 Using Resistant Cultivars:

1. Selecting and planting disease-resistant varieties is a fundamental strategy to manage diseases effectively (Panth et al., 2020).
2. Deep Ploughing: This technique helps in removing plant debris that could harbor pathogens, reducing disease incidence.
3. Crop Rotation: Rotating crops helps to prevent the buildup of soil-borne diseases (Panth et al., 2020).

4. Early Planting: Planting early can help avoid peak disease periods, reducing the risk of infection.
5. Weed and Alternate Host Removal: Regularly removing weeds and alternate hosts can prevent the spread of diseases (Panth et al., 2020).
6. Improving Soil Drainage: Well-drained soils help prevent diseases that thrive in waterlogged conditions.
7. Burning Affected Plants: This helps to prevent the spread of diseases.
8. Fungicide Application: Using appropriate fungicides can control fungal diseases effectively (Panth et al., 2020).

2.9.2 Pests:

Groundnuts are also susceptible to insect and mite pests, including:

Leaf-Feeding Caterpillars, Thrips, Stalk Borers, Leaf-Eating Ants, Bean and Flea, Beetles, Aphids, Leaf Miners (Flint, 2018)

Effective pest management strategies include regular monitoring, applying appropriate insecticides, and employing integrated pest management practices.

Intercropping: Intercropping involves growing groundnuts alongside other crops, which can provide several agronomic benefits such as improved resource use efficiency, pest and disease management, and soil health. Key intercropping practices include:

- In the North Guinea Savanna Zone of West Africa: Around 70% of groundnuts are intercropped with crops like pearl millet, sorghum, and cowpea (Namatsheve et al., 2020).
- In Senegal: A higher proportion of groundnuts are grown as a sole crop.

- In Nigeria and Uganda: Groundnuts are commonly intercropped with other crops, with intercropping comprising 96% and 78% of the total sown area, respectively (Khanal & Mishra, 2017).

2.9.3 Regional Practices:

- Short Wet and Dry Seasons: In these regions, groundnuts are often mixed with short-season crops.
- Extended Rainfall Areas: Groundnuts may be intercropped with both annual and biannual crops. An example is in South Cameroon, groundnuts are intercropped with tubers and plantains (Santo, 2011).
- India: Groundnuts are interplanted with pigeon pea and cotton (Mkandwire & Likoswe, 2015).

2.9.4 Benefits of Intercropping

- Yield Advantages: Intercropping can provide yield benefits. For instance, studies by Akuja et al. (2016) indicated that intercropped with maize yielded 0.46 t/ha and 1.38 t/ha of groundnut and maize respectively.
- Improved Resource Use: Bogie et al. (2019) found that intercropping can offer a small yield advantage when growth durations are similar, as seen with groundnut and pearl millet. A larger yield benefit is observed when growth durations differ significantly, such as with groundnut and pigeonpea (Dwivedi et al., 2015).

Intercropping not only optimizes land use but also reduces the incidence of pests and diseases by diversifying crop systems.

2.9.5 Harvesting

Groundnut harvesting is a critical phase, and timing can greatly impact both yield and quality. The timing and method of harvesting vary based on the type of groundnut:

- Spreading Varieties: Typically harvested between 140 and 145 days after planting.
- Semi-Spreading Varieties: Harvested between 120 and 130 days.
- Bunch Types: Harvested between 100 and 110 days (Singh, 2011).

2.9.6 Maturity Indicators:

- Leaf Yellowing and Dropping: The leaves turn yellow and fall off.
- Pod Hardening: Pods become firm.
- Leaf Spotting: Spotting on leaves may occur.
- Seed Separation: Seeds should be easily separated from the pods (Singh et al., 2020).

2.9.7 Harvesting Methods:

- Hand Pulling: Commonly used for bunch and semi-spreading varieties.
- Mechanical Harvesting: Spreading types are often harvested using ploughs or bullock-drawn harrows (Ajeigbe et al., 2015).

2.9.8 Challenges:

- Underground Pods: Since groundnut pods develop underground, extraction can be difficult.
- Flowering Period: Flowering occurs over an extended period, requiring careful pod selection to test for maturity (Lavkor & Var, 2017).

2.9.9 Post-Harvest Processing:

- Drying: Uprooted plants are typically dried in the field or on level platforms. Plants should be placed root-up to ensure even and faster drying. They are usually left in the field for 2-3 days, depending on weather conditions (Shamshir et al., 2018).
- Pod Separation: After drying, pods are separated from the plants either by hand or using threshers (Paulsen et al., 2015).

2.9.10 Importance of Harvest Timing:

- Early Harvesting: Can lead to reduced yield and quality.
- Delayed Harvesting: Risks include pods remaining in the soil or becoming more susceptible to diseases and post-harvest losses.

2.9.11 Effect of Weed Control on Groundnut Growth and Yield

Weeds pose significant challenges to groundnut cultivation by competing for resources and potentially harboring pests and diseases:

- Resource Competition: Weeds contend with crops for light, moisture, nutrients, and space (Gopal, 2013).
- Pest or Disease Harboring: Weeds can host pests and diseases, which can further reduce crop yields (Singh, 2019).
- Soil Contamination: Some weeds release harmful substances into the soil, impacting crop growth (Oudhia, 2014).

2.9.12 Additional Issues:

- Increased Costs: Weeds increase labor and equipment costs due to the need for more frequent and intensive management (Singh, 2019).

- Harvest Complications: Weeds can complicate harvesting operations and decrease the quality and marketability of produce.
- Environmental Impact: Dense weed growth in water bodies can deplete oxygen levels and harm aquatic life (Oudhia, 2014).

Effective weed management strategies are crucial for maintaining groundnut productivity and ensuring a good quality harvest. Regular and timely weeding is essential to minimize competition and the associated negative impacts on crop yield and quality.

Ahmed et al. (2013) discovered that weed control treatments increased the dry weight of groundnut plants. Regular weeding resulted in the highest plant height and leaf count per plant, followed by weeding at 2 and 4 weeks after planting (WAP), with the lowest results in unweeded plots (3200 kg/ha). Regular weeding also led to the highest plant dry matter production, followed by weeding at 4 and 6 WAP, due to reduced weed density (Kanagam & Chinnamuthu, 2009). Additionally, regular weed control significantly increased yield and yield attributes compared to no weeding (Awodoyin et al., 2013; Abouziena et al., 2014).

Sukhadia et al. (2015) reported that uncontrolled weed growth could reduce groundnut yields by 68.5–69.8%. This is corroborated by Shanwad et al. (2011) and Etejere et al. (2013), who noted yield reductions of 50-60% and 70-80%, respectively, due to uncontrolled weed growth compared to regular weeding. Tijani-Eniola (2011) also reported yield losses ranging from 50 to 80%. Cowpea pod weight and grain yield were generally higher in the late wet season compared to the early wet season, despite high early-season rainfall, due to higher weed infestation in the early season (Adigun, 2014; Badmus et al., 2016). Uncontrolled weed growth resulted in significant yield reductions, with Tripathi and Singh (2011) reporting an 82% reduction in cowpea yield, and Le et al. (2004) noting that weed density, type, persistence, and crop management practices affect yield loss.

2.10 Effect of Plant Population Density on the Yield of Groundnuts

Research indicates that increasing crop density can mitigate the effects of weed competition on crops. The appropriate plant spacing varies by species and must be managed to avoid overcrowding, which can negatively affect growth, development, and yield. Proper spacing is critical for achieving optimal yields. Mehmud et al. (2016) found that wider row spacing resulted in greater seed weight, pod weight, and 1000-seed weight, although it reduced plant height and seed yield. Conversely, semi-dwarf varieties performed better at narrower row spacings. Biswan et al. (2012) reported that plant population density significantly impacts crop varieties, with closer spacing leading to higher total yields per hectare despite lower yields per plant, provided that the optimal population density is maintained. Thellen (2016) noted that reducing row spacing led to decreased yield per plant, but overall yield per hectare increased significantly without affecting cowpea pod and seed yields.

Many studies confirm that appropriate row spacing affects seed yield, with Morrison et al. (2002) finding that narrower row spacing results in higher yields. Various planting patterns can adjust plant population, but spacing must be carefully controlled to avoid overcrowding, which can negatively impact crop performance. Wider spacing (35 cm) often results in shorter plants due to reduced competition for growth factors. Increased crop density has been shown to reduce weed competition (Adigun, 2012). Cooper (2005) found that semi-dwarf soybean cultivars had higher yields at a narrow spacing of 17 cm, with minimal benefits over standard cultivars at 75 cm row spacing and lower plant densities.

In groundnut cultivation, better yields were achieved through narrow row spacing, which improved weed competition (Buchaman et al., 2014). Biswan et al. (2016) reported that plant spacing significantly impacted cowpea pod and seed yields. The maximum yield of legume crops depends on factors such as the number of branches, pods per plant, seeds per pod, and seed weight. Plant density is a crucial factor affecting yield and its components. Ayaz et al. (2004) and Tawaha and Turk (2004) studied the effects of plant density on legume yield, revealing that plant density is a key and variable factor, with results differing by climate. Kakiuchi and Kobata (2004) found that lower plant density increased the number of pods per plant, while higher density reduced it. Hussein et al. (2019) reported that plant height increased with population density up to 33.3 plants/m^2, but Shahein et al. (2014), Hussein et al. (2015), and Mokhtar (2001) found that higher plant density negatively affected the number of pods per plant.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Experimental Site and Location

Two field trials were carried out at the Multiuse Crop Nursery of Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Mampong-Ashanti Campus, during two crop growing periods: from May to August 2022 and from September to December 2022. Mampong-Ashanti, located at the transition zone between Ghana's forest and northern savanna regions, is situated at latitude 7° 3' 11.2932" N and has an elevation of 457.5 meters above sea level. This area experiences a bimodal rainfall pattern with total annual precipitation ranging from 1094.4 mm to 1200 mm, averaging about 91.2 mm per month. The major rainy season occurs from March to July, while the minor rainy season spans from late August to November. A brief dry period occurs in August, followed by the harmattan dry season from December to March. The average daily temperature in Mampong-Ashanti is approximately 30.5°C.

3.2 Soil Type and Vegetation at the Experimental Site

The soil at the experimental site is derived from the Voltaian Sandstone of the Afram Plains and is classified under the Savannah Ochrosol class. It is characterized by deep, pebble-free sandy loam that is well-drained and contains moderate organic matter, with good water retention capacity. According to the FAO/UNESCO classification, it is categorized as Chromic Luvisol and locally known as the Bediesi series. This soil type supports the cultivation of tubers, cereals, and legumes. The soil pH ranges from 6.0 to 6.5. The site has been previously used for growing various crops such as carrots, tomatoes, maize, cowpea, okra, and sweet potatoes. Dominant grass species include nut grass (Cyperus rotundus), giant star grass (Cynodon plectostachus), and guinea grass (Panicum maximum).

3.3 Experimental Design, Treatment, and Field Layout

The study employed a Split-plot design with four replications. The main-plot factor was weed control, with the following treatments:

1. Weed free (weeding every 2 weeks)
2. Weeding once at 4 weeks after planting (WAP)
3. Weeding twice at 2 and 6 WAP
4. Weeding twice at 4 and 8 WAP
5. Unweeded (control)

The sub-plot factor was plant population density, with the following treatments:

1. 50 cm x 10 cm (comparable to 100,000 plants ha^{-1})
2. 50 cm x 20 cm (comparable to 200,000 plants ha^{-1})
3. 50 cm x 30 cm (comparable to 66,667 plants ha^{-1})

Each plot measured 3 meters in width by 45 cm in row length and contained 6 rows. A 1.0-meter space was maintained between blocks and 0.5 meters between plots.

3.4 Planting Material

The groundnut seeds used in this experiment were sourced from the CSIR-Crops Research Institute in Fumesua, near Kumasi. The variety used was Yenyawoso, which is high-yielding, has a higher oil content, matures early in about 90 days, and is resistant to diseases and drought while growing vigorously.

3.5 Cultural Practices

3.5.1 Land Preparation and Planting

The site was prepared by ploughing, harrowing, and forming ridges to facilitate optimal germination and crop growth. Seeds were sown in May 2022 for the main growing season and in September 2022 for the secondary season, at a depth of 5 cm on ridges. Three seeds were placed per hill, with spacing configurations of 50 cm x 10 cm, 50 cm x 20 cm, and 50 cm x 30 cm according to the specific plots and treatments. Eight days after emergence, the seedlings were thinned to leave one plant per hole.

3.5.2 Weed, Pest and Disease Control

Weed control was carried out based on the assigned treatment using a hoe. Pests and diseases were monitored regularly through frequent visits to the experimental site, checking for issues such as rosette, rust, early and late leaf spot. However, no diseases were observed during the entire experimental period.

3.6 Data Collected

3.6.1 Phenological Data

3.6.1.1 Days to 50 % Emergence

This was estimated as the sum of days when 50 % or half of the plants within harvestable row had emerged from planting.

3.6.1.2 Percentage Plant Establishment

The percentage of plant establishment was calculated by counting the plants that had become established after 21 days of planting. This number was then calculated as a percentage of the total number of plants anticipated to emerge from the two central rows designated for harvest.

3.6.1.3 Days to 50% flowering

This was calculated as the number of days it took for 50% of the plants in the two central rows designated for harvest to flower, starting from the day the seeds were planted.

3.6.1.4 Days to 50 % Pegging

This was assessed when 50% of the plants in the two central rows designated for harvest had pegged, starting from the day the seeds were planted.

3.7 Vegetative Growth

3.7.1 Plant Height

Height of plant was recorded for four tagged plants from the two central rows, measured from the base to the top leaf using a meter rule. Measurements were taken four weeks after planting and then every two weeks thereafter, with the average height calculated.

3.7.2 Number of Branches

The total number of branches per plant was counted for each of the four tagged plants, which were randomly selected from the two central rows of each plot. This counting was done four weeks after planting and then every two weeks, with the average number of branches calculated.

3.7.3 Canopy Width

The canopy width of four randomly chosen plants from the two central rows of each plot was measured at its widest point using a meter rule. Measurements were taken four weeks after planting and then at two-week intervals, with the average width calculated.

3.7.4 Dry Matter Accumulation

Three plants were removed from the border and divided into root and shoot sections. The fresh weights of the root and shoot were recorded with an electronic scale, after which they were oven-dried at 70°C until a constant weight was achieved. The dry matter was then measured with an electronic scale, and the average was calculated. This procedure was carried out four weeks after planting and subsequently at two-week intervals.

3.7.5 Weed Dry Matter

Weed dry matter was assessed using 0.5 m^2 quadrat samples taken from each plot. These samples were weighed with an electronic scale and then dried in an oven at 70°C until a constant weight was reached. The dry matter was measured again with the electronic scale, and the average was calculated. This process was repeated four weeks after planting and every two weeks thereafter. The data from the weed biomass were used to calculate Weed Control Efficacy (WCE) using the formula:

(“$\frac{Wbc-Wbt}{Wbc} * 100$”.)

where Wbc represents the weed biomass of the untreated plots (g/m²) and Wbt represents the weed biomass of the treated plots (g/m²).

3.8 Yield and Yield Components

3.8.1 Number of Plants Harvested

The total number of plants harvested from the two central rows was counted and the mean computed to give the number of plants per row.

3.8.2 Number of Pod per Plant

The total number of pods per plant from the four (4) randomly selected plant from the two central rows was counted after harvest and the mean estimated.

3.8.3 Number of Pods per Plot

The total number of cobs per plant after harvest from the two central rows was counted and the mean recorded.

3.8.4 100-Seed Weight

The 100 -seed weight was determined by weighing 100 seeds randomly selected from mature shelled cobs within the two middle rows per plot using electronic weighing scale and the mean computed.

3.8.5 Number of Seeds per Pod

The total number of seeds per pod from the two central rows was counted after harvest and the mean estimated.

3.8.6 Pod Yield

The pod yield from the harvestable area per plot of groundnut was calculated and the results were then used to compute the yield per hectare. Thus, pod yield per hectare is given as;

Pod yield (kg) per hectare = $\frac{10000m^2\ x\ Q\ grain\ (kg)}{Harvest\ area\ (m^2)}$ (Makarova *et al*., 2020)

3.8.7 Total Seed Yield (kg/ha)

Total seed yield was determined from twenty (20) plants from the two middle rows. Seed from pods after harvest were removed manually and sun dried out to a constant moisture. The seeds weighed with an electronic weighing scale and their seed yield per plot was estimated in kg/ha.

3.8.8 Harvest Index

The harvest index is the ratio of grain yield per plant biomass produced. It was estimated by dividing the grain yield by the total biomass yield.

HI =GY/TY

Where:

HI = harvest index

GY = grain yield

TY = Total biomass yield

3.8.9 Haulm weight per plot at harvest

At harvest, the shoot of all plants from the two central rows was weighed and the mean computed and recorded.

3.9 Economic Benefit (Partial Budget Analysis)

A partial budget analysis was conducted using the Marginal Rate of Returns to determine the economic benefit or profitability of the treatment, especially the weed control treatments.

Table 3.1: Information used for partial budget Analysis

Variables	Quantity Amount
Adjusted groundnut yield (t/ha)	10%
Farm gate price of groundnut	12,000
Labour for weeding	Weed free =5 times =50 Man days Weed once (4 WAP) =1 time =10 Man days Weed twice (2,6 WAP) 2 times = 20 Man days Weed twice (4,8 WAP) 2 times = 20 Man days Unweeded 0 = 0 mondays
Labour cost	GH₵70 Man days

3.10 Data Analysis

The collected data were analyzed statistically using the Genstat statistical package (2007) version 9.2. Analysis of variance (ANOVA) was performed to evaluate the data, and significant differences between treatment means were determined using the Least Significant Difference (LSD) test at a 5% probability level.

CHAPTER FOUR: RESULTS

4.1 Phenology

4.1.1 Days to 50% Emergence

There were no significant differences (P≥ 0.05) observed in days to 50% emergence with respect to weed control, plant spacing, or the interaction between weed control and plant spacing during the major season (Table 4.1). Similarly, there were no significant differences among these factors in the minor season. The days to reach 50% emergence ranged from 6 to 7 days in the major season and from 8 to 10 days in the minor season (Table 4.1).

Table 4.1: Days to 50% emergence of groundnuts as influenced by weed control and plant spacing at Mampong- Ashanti in the 2022 major and minor cropping seasons

	Major Season				**Minor Season**			
	Planting Spacing (cm)			**Days to 50 % emergence**	**Planting Spacing (cm)**			
Weed Control	**50 x10**	**50 x20**	**50 x30**	**Mean**	**50 x 10**	**50 x 20**	**50 x 30**	**Mean**
Weed free	7	7	6	7	9	9	8	8
Weed once (4 WAP)	6	6	6	6	10	9	9	9
Weed twice (2, 6 WAP)	6	6	6	6	8	9	9	9
Weed twice (4, 8 WAP)	7	6	7	6	8	9	8	9
Unweeded (Control)	6	6	7	6	9	10	9	9
Mean	6	6	6		9	10	9	
CV (%)		**13.1**				**10.9**		
Weed control		**HSD (0.05)=NS**				**HSD (0.05)=NS**		
Plant Spacing		**HSD (0.05)=NS**				**HSD (0.05)=NS**		
Weed control x Plant spacing		**HSD (0.05)=NS**				**HSD (0.05)=NS**		

4.2 Percentage Plant Establishment

Weed control and the interaction between weed control and plant spacing did not significantly impact the percentage of plant establishment in either the major or minor seasons. However, plant spacing had a significant effect on percentage plant establishment in both seasons. The 50 x 10 cm spacing resulted in the highest percentage of plant establishment, while the 50 x 30 cm spacing showed the lowest. The percentage of plant establishment at the 50 x 10 cm spacing was nearly five times greater than that at the 50 x 30 cm spacing (Table 4.2).

Table 4.2: Percentage plant establishment of groundnuts as influenced by weed control and plant spacing at Mampong- Ashanti in 2022 major and minor cropping seasons

Weed Control	**Percentage plant establishment Major Season Planting Spacing (cm)**				**Minor Season Planting Spacing (cm)**			
	50 x10	50 x20	50 x30	Mean	50 x 10	50 x 20	50 x 30	Mean
Weed free	97.8	94.1	95.0	95.6	96.0	94.5	92.0	24.3
Weed once (4 WAP)	98.2	95.5	95.1	96.2	92.2	92.0	97.0	24.0
Weed twice (2, 6 WAP)	98.9	98.6	95.0	95.2	95.6	91.2	97.0	24.6
Weed twice (4, 8 WAP)	98.2	91.8	95.3	96.6	95.6	93.2	95.0	24.5
Unweeded	97.8	96.3	92.1	96.8	94.4	94.7	92.0	24.1
Mean	98.2	95.0	94.5		92.6	90.9	95.0	
CV (%)		**3.32**				**5.30**		
Weed control	**HSD (0.05)=NS**				**HSD (0.05)=NS**			
Plant Spacing	**HSD (0.05)=0.64 (p < 0.001)**				**HSD (0.05)=1.00 (p < 0.001)**			
Weed control x Plant spacing	**HSD (0.05)=NS**				**HSD (0.05)=NS**			

4.2.1 Days to 50% Flowering

The results indicated the average number of days to 50% flowering during the major season. Significant differences ($P \leq 0.05$) were observed among the weed control methods, plant spacing, and the interaction between weed control and plant spacing for the days to 50% flowering in the major season (Table 4.3). Overall, plots that were weeded twice at 4 and 8 weeks after planting (WAP) flowered 4-5 days earlier compared to those that were weeded once at 4 WAP or twice at 2 and 6 WAP, as well as the weed-free plots (Table 4.3). Additionally, plants spaced at 50 cm x 10 cm flowered 3 days earlier than those spaced at 50 cm x 20 cm and 50 cm x 30 cm. In the minor season, the days to 50% flowering were not significantly influenced by the interaction between weed control and planting spacing (Table 4.3).

Table 4.3: Days to 50% flowering of groundnut as influenced by weed control and plant spacing at Mampong – Ashanti in 2022 major and minor cropping seasons

	Days to 50% flowering							
	Major Season				**Minor Season**			
	Planting Spacing (cm)				**Planting Spacing (cm)**			
Weed Control	50 x10	50 x20	50 x30	Mean	50 x 10	50 x 20	50 x 30	**Mean**
Weed free	29	34	34	32	35	34	37	35
Weed once (4 WAP)	30	35	33	33	33	34	34	36
Weed twice (2, 6 WAP)	28	35	37	33	33	34	34	34
Weed twice (4, 8 WAP)	27	29	28	28	31	35	32	32
Unweeded (Control)	29	28	29	29	36	36	37	36
Mean	29	32	32		33	33	35	
CV (%)		**5.64**				**4.61**		
Weed control	**HSD (0.05) =2.59 (p < 0.001)**				**HSD (0.05) =2.98 (p = 0.017)**			
Plant Spacing	**HSD (0.05) =1.36 (p < 0.001)**				**HSD (0.05) =1.22 (p = 0.024)**			
Weed control x Plant spacing	**HSD (0.05)=4.54 (p < 0.001)**				**HSD (0.05) =NS**			

4.2.2 Days to 50% Pegging

During the major season, weed control did not influence the number of days to 50% pegging, though planting spacing and the interaction between weed control and plant spacing were significant. In contrast, during the minor season, while weed control did affect the days to 50% pegging, neither plant spacing nor the interaction between weed control and plant spacing had a significant impact (Table 4.4). Generally, plants spaced at 50 cm x 20 cm and 50 cm x 30 cm pegged 2-3 days earlier compared to those spaced at 50 cm x 10 cm. Specifically, under the 50 cm x 10 cm spacing, those weeded once at 4 weeks after planting (WAP) pegged later, whereas those weeded twice at 4 and 8 WAP under the 50 cm x 20 cm spacing pegged late, and those weeded twice at 2 and 6 WAP under the 50 cm x 30 cm spacing pegged (Table 4.4).

Table 4.4: Days to 50% pegging as influenced by weed control and plant spacing in 2022 major and minor cropping seasons

Weed Control	**Days to 50% pegging** **Major Season** **Planting Spacing (cm)**				**Minor Season** **Planting Spacing (cm)**			
	50 x10	50 x20	50 x30	Mean	50 x 10	50 x 20	50 x 30	**Mean**
Weed free	43	51	48	47	45	50	49	48
Weed once (4 WAP)	50	46	46	47	50	45	47	47
Weed twice (2, 6 WAP)	43	48	50	47	46	48	49	47
Weed twice (4, 8 WAP)	44	56	47.7	49	47	52	48	49
Unweeded (Control)	49	49	48.5	49	51	54	55	53
Mean	46	49	47.9		48	49	50	
CV (%)		**8.78**				**6.61**		
Weed control	**HSD (0.05) = NS**				**HSD (0.05) =5.09 (p = 0.013)**			
Plant Spacing	**HSD (0.05) = 3.27 (p = 0.033)**				**HSD (0.05) = NS**			
Weed control x Plant spacing	**HSD (0.05) =10.92 (p = 0.034)**				**HSD (0.05) = NS**			

4.2.3 Days to Podding

Table 4.5 illustrates that both weed control and plant spacing influenced the days to podding during both crop growing seasons. While the interaction between weed control and plant spacing did not significantly impact the days to podding in the major season ($p \geq 0.05$), it did have a significant effect in the minor season (Table 4.5). In the major season, the weed-free treatment resulted in the earliest podding, occurring about 12 days before the unweeded plots, which podded the latest. Among the plant spacings, 50 cm x 20 cm and 50 cm x 30 cm exhibited earlier podding compared to other spacings. Similarly, in the minor season, groundnuts in unweeded plots podded 6-8 days later than those in other treatments. The closer spacing of 50 cm x 10 cm led to podding approximately 3 days earlier than the wider spacings of 50 cm x 20 cm and 50 cm x 30 cm (Table 4.5).

Table 4.5: Days to podding as influenced by weed control and plant spacing in 2022 major and minor cropping seasons

	Days to podding							
	Major Season				**Minor Season**			
Weed Control	**Planting Spacing (cm)**				**Planting Spacing (cm)**			
	50 x10	50 x20	50 x30	Mean	50 x 10	50 x 20	50 x 30	**Mean**
Weed free	58	66	63	62	78	85	86	83
Weed once (4 WAP)	63	68	67	66	82	79	81	81
Weed twice (2, 6 WAP)	60	65	69	64	79	81	83	1
Weed twice (4, 8 WAP)	68	68	74	68	78	86	79	81
Unweeded (Control)	75	71	77	74	87	90	92	89
Mean	64	67	68		81	84	84	
CV (%)		**6.93**				**4.40**		
Weed control	**HSD (0.05) = 6.19 (p = 0.001)**				**HSD (0.05) = 5.82 (p = 0.002)**			
Plant Spacing	**HSD (0.05) = 3.63 (p < 0.004)**				**HSD (0.05) = 2.84 (p = 0.016)**			
Weed control x Plant spacing	**HSD (0.05)= NS**				**HSD (0.05) = 9.48 (p = 0.041)**			

4.2.4 Days to Maturity

There were significant differences ($P \leq 0.05$) in the days to maturity due to weed control, plant spacing, and the interaction between weed control and plant spacing in both seasons. On average, unweeded plots matured later, while the weed-free groundnuts matured approximately 10 days earlier during the major season (Table 4.6). Similarly, in the minor season, the weeded treatments reached maturity later. Additionally, the closer spacing (50 cm x 10 cm) also resulted in later maturity compared to the wider spacings (Table 4.6).

Table 4.6: Days to maturity as influenced by weed control and plant spacing in 2022 minor and major cropping seasons

	Days to maturity							
	Major Season				**Minor Season**			
	Planting Spacing (cm)				**Planting Spacing (cm)**			
Weed Control	50x10	50 x20	50 x30	**Mean**	50 x 10	50 x 20	50 x 30	**Mean**
Weed free	98	98	101	99	113	113	113	113
Weed once (4 WAP)	104	100	104	102	116	113	113	113
Weed twice (2, 6 WAP)	106	98	98	101	112	112	113	112
Weed twice (4, 8 WAP)	109	98	109	105	113	112	113	113
Unweeded (Control)	109	109	109	109	116	113	113	114
Mean	105	101	104		114	113	113	
CV (%)		**3.48**				**0.28**		
Weed control	**HSD (0.05) = 2.44 (p < 0.001)**				**HSD (0.05) = 0.35 (p < 0.001)**			
Plant Spacing	**HSD (0.05) = 2.76 (p < 0.001)**				**HSD (0.05) = 0.25 (p < 0.001)**			
Weed control x Plant spacing	**HSD (0.05) = 9.24 (p = 0.009)**				**HSD (0.05) = 0.85 (p < 0.001)**			

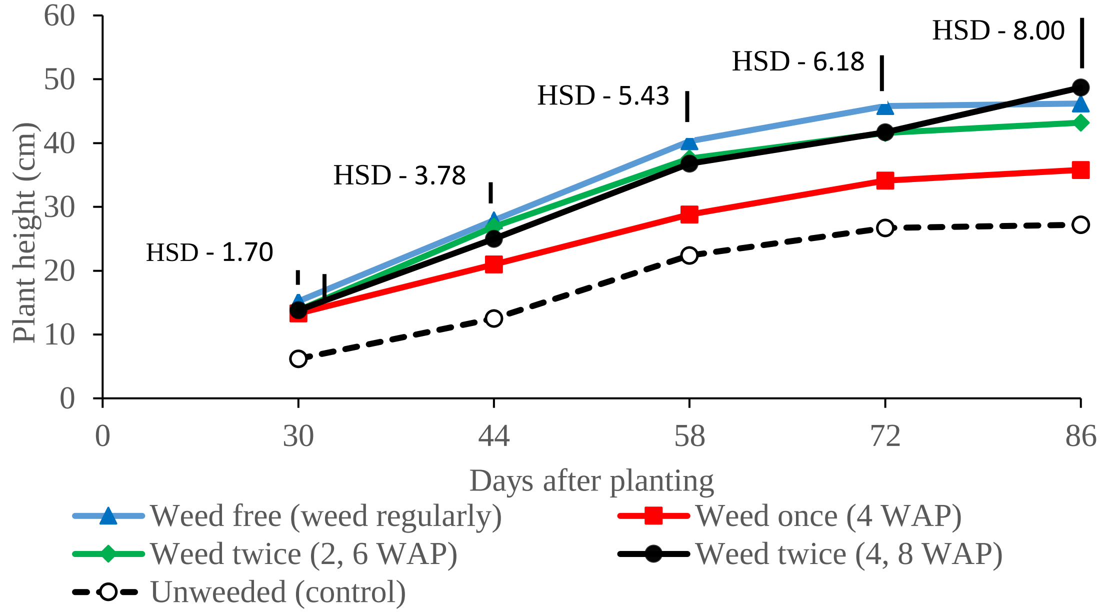
4.3 Vegetative Growth

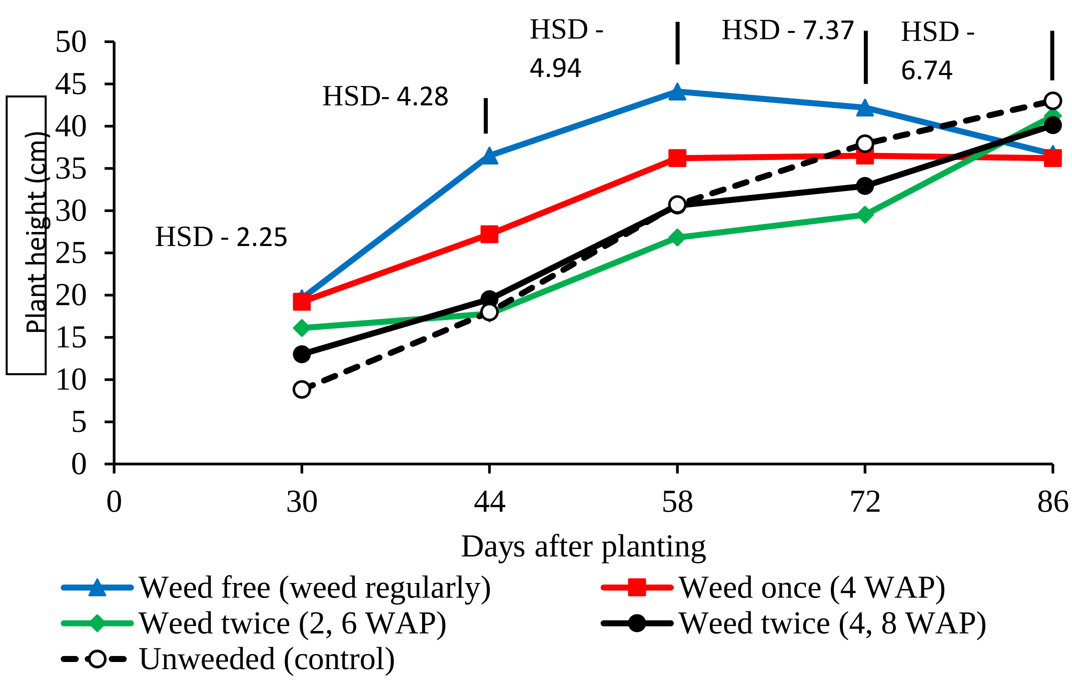
4.3.1 Plant Height

During the major season, plant height differences in groundnut were noted from 30 days after planting (DAP) to 86 DAP. The weed-free treatment resulted in the tallest plants from 30 DAP to 72 DAP, with the "weed once" treatment (at 4 weeks after planting) coming next in height (Fig 4.1a). No significant differences in plant height were observed between the unweeded control and the "weed twice" treatment (at 4 and 8 weeks after planting) from 58 DAP to 86 DAP. The "weed twice" treatment produced the shortest plants from 44 DAP to 72 DAP (Fig 4.1a). The minor season recorded significant differences in plant height were also detected from 30 DAP to 86 DAP, with the weed-free treatment producing the tallest plants throughout, followed by the "weed once" treatment (Fig 4.1b).

For plant spacing in the major season, the 50 cm × 30 cm spacing resulted in the tallest plants from 44 DAP to 86 DAP, while the 50 cm × 10 cm and 50 cm × 20 cm spacings yielded similar plant heights (Fig 4.1b). In the minor season, the 50 cm × 30 cm spacing produced the tallest plants from 30 DAP to 86 DAP, whereas the 50 cm × 10 cm spacing resulted in the shortest plants from 58 to 86 DAP compared to the 50 cm × 20 cm spacing, which had intermediate plant heights (Fig 4.2b).

(A) Major Season, 2022





(B) Minor season, 2022

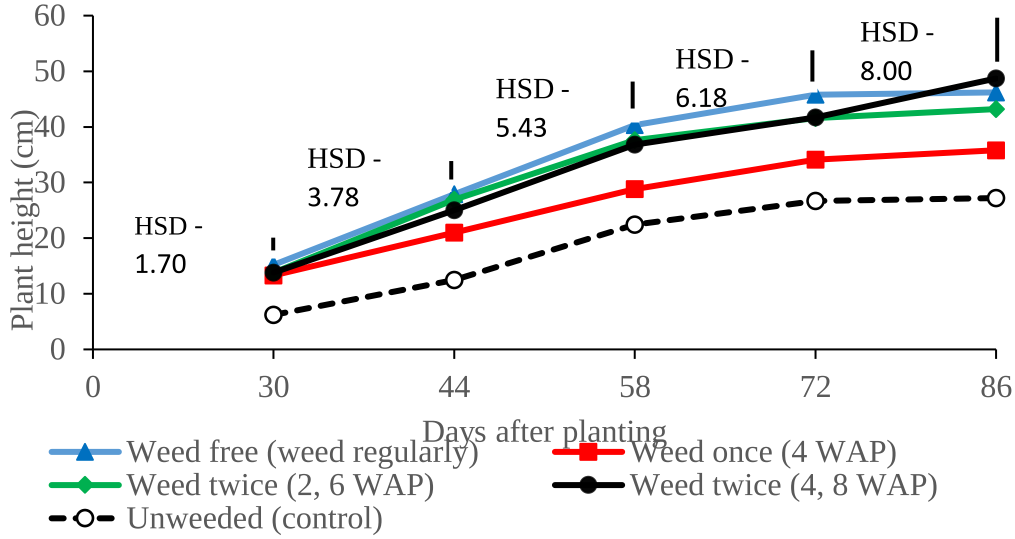
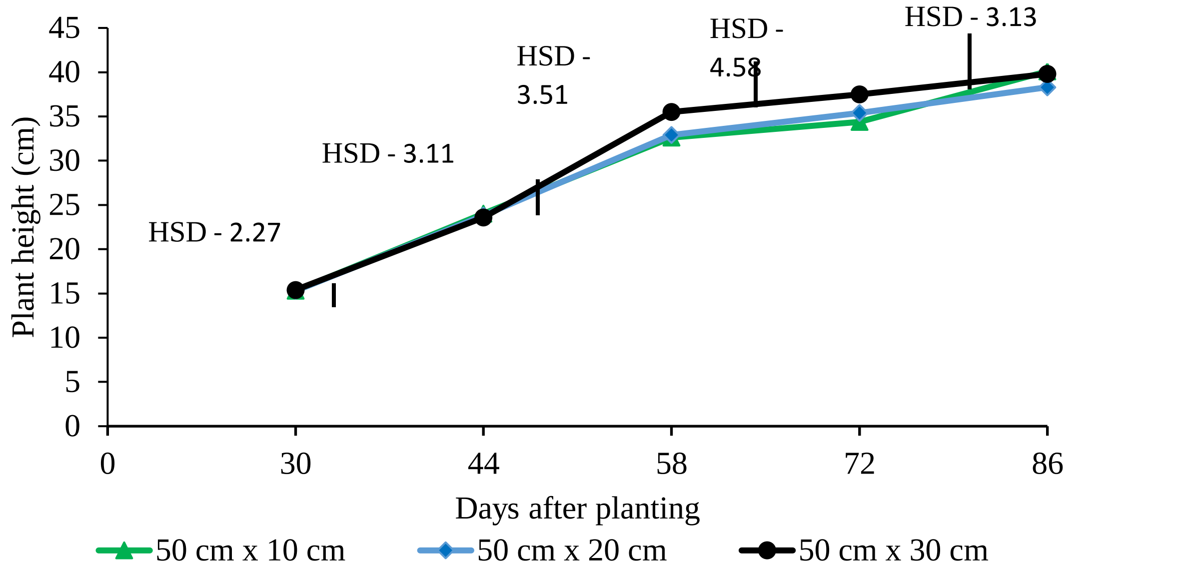


Figure 4.1a and 4.1b: Plant height of groundnut as influenced by weed control at Mampong-Ashanti in the 2022 crop growing seasons

(A) Major Season, 2022



(B) Minor season, 2022

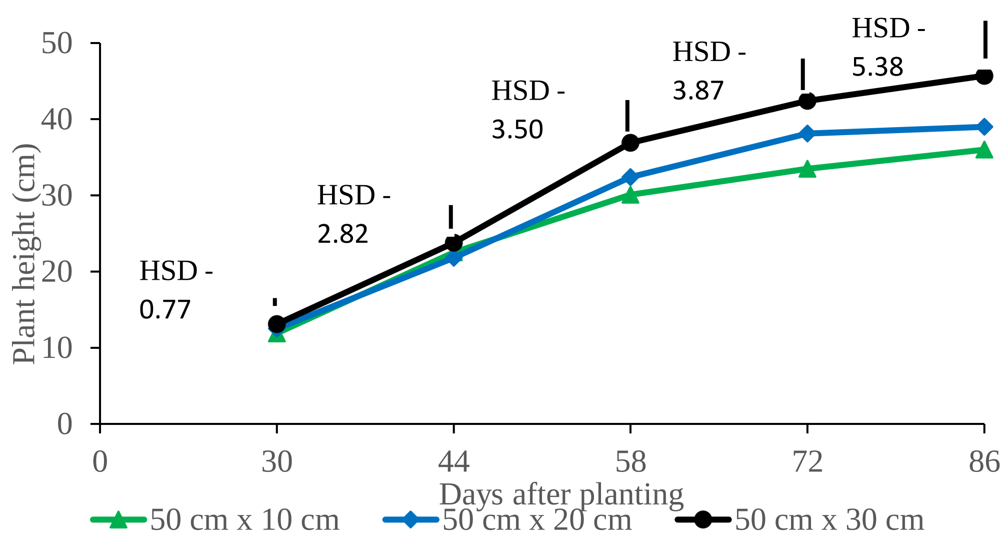


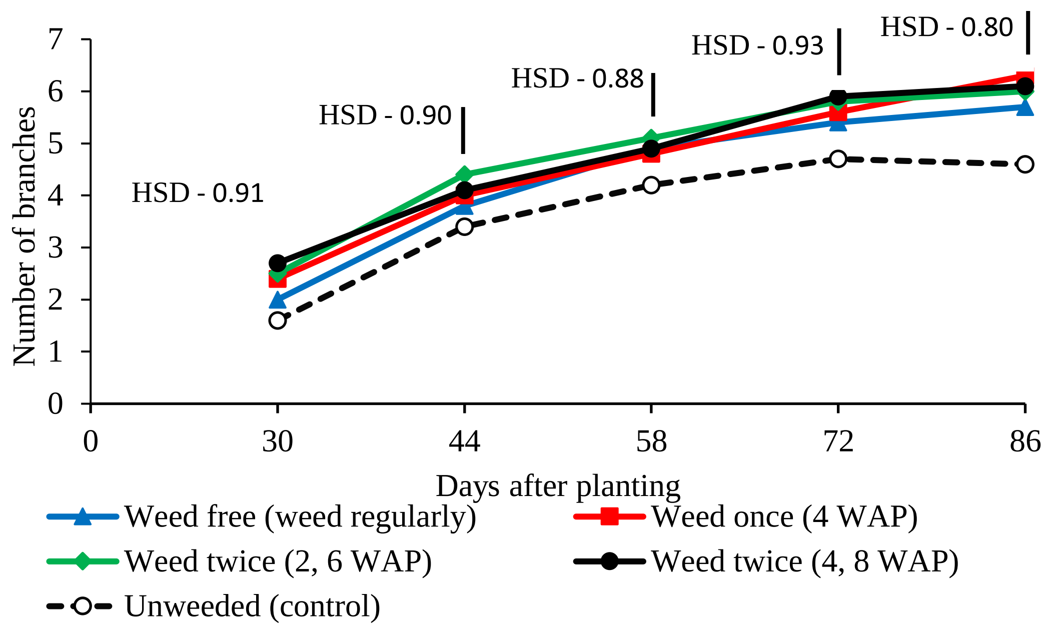
Figure 4.2a and 4.2b: Plant height of groundnut as influenced by plant spacing at Mampong-Ashanti in the 2022 major and minor seasons

4.3.2 Number of Branches

Figure 4.3a illustrates the impact of weed control on the number of groundnut branches during both the major and minor cropping seasons. In the major season, plants subjected to the "weed twice" treatments (at 2 and 6 weeks after planting, and at 4 and 8 weeks after planting) and the "weed once" treatment (at 4 weeks after planting) generally exhibited a higher number of branches compared to other treatments, with the weed-free treatment showing intermediate results. The unweeded treatment had the fewest branches per plant (Fig 4.3a).

During the minor season, the number of branches per plant was higher for the "weed twice" treatments (at 2 and 6 weeks, and at 4 and 8 weeks) compared to the weed-free treatment, which resulted in the fewest branches over the sampling period (Fig 4.3b). In the major season, the 50 cm × 30 cm spacing produced more branches per plant than the 50 cm × 10 cm and 50 cm × 20 cm spacings throughout the sampling period (Fig 4.4a). However, in the minor season, the number of branches per plant was similar across different plant spacings (Fig 4.4b).

(A) Major Season, 2022



(B) Minor Season

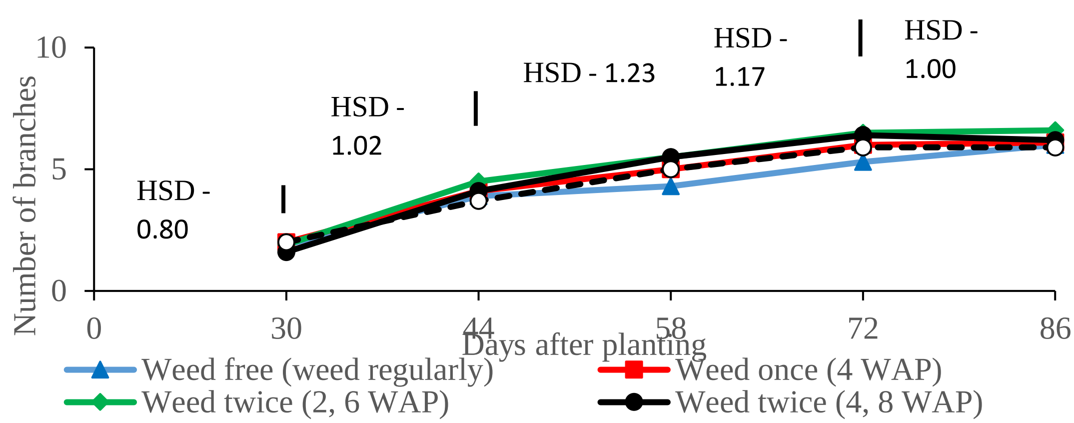
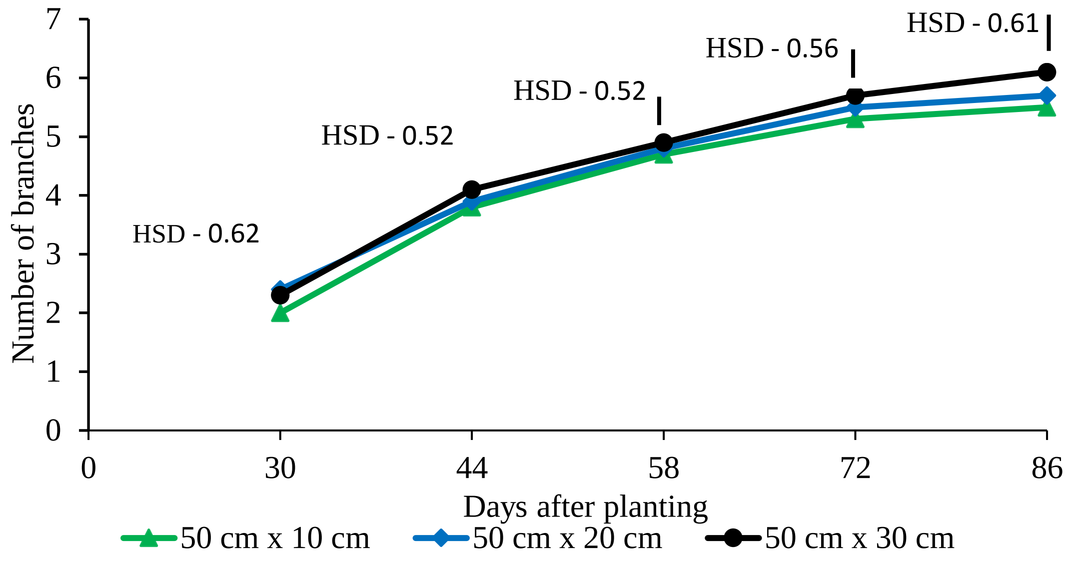


Figure 4.3a and 4.3b: Number of branches of groundnut as influenced by weed control at Mampong-Ashanti in the 2022 crop growing seasons

(A) Major Season, 2022



(B) Minor Season, 2022

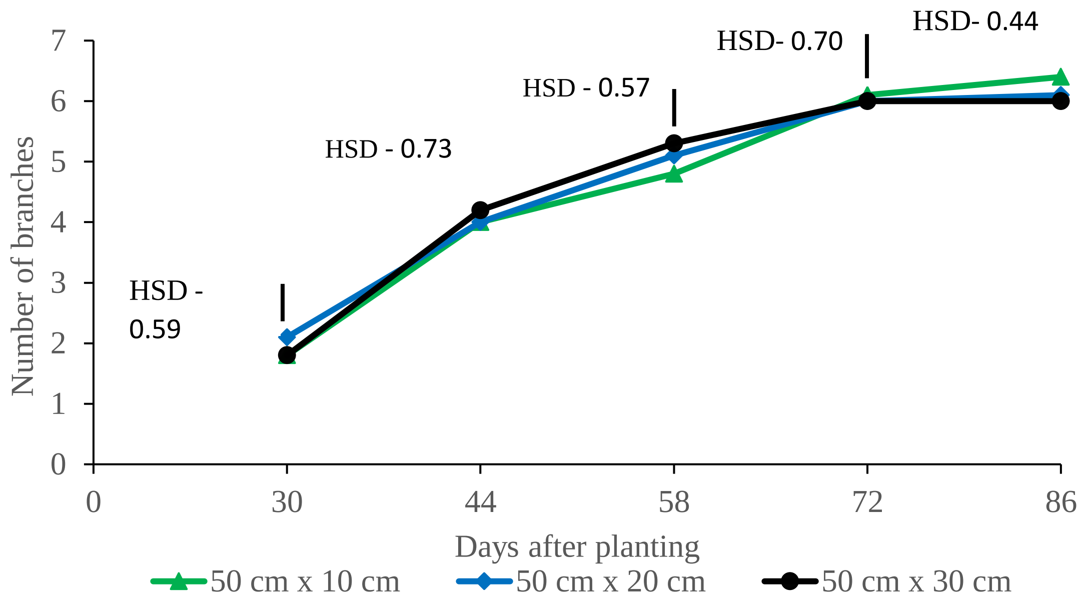


Figure 4.4a and 4.4b: Number of branches of groundnut as influenced by plant spacing at Mampong-Ashanti in the 2022 major and minor seasons

4.3.3 Canopy Spread

In the major season, canopy spread did not show a significant difference among the weed control treatments from 30 to 44 weeks after planting (WAP). However, treatments involving weeding twice (at 2 and 6 WAP) and the weed-free treatment exhibited a significantly greater canopy spread per plant compared to other treatments. Intermediate canopy spread was observed for the "weed once" (at 4 WAP) and "weed twice" (at 4 and 8 WAP) treatments, while the unwedded control had the smallest canopy spread during the same period (Fig 4.5a).

During the minor season, no significant differences in canopy spread were noted among treatments from 30 to 58 days after planting (DAP). Nonetheless, the "weed once" treatment (at 4 WAP) produced the widest canopy from 58 to 86 DAP, while the "weed twice" (at 2 and 6 WAP) and unwedded control treatments had similar canopy spreads.

Results from Fig 4.4a show a significant difference in canopy spread among planting spacings from 30 to 86 DAP, with the 50 cm × 30 cm spacing generally resulting in the least canopy spread. The 50 cm × 30 cm spacing had the highest canopy spread from 30 to 44 DAP but the lowest from 58 to 86 DAP. The 50 cm × 10 cm and 50 cm × 20 cm spacings exhibited similar trends at 30 and 44 DAP. Throughout the seasons, canopy spread increased linearly (Fig 4.5b).

(A) Major Season, 2022

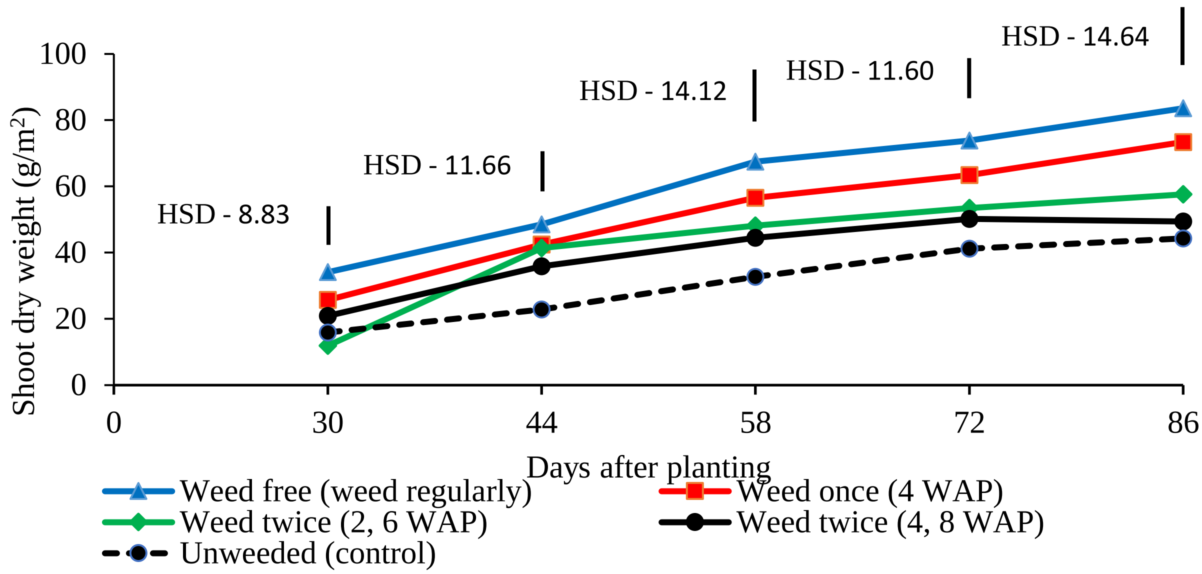
4.3.4 Shoot Dry Weight

During the major season, regular weeding (weed-free) and weeding once (at 4 WAP) resulted in higher shoot dry weights compared to other weed control methods. The treatments with weeding twice (at 2 and 6 WAP, or 4 and 8 WAP) had intermediate shoot dry weights, while the unweeded control produced the lowest shoot dry weight throughout the sampling period (Fig 4.6a).

Significant differences ($P \leq 0.05$) in shoot dry weight were observed among plant spacings from 30 to 86 days after planting (DAP). In the minor season, the treatments involving weeding twice (at 2 and 6 WAP) and the weed-free treatment yielded the highest shoot dry weights, which were significantly different ($P < 0.05$) from the other weed control treatments (Fig 4.7a). The control treatment had the lowest shoot dry weight.

Among plant spacings, the 50 cm × 10 cm spacing resulted in the highest shoot dry weight, followed by the 50 cm × 20 cm spacing, while the 50 cm × 30 cm spacing had the lowest shoot dry weight throughout the growing period. In the major season, the 50 cm × 20 cm spacing produced significantly higher shoot dry weights compared to the 50 cm × 10 cm and 50 cm × 30 cm spacings from 44 to 72 DAP. However, at 30, 72, and 86 DAP, the 50 cm × 20 cm spacing recorded the lowest shoot dry weight.

(A) Major season



(B) Minor Season

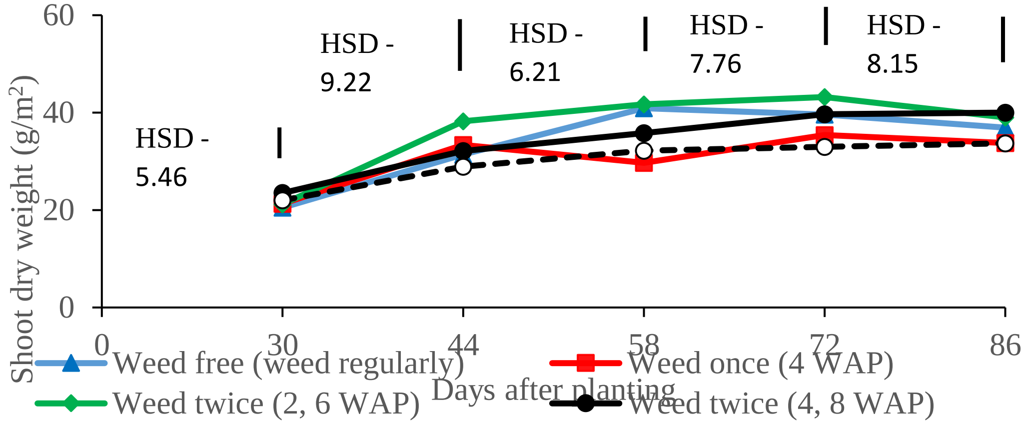
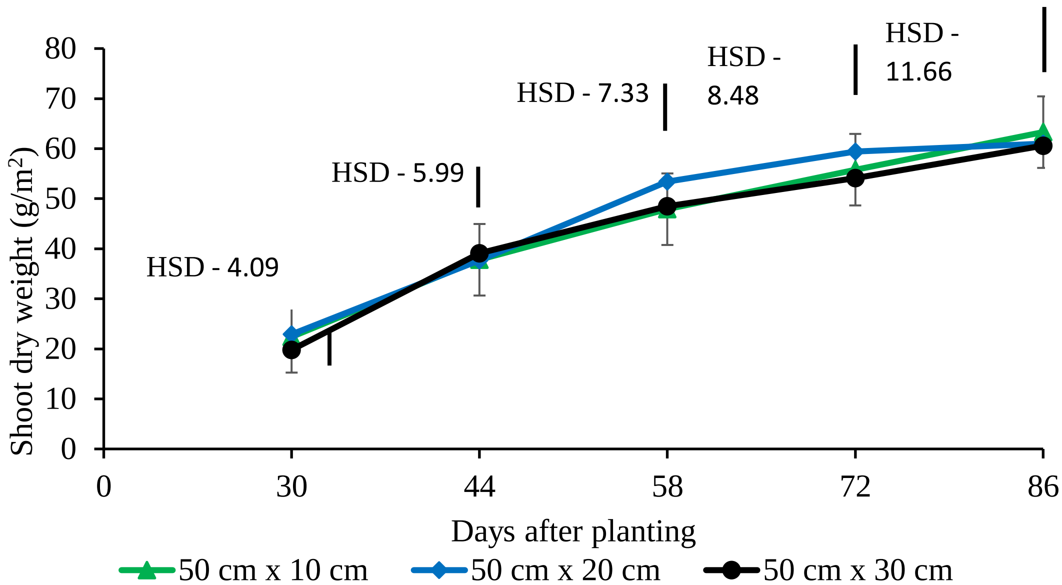


Figure 4.5a and 4.5b: Shoot dry weight of groundnut as influenced by weed control at Mampong-Ashanti during 2022 crop growing seasons

(A)Major season, 2022



(B) Minor Season

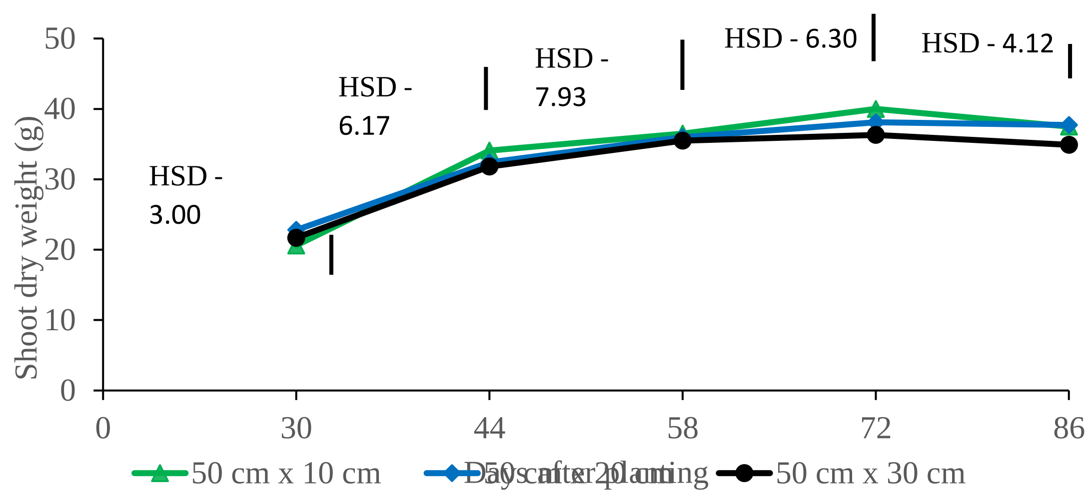


Figure 4.6a and 4.6b: Shoot dry weight of groundnut as influenced by plant spacing at Mampong-Ashanti in the 2022 major and minor seasons

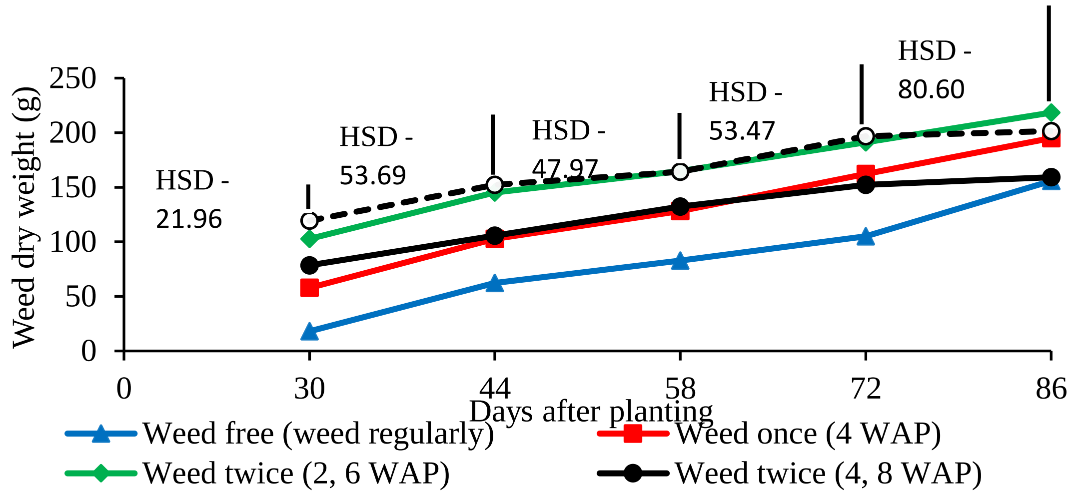
4.3.5 Weed Dry Weight

In the major cropping season, the unweeded (control) treatment resulted in the highest weed dry weight from 30 to 44 days after planting (DAP) and at 72 DAP. This was followed by the weed twice (2 & 6 WAP) treatment, which had the second highest weed dry weight among all weed control treatments. The weed twice (4 & 8 WAP) and weed once (4 WAP) treatments had intermediate levels of weed dry weight, while the weed-free treatment had the lowest weed dry weight throughout the growing period (Fig 4.6a).

In the minor cropping season, the weed once (4 WAP) treatment recorded the highest weed dry weight, with the unweeded and weed twice (4 & 8 WAP) treatments showing intermediate levels. The weed-free treatment resulted in the lowest weed dry weight (Fig 4.6b).

Significant ($P \leq 0.05$) differences were recorded between plant spacings (50 cm × 10 cm, 50 cm × 20 cm, and 50 cm × 30 cm) regarding weed dry weight in the major season. The 50 cm × 30 cm spacing had the highest weed dry weight from 30 to 86 DAP, while the 50 cm × 20 cm spacing recorded the lowest weed dry weight during the same period (Fig 4.10a). In the minor season, the weed dry weights for the 50 cm × 10 cm and 50 cm × 20 cm treatments were similar and higher than those for the 50 cm × 30 cm spacing (Fig 4.8b).

A) Major Season, 2022



(B) Minor Season, 2022

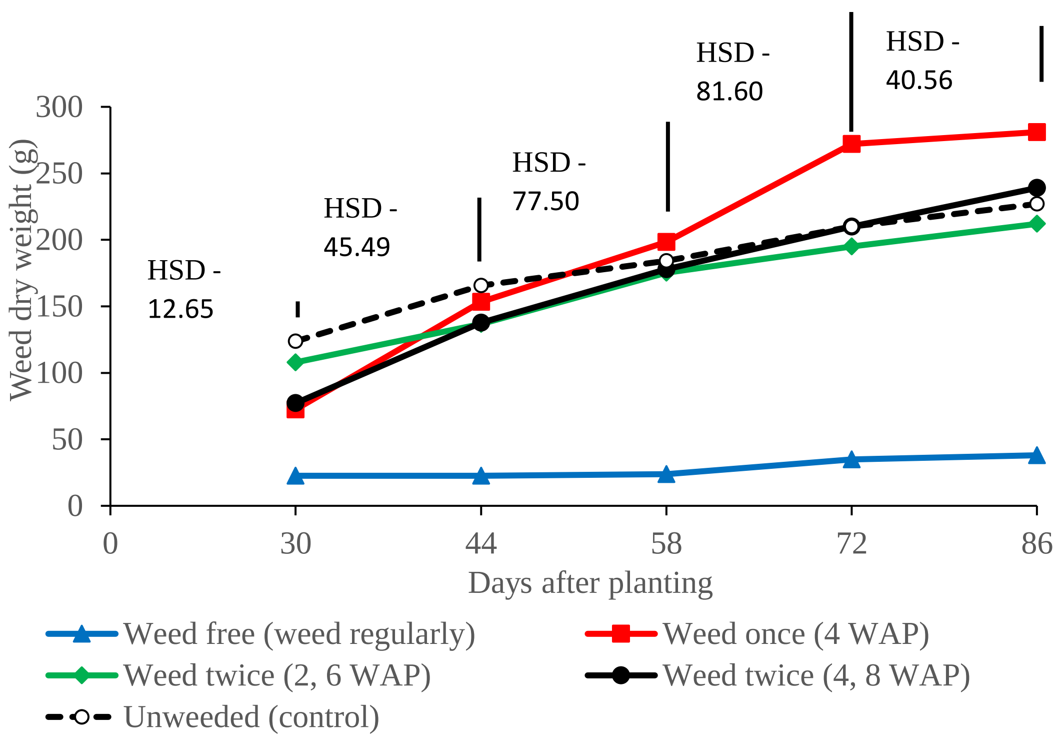
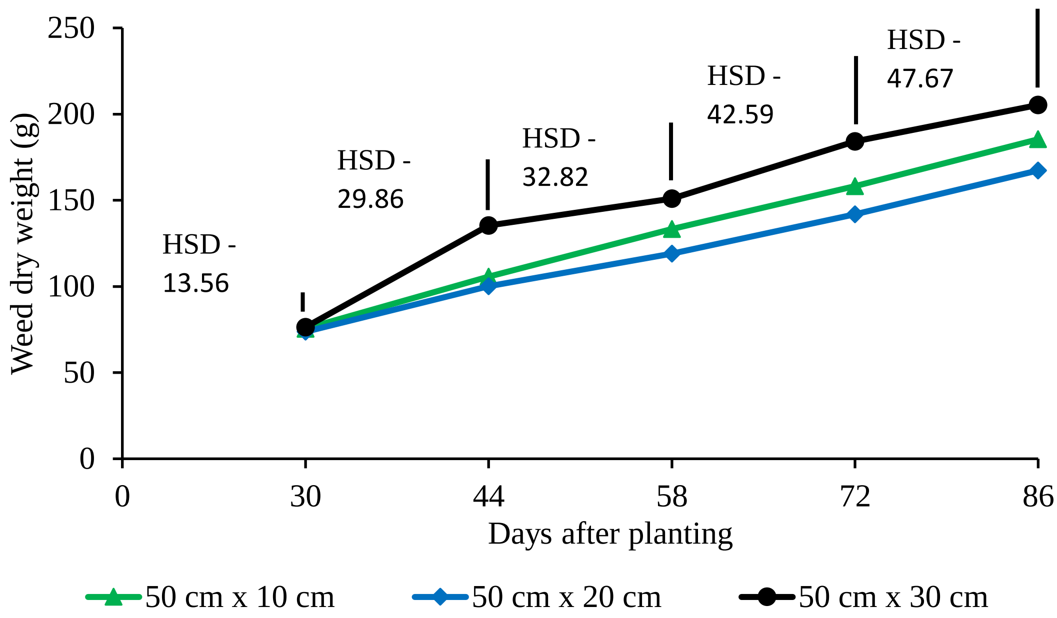


Figure 4.7a and 4.7b: Weed dry weight of groundnut as influenced by weed control at Mampong-Ashanti in the 2022 major and minor cropping seasons

(A) Major Season, 2022



(B) Minor Season, 2022

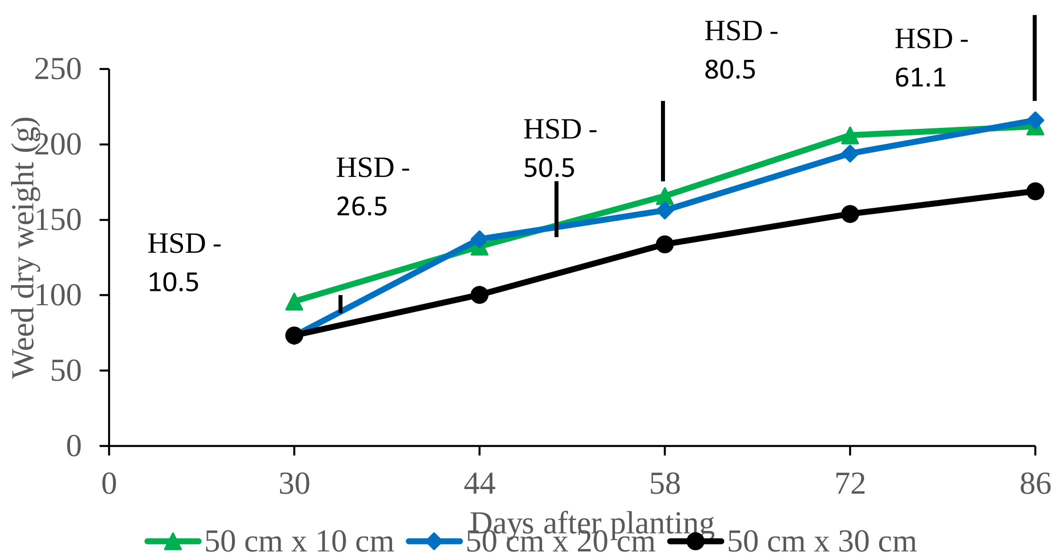


Figure 4.8a: 4.18b: Weed dry weight of groundnut as influenced by plant density at Mampong-Ashanti in the 2022 major and minor cropping season

4.4 Yield and Yield Components

4.4.1 Number of Plants Harvested

There were no significant differences ($P \geq 0.05$) in the number of plants harvested among the various weed control treatments during both the major and minor cropping seasons (Table 4.7). Similarly, the interaction between weed control and plant space did not meaningfully affect the number of plants harvested in either season (Table 4.7). However, the number of plants harvested varied among the different plant spacing treatments, with the 50 cm x 10 cm spacing resulting in the highest number of plants harvested, followed by the 50 cm x 20 cm spacing, and the 50 cm x 30 cm spacing yielding the lowest number of plants harvested in both the major and minor seasons (Table 4.7).

Table 4.7: Number of plants harvested influenced as by weed control and plant spacing in 2022 major and minor cropping season

Weed Control	**Number of plants harvested Major Season Planting Spacing (cm)**				**Minor Season Planting Spacing (cm)**			
	50 x 10	50 x 20	50 x 30	**Mean**	50 x 10	50 x 20	50 x 30	**Mean**
Weed free	80	37	18	45	80	38	18	45
Weed once (4 WAP)	78	36	17	44	78	39	18	44
Weed twice (2, 6 WAP)	78	39	17	45	82	42	17	47
Weed twice (4, 8 WAP)	82	38	18	46	78	40	18	45
Unweeded (Control)	82	38	17	46	76	38	17	44
Mean	80	38	17		78	40	17	
CV (%)		**6.71**				**8.06**		
Weed control	**HSD=(0.05) = NS**				**HSD=(0.05)= NS**			
Plant Spacing	**1.18 (p < 0.001) 1.8 (p<0.01)**				**HSD=(0.05) = 1.41 (p < 0.001)**			
Weed control x Plant spacing	**HSD=(0.05)= NS**				**HSD=(0.05)= NS**			

4.4.2 Number of Pods per Plant

Table 4.8 shows that there was a significant difference ($P \geq 0.05$) between weed control and plant space in the number of pods per plot during both the major and minor cropping seasons. In the major season, the highest number of pods per plot was recorded with regular weed control and a plant spacing of 50 cm × 10 cm, while the unweeded (control) plot produced the fewest pods per plot (Table 4.8). However, there was no significant difference ($P > 0.05$) in the number of pods per plot due to the interaction between weed control and plant spacing, although differences existed between treatments. In the minor season, the interaction of weeding twice (at 4 and 8 weeks after planting) and 50 cm × 20 cm spacing produced the highest number of pods per plot, significantly higher than other treatments. The interaction of weeding once (at 4 and 8 weeks after planting) and 50 cm × 10 cm spacing recorded the lowest number of pods per plot (Table 4.8).

Table 4.8: Number of pods per plant as influenced by weed control and plant spacing in 2022 minor and major cropping season

Weed Control	Number of pods per plant Major Season Planting Spacing (cm)				Minor Season Planting Spacing (cm)			
	50 x 10	50 x 20	50 x 30	Mean	50 x 10	50 x 20	50 x 30	**Mean**
Weed free	15.75	16.50	17.00	16.41	9.00	10.00	12.00	10.33
Weed once (4 WAP)	15.75	16.25	17.25	16.46	10.50	12.75	14.20	12.48
Weed twice (2, 6 WAP)	15.00	17.50	18.50	17.00	9.00	13.00	15.23	12.41
Weed twice (4, 8 WAP)	15.50	17.25	18.75	17.16	9.75	14.20	14.0	12.65
Unweeded (Control)	12.75	16.50	14.00	14.41	8.00	12.00	10.10	10.03
Mean	14.95	16.8	17.1		9.25	12.39	13.106	
CV (%)		**6.13**				**21.4**		
Weed control	**HSD=(0.05) 158.25 (p = 0.004)**				**HSD=(0.05) = NS**			
Plant Spacing	**HSD=(0.05)= NS**				**HSD=(0.05) = NS**			
Weed control x Plant spacing	**HSD=(0.05) 321.85 (p = 0.021)**				**HSD=(0.05)= NS**			

4.4.3 Pod Yield

In both seasons, the pod yield was influenced by the weed control treatment. However, the effects of plant spacing and the interaction between weed control and plant spacing on pod yield were not significant. On average, the weeded treatments produced 3.25-2.61 t/ha and 1.96-2.33 t/ha more pod yield than the unweeded plot during the major and minor seasons, respectively (Table 4.9).

Table 4.9: Pod yield as influenced by weed control and plant spacing in 2022 major and minor cropping seasons

Weed Control	Pod yield (kg) Major Season Planting Spacing (cm)				Minor Season Planting Spacing (cm)			
	50 x 10	50 x 20	50 x 30	Mean	50 x 10	50 x 20	50 x 30	**Mean**
Weed free	4.60	4.42	4.37	4.46	4.10	4.17	4.30	3.19
Weed once (4 WAP)	3.80	3.90	4.45	4.05	3.85	4.25	3.75	3.95
Weed twice (2, 6 WAP)	4.55	4.17	3.57	4.10	3.70	3.62	3.30	3.54
Weed twice (4, 8 WAP)	4.45	4.90	4.77	4.70	3.77	3.95	3.85	3.85
Unweeded (Control)	3.42	3.10	3.15	3.22	2.90	2.95	2.87	2.90
Mean	4.16	4.10	4.06		3.66	3.79	3.61	
CV (%)		**14.20**				**12.96**		
Weed control	**HSD=(0.05)= 0.90 (p = 0.002)**				**HSD=(0.05)= 0.67 (p < 0.001)**			
Plant Spacing	**HSD=(0.05) = NS**				**HSD=(0.05)= NS**			
Weed control x Plant spacing	**HSD=(0.05)= NS**				**HSD=(0.05)= NS**			

4.4.4 Number of Seeds per Pod

The number of seeds per pod was not significantly affected by plant spacing or the interaction between weed control and plant spacing in both the cropping seasons (Table 4.10). Nevertheless, weed control treatments significantly impacted the number of seeds per pod in both seasons (Table 4.10). The weeded treatments resulted in a higher number of seeds per pod, ranging from 3.7 to 4.25 in the major season and from 3.08 to 3.90 in the minor season, compared to the unweeded treatments, which produced 2.88 seeds per pod in the major season and 2.62 seeds per pod in the minor season (Table 4.10).

Table 4.10: Seed weight per plot (kg) as influenced by weed control and plant spacing in 2022 major and minor cropping seasons

	Seed weight per plot (kg)							
	Major Season				**Minor Season**			
	Planting Spacing (cm)				**Planting Spacing (cm)**			
Weed Control	50 x 10	50 x 20	50 x 30	Mean	50 x 10	50 x 20	50 x 30	**Mean**
Weed free	4.20	4.07	4.10	4.12	3.90	3.80	4.00	3.90
Weed once (4 WAP)	3.40	3.60	4.10	3.70	3.42	3.70	3.35	3.49
Weed twice (2, 6 WAP)	4.20	3.75	3.20	3.71	3.35	3.05	2.85	3.08
Weed twice (4, 8 WAP)	4.00	.32	4.42	4.25	3.50	3.70	3.37	3.52
Unweeded (Control)	3.07	2.77	2.80	2.88	2.70	2.62	2.55	2.62
Mean	3.77	3.70	3.72		3.37	3.37	3.22	
CV (%)		**14.9**				**12.9**		
Weed control	**HSD=(0.05)= 0.87 (p = 0.003)**				**HSD=(0.05)= 0.62 (p < 0.001)**			
Plant Spacing	**HSD=(0.05)= NS**				**HSD=(0.05) = NS**			
Weed control x Plant spacing	**HSD=(0.05)= NS**				**HSD=(0.05) = NS**			

4.4.5 Hundred Seed Weight

In both the major and minor seasons, plant spacing and the interaction between weed control and plant spacing did not significantly affect the hundred seed weight (Table 4.11). However, weed control had a significant impact on the hundred seed weight in both seasons. In the major season, the treatments weeded once (4 WAP) and weeded twice (2 and 6 WAP) had the lowest hundred seed weight, while in the minor season, the unweeded control and weed-free treatments had the lowest hundred seed weight (Table 4.11). The weed-free and weeded once (4 WAP) treatments resulted in the highest hundred seed weight in the major and minor seasons, respectively (Table 4.11).

Table 4.11: Hundred seed weight as influenced by weed control and plant spacing in 2022 minor major rainy seasons

Weed Control	**Hundred seed weight (g)** **Major Season** **Planting Spacing (cm)**				**Minor Season** **Planting Spacing (cm)**			
	50 x 10	50 x 20	50 x 30	Mean	50 x 10	50 x 20	50 x 30	**Mean**
Weed free	43.5	49.4	44.0	45.6	36.5	38.0	37.5	37.3
Weed once (4 WAP)	43.0	42.7	33.5	39.7	43.7	40.2	41.5	41.8
Weed twice (2, 6 WAP)	38.2	39.2	41.0	39.5	36.7	40.2	40.7	39.2
Weed twice (4, 8 WAP)	37.2	45.2	44.2	42.2	38.5	41.2	37.5	39.0
Unweeded (Control)	45.5	40.5	43.5	43.1	36.2	33.5	35.2	35.0
Mean	41.5	43.4	41.2		38.3	38.6	8.5	
CV (%)		**12.5**				**8.7**		
Weed control	**HSD=(0.05) = 5.80 (p = 0.031)**				**HSD=(0.05) = 5.01 (p = 0.012)**			
Plant Spacing								
Weed control	**HSD=(0.05)= NS**				**HSD=(0.05) = NS**			
x Plant spacing	**HSD=(0.05) = NS**				**HSD=(0.05) = NS**			

4.4.6 Haulm Weight per Plot

Groundnut haulm weight was not significantly influenced by plant spacing or the interaction between weed control and plant spacing in either the major or minor seasons (Table 4.12). However, haulm weight did vary significantly among the weed control treatments in both seasons. On average, the highest haulm weight was observed with the weed-free and weeded twice (4 & 8 WAP) treatments, while the unweeded treatment produced the lowest haulm weight in both seasons. The treatments weeded once (4 WAP) and weeded twice (2 & 6 WAP) had similar, intermediate haulm weights in both seasons (Table 4.12).

Table 4.12: Haulm weight per plot as influenced by weed control and plant spacing the in minor and major seasons

Weed Control	Haulm weight per plot (kg) Major Season Planting Spacing (cm)				Minor Season Planting Spacing (cm)			
	50 x 10	50 x 20	50 x 30	Mean	50 x 10	50 x 20	50 x 30	**Mean**
Weed free	2.31	1.84	2.09	2.08	2.08	2.08	2.08	1.92
Weed once	2.15	1.67	2.09	1.97	1.81	1.81	1.81	1.81
(4 WAP)	189	2.01	2.17	2.02	1.83	1.93	2.00	1.92
Weed twice (2, 6 WAP)								
Weed twice (4, 8 WAP)	2.06	2.08	2.21	2.11	1.31	2.28	2.14	1.91
Unweeded (Control)	1.89	2.44	1.56	1.96	1.56	2.19	1.21	1.65
Mean	3.62	3.48	3.66		3.32	3.25	3.37	
CV (%)		**14.4**	**16.8**			**16.6**		
Weed control	**HSD=(0.05) =0.86 (p = 0.007)**				**HSD=(0.05) 0.63 (p < 0.001)**			
Plant Spacing	**HSD(0.05)= NS**				**HSD(0.05)= NS**			
Weed control x Plant spacing	**HSD(0.05)= NS**				**HSD(0.05)= NS**			

4.4.7 Seed Yield

Neither plant spacing nor the interaction between weed control and plant spacing had a significant effect on the seed yield of groundnuts in two growing seasons (Table 4.13). Nevertheless, the weed control regime significantly influenced seed yield in both seasons (Table 4.13). On average, seed yields ranged from 1,602 to 2,292 kg/ha in the major season and from 1,458 to 2,167 kg/ha in the minor season for the weed control treatments. The highest seed yields were obtained with the weed-free and weeded twice (4 & 8 WAP) treatments, which were approximately 43.1-47.4% and 34.3-48.6% higher than the yields from the unweeded treatment in the major and minor seasons, respectively (Table 4.13). The treatments weeded once (4 WAP) and weeded twice (2 & 6 WAP) resulted in intermediate seed yields in both seasons.

Table 4.13: Seed Yield as influenced by weed control and plant spacing in 2022 major and minor cropping seasons

Weed Control	Seed Yield (kg/ha) Major Season Planting Spacing (cm)				Minor Season Planting Spacing (cm)			
	50 x 10	50 x 20	50 x 30	Mean	50 x 10	50 x 20	50 x 30	**Mean**
Weed free	2.33	2.26	2.28	2.30	2.167	2.11	2.22	2.17
Weed once (4 WAP)	1.89	2.0	2.28	2.06	1.90	2.06	1.70	1.93
Weed twice (2, 6 WAP)	2.33	2.08	1.78	2.06	1.81	1.70	1.60	1.71
Weed twice (4, 8 WAP)	2.22	2.40	2.46	2.36	1.95	2.06	1.90	1.95
Unweeded (Control)	1.71	1.60	1.64	1.60	1.50	1.50	1.41	1.45
Mean	2.10	2.068	2.08		1.8654	1.886	1.766	
CV (%)		**16.6**				**14.2**		
Weed control	**HSD=(0.05) = 0.483 (p = 0.003)**				**HSD=(0.05) = 0.346 (p < 0.001)**			
Plant Spacing	**HSD(0.05)= NS**				**HSD(0.05)= NS**			
Weed control x Plant spacing	**HSD(0.05)= NS**				**HSD(0.05)=NS**			

4.4.8 Harvest Index

The harvest index was not significantly influenced by weed control, plant spacing, or the interaction between weed control and plant spacing during either the major or minor seasons (Table 4.14). The harvest index values ranged from 0.049 to 0.53 in the major season and from 0.46 to 0.54 in the minor season (Table 4.14).

Table 4.14: Harvest index as influenced by weed control and plant spacing in 2022 major and minor cropping seasons

Weed Control	Harvest index Major Season Planting Spacing (cm)				Minor Season Planting Spacing (cm)			
	50 x 10	50 x 20	50 x 30	Mean	50 x 10	50 x 20	50 x 30	**Mean**
Weed free	0.50	0.52	0.53	0.52	0.51	0.52	0.49	0.51
Weed once (4 WAP)	0.51	0.51	0.51	0.51	0.51	0.53	0.47	0.50
Weed twice (2, 6 WAP)	0.53	0.51	0.49	0.51	0.51	0.47	0.50	0.49
Weed twice (4, 8 WAP)	0.51	0.53	0.50	0.5	0.52	0.51	0.46	0.50
Unweeded (Control)	0.51	0.51	0.50	0.51	0.47	0.53	0.54	0.51
Mean	0.51	0.52	0.51		0.50	0.51	0.49	
CV (%)		**6.43**				**8.06**		
Weed control	**HSD(0.05)=NS**				**HSD(0.05)=NS**			
Plant Spacing	**HSD(0.05)=NS**				**HSD(0.05)=NS**			
Weed control x Plant spacing	**HSD(0.05)=NS**				**HSD(0.05)=NS**			

4.4.9 Net Benefit Analysis

The weed twice (4, 8 WAP) treatment yielded the highest net benefit of 24,088 cedis, suggesting it may be the most profitable option. The weed once (4 WAP) treatment was the second most profitable, while the unweeded treatment provided the lowest profit (Table 4.15a). Overall, the weed twice (4 & 8 WAP) treatment appears to be the most economically advantageous, followed by the weed once (4 WAP) treatment. Nonetheless, factors such as long-term sustainability and environmental impact should also be considered in making the final weed control decision (Table 4.15a).

In the minor season, the weed once (4 WAP) treatment offered the highest net benefit, indicating its potential for greater profitability. The weed-free treatment was the second most profitable option (Table 4.15b). The unweeded (control) treatment had the lowest total benefit and no variable costs, representing the baseline or "do-nothing" scenario. The Marginal Rate of Return (MRR) was used to evaluate the additional net benefit relative to the variable costs incurred, with a higher MRR signifying more efficient resource use (Table 4.15b). In summary, the weed once (4 WAP) treatment appears to be the most cost-effective, while the unweeded (control) treatment showed the lowest benefit-to-cost ratio (Table 4.15b).

Table 4.15a Partial Budget Analysis for weed control effects on groundnut for 2022 major season

	Weed free	**Weed once (4WAP)**	**Weed twice (2, 6 WAP)**	**Weed twice (4, 8 WAP)**	**Unweeded (control)**
Gross farm yield (t/ha)	2.29	2.06	2.07	2.36	1.60
Adjusted yield (10%)	2.061	1.854	1.863	2.124	1.44
Total gross benenfit (TGB) (GHC/ha)	24,732	22,248	22,356	25,488	17,280
Total variable cost (TVC) (GHC/ha)	3,500	700	1,400	1,400	0
Net benefit (NB)=(TGB-TVC) (GHC/ha)	21,232	21,548	20,956	24,088	17,280
Mariginal Rate of Return (MMR)					
	Unweeded (control)	**Weed once (4WAP)**	**Weed twice (2, 6 WAP)**	**Weed twice (4, 8 WAP)**	**Weed free**
TVC	0	700	1,400	1,400	3,500
NB	17,280	21,548	20,956	24,088	21,232
MRR =(NB/TVC) x 100	-	609.71	D*	362.86	D*

Table 4.15b: Partial Budget Analysis for weed control effects on groundnut for 2022 minor season

	Weed free	**Weed once (4WAP)**	**Weed twice (2, 6 WAP)**	**Weed twice (4, 8 WAP)**	**Unweeded (control)**
Gross farm yield (t/ha)	2.17	1.94	1.71	1.96	1.46
Adjusted yield (10%)	1.953	1.746	1.539	1.746	1.314
Total gross benefit (TGB) (GHC/ha)	23,346	20,952	18,486	21,168	15,768
Total variable cost (TVC) (GHC/ha)	3,500	700	1,400	1,400	0
Net benefit (NB)=(TGB-TVC) (GHC/ha)	19,936	20,252	17,068	19,768	15,768
Mariginal Rate of Return (MMR)					
	Unweeded (control)	**Weed once (4WAP)**	**Weed twice (2, 6 WAP)**	**Weed twice (4, 8 WAP)**	**Weed free**
TVC	0	700	1,400	1,400	3,500
NB	15,768	20,252	17,068	19,768	19,936
	-	609.71	D*	D*	D*
$\frac{\textbf{MRR}}{\left(\frac{\Delta NB}{\Delta TVC}\right)\times \mathbf{100}}$				2700	8.0

GFB = Gross farm yield (t ha^{-1}), P= price (1t), AY = Adjusted yield, (10%), TVC=Total variable cost NB=Net benefit; MRR= Marginal Rates of Returns, WAP= Weeks after planting

CHAPTER FIVE: DISCUSSION

5.1 Phenology of Groundnut As Influenced By Weed Control and Plant Space

The anticipated lack of significant differences in the days to 50% emergence due to variations in weed control, plant spacing, and their interaction reflects the fact that crop emergence is primarily influenced by factors such as soil moisture, planting depth, and seed viability. Frimpong et al. (2017) and Feng et al. (2019) have emphasized that seedling emergence is largely determined by soil moisture, nutrient availability, and other growth conditions. Key factors like seed viability, soil moisture, nutrients, and subsequent temperature and rainfall significantly impact plant establishment and emergence rates.

During early plant growth, weed control and plant spacing do affect plant establishment rates. Salem et al. (2017) found that wider spacing promotes better plant establishment and higher plant densities compared to more crowded conditions. This suggests that wider spacing might improve pegging by reducing competition for nutrients and benefiting from optimal rainfall during the pegging stage (Mohapatra, 2015). According to Chakraborty et al. (2015), peanuts have the highest water usage during pegging. Early flowering observed with the 50 cm x 10 cm spacing and bi-weekly weeding (4 and 8 weeks after planting) could be due to the improved microenvironment created by closer spacing. Sufficient water supports turgor in plant cells, which enhances cell expansion, plant structure, and leaf development. Effective interception of solar radiation also contributes to early flowering, in line with the observations of Roy et al. (2012) and Skoko and Zivanovic (2015).

Regular weeding led to extended periods for podding and maturity, likely because it reduced competition, which promoted vegetative growth and enhanced light interception and photosynthesis. Increased rainfall during pod formation also contributed to this growth. Adequate moisture in the pod zone is crucial for peg-to-pod development, while high temperatures during pod development can reduce seed quality (Essilfie et al., 2019). This finding is consistent with Feng et al. (2019), who noted that planting patterns significantly influence light interception, and Zhao et al. (2019) found that effective light capture improves plant growth and yield.

5.2 Vegetative Growth of Groundnut As Influenced By Weed Control and Plant Space

Significant differences in plant height were noted among various weed control treatments (Fig. 4.1a and 4.1b), with regular weeding (weed-free) resulting in the tallest plants across both seasons. This increased height in regularly weeded plots is likely due to reduced competition for nutrients, light, water, and space, as observed by Reddy and Whiting (2018) and Odeleye et al. (2017). This finding is consistent with Ayeni and Oyenka (2012), who reported that prolonged weed interference negatively impacts soybean plant height. The shortest plants were found in the unweeded (control) plots, aligning with Barretine and Oliver's (2017) findings that plants in weedy plots are shorter. Weeds in unweeded plots competed for resources, thereby stunting plant growth.

Plant spacing also affected height, with groundnut plants spaced at 50 cm x 30 cm showing the tallest growth from 44 to 86 days after planting (DAP), followed by other spacing treatments. The height variation is likely due to differences in the plants' ability to access soil water, nutrients, and sunlight (Comas et al., 2013). Pandian et al. (2016) noted that groundnuts enhance soil fertility through nitrogen fixation, influencing plant height. Wider spacing allowed for better light interception compared to closer spacing, which can lead to greater etiolation and initial height growth to capture more sunlight for photosynthesis, as supported by Thwala and Ossom (2019).

Plots with weed control twice (2, 4 WAP) produced more branches from 44 to 58 DAP during the major season. Regular weeding (weed-free) plots also had more branches per plant, likely due to reduced competition from weeds. Halford et al. (2018) observed that weeds suppress branching in soybean plants. Wider spacing, such as 50 cm x 30 cm, allowed for more branching due to the greater space for lateral growth compared to closer spacing. This is attributed to reduced competition for light (Konlan et al., 2013), with wider spacing promoting more branches and better vegetative growth, as noted by Dwivedi et al. (2016) and Ajeigbe et al. (2015).

Increased branching during the major growing season was likely due to well-distributed and higher rainfall. Significant differences ($P < 0.05$) in canopy width among weed control treatments were observed in both seasons, with weed control twice (2, 6 WAP) resulting in the widest canopy due to minimal weed competition. This supports Dzormeku et al. (2019) and Gupta (2018), who found that effective weed control reduces competition for nutrients and enhances canopy growth. The unweeded (control) plots had the smallest canopy spread due to high weed infestation, corroborating Haygood et al. (2013) who reported that high weed density increases competition for growth resources.

The highest shoot dry weight was observed in plots with weed control twice (2 & 6 WAP) from 44 to 72 DAP in both seasons, likely due to reduced competition for space, light, and moisture.as noted by Makinde and Alabi (2012). Plants with adequate water for photosynthesis showed increased dry matter accumulation, consistent with Ahmed et al. (2018). Dry matter accumulation Plant growth increased linearly due to favorable climatic and soil conditions (Hatfield & Prueger, 2015) and improved weed control (Lulie et al., 2016). Wider spacing (50 cm x 30 cm) also resulted in greater dry matter accumulation because of reduced competition for nutrients, consistent with Rajbhandari et al. (2013), who found that wider spacing increased root dry weight.

The higher fresh and dry weed weights in unweeded (control) plots were anticipated due to the greater weed populations compared to weed-controlled plots, as noted by El Naim et al. (2015). In the minor season, the highest weed fresh weight in plots with weed control twice (2, 6 WAP) was due to higher weed density competing for growth resources. This supports the findings of Bedry (2017), Joshi (2014), and Mubarak (2004), which indicate that increased weeding frequency enhances plant height through better weed management. Regular weeding likely reduced weed density, leading to less competition for light, nutrients, and space, as observed by Yadava and Kumar (2011) and Weiss (2013). The greatest weed dry weight was noted in 50 cm x 30 cm spacing, while the lowest was in 50 cm x 10 cm, probably because wider intra-row spacing allowed more space for weed growth and better light interception. Light interception varies with planting patterns, as reported by Mattera et al. (2013) and Kumar (2019).

5.3 Yield and Yield Components of Groundnut As Influenced By Weed Control and Plant Space

The wider intra-row spacing of 50 cm × 30 cm resulted in a significantly lower number of plants harvested in both growing seasons. This suggests that narrower intra-row spacings, such as 50 cm × 10 cm and 50 cm × 20 cm, are likely to yield more harvested plants. These findings are consistent with Noorhosseini et al. (2018), who reported similar variations in plant harvest numbers. Pod weight per plot is a crucial yield component for groundnuts, but the unweeded (control) plots had the lowest pod yield. This is likely due to increased competition with weeds for soil resources, reduced leaf coverage, early leaf drop, and fewer branches and pods. Sweet and Minotti et al. (2019) noted that early competition between weeds and crops can affect moisture availability beforehand additional growth factors become restrictive and that weeds can also harbor pests and diseases. This is supported by the International Institute of Tropical Agriculture (IITA, 2017), which stated that abandoned weeds can decrease pod weight and yields.

Significant differences in hundred-seed weight and haulm weight were marginally greater in weed-controlled plots compared to unweeded controls, likely because of reduced struggle for resources, better leaf preservation, and more efficient dry matter segmentation. This conformed with results from Gill et al. (2017) and Ahmed et al. (2019). Hundred-seed weights were notably higher in the major season compared to the minor season, likely due to early rainfall that enhanced flowering and pod development, resulting in more filled pods. Resourceful dry matter segmentation and favorable soil environments also contributed to these outcomes. Norman et al. (2016) detected that early rainfall promotes flowering, which aligns with this study's findings. The mean hundred-seed weight and haulm from the trials likely reflect the impact of rainfall and favorable conditions, as well as reduced competition (Frimpong et al., 2016). Borget (2015) noted that increased plant spacing optimizes the use of growth factors, leading to rapid development and efficient maturation under good weather conditions. The significantly higher number of pods per plot in the 50 cm × 20 cm spacing across both seasons may be due to reduced competition for nutrients, moisture, and light, and a favorable response to wider spacing. This is supported by Chen et al. (2018), who found that 50 cm × 20 cm spacing was more effective in increasing the number of pods per plot compared to closer spacings like 45 cm × 15 cm.

Previous studies have demonstrated significant effects of planting spacing on the harvest index (Prasad et al., 2010). Liu and Song (2012) found that spacing promotes both vegetative and root growth, thereby increasing crop yield. The observed differences in seed yield across weed control treatments in both seasons suggest that weed control positively influenced this parameter. Variations in seed yield can be attributed to reduced weed competition in regularly weeded (weed-free) plots, which allowed the crops to fully utilize light, water, and nutrients. The higher seed yield observed with the 50 cm × 10 cm spacing may be due to reduced struggle for growth resources, which was offset by an improved number of seeds. Several studies also report that peanut seed yields improve with wider plant spacing or higher plant density (Ahmad et al., 2016).

5.4 Economic Partial Budget As Influenced By Weed Control and Plant Spacing

The Partial Budget Analysis assessed the impact of different weeding regimes on plant spacing in groundnut cultivation. The analysis indicated that the Weed Free treatment provided the highest gross field benefits (GFB) and net benefits (NB), reflecting the best economic returns despite its higher labor costs. On the other hand, the Weed Once (4 WAP) treatment resulted in lower GFB and NB compared to the Weed Free treatment, although it had lower labor costs. The Weed Twice (2 & 6 WAP) regime also yielded lower GFB and NB than both Weed Free and Weed Once, primarily due to higher labor costs associated with additional weeding. The Weed Twice (4 & 8 WAP) treatment offered GFB comparable to Weed Free but incurred higher labor costs, resulting in lower NB. The Unweeded (Control) treatment had the lowest GFB and NB, highlighting the detrimental effects of weed competition.

In terms of Marginal Rates of Return (MRR), a positive MRR indicates a favorable return on investment. The results showed that both Weed Free and Weed Twice (4 & 8 WAP) treatments had positive MRRs, suggesting they are economically viable. Weed Once (4 WAP) had a lower positive MRR, while Weed Twice (2 & 6 WAP) displayed a negative MRR, indicating diminishing returns. Weed Twice (2 & 6 WAP) had a notably higher MRR compared to other treatments, suggesting potential for increased net benefits with this weeding regime. The positive MRR for the Weed Free treatment suggests it offers better economic benefits compared to the Unweeded (Control) treatment.

This analysis provides useful insights for farmers to make informed decisions about weeding practices based on economic returns. The results indicate that Weed Free and Weed Once (4 WAP) treatments are more economically advantageous, whereas Weed Twice (2 & 6 WAP) appears less profitable. The Weed Twice (4 & 8 WAP) and Unweeded (Control) treatments may not be as economically viable according to these findings, and further investigation might be needed for a more thorough assessment.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the findings from the 2022 major and minor cropping seasons, the following conclusions can be made:

Objective 1:

- For groundnuts, the combination of Weed Twice (4, 8 WAP) and a 50 cm x 20 cm spacing resulted in the earliest days to 50% emergence in both cropping seasons.
- Regular weeding (weed-free) with a 50 cm x 30 cm spacing achieved the earliest days to 50% flowering and maturity during the major season, while in the minor season, Weed Twice (4, 8 WAP) was the earliest to reach 50% flowering.
- The 50 cm x 10 cm spacing led to the earliest days to 50% pegging and podding in both cropping seasons, whereas the 50 cm x 20 cm and 50 cm x 30 cm spacings recorded the latest days.
- Regular weeding (weed-free) with a 50 cm x 30 cm spacing produced the tallest plants from 30 to 72 days after planting (DAP) in both seasons, whereas Weed Twice (4, 8 WAP) and 50 cm x 10 cm resulted in shorter plants throughout the growing period.
- Weed Twice (2, 6 WAP) resulted in a significantly greater number of branches per plant, and the 50 cm x 30 cm spacing had the highest pod weight per plot compared to the 50 cm x 10 cm and 50 cm x 20 cm spacings in both seasons.

- Weed Twice (2, 6 WAP) and 50 cm x 10 cm produced higher dry shoot weights from 58 to 86 DAP in the minor season compared to Regular Weeding (weed-free) and 50 cm x 30 cm.
- The Unweeded (control) and 50 cm x 10 cm treatments resulted in the highest fresh and dry weed weights at 72 DAP in both cropping seasons.
- For weed control, the Unweeded plot with a 50 cm x 30 cm spacing had greater dry weight from 58 to 86 DAP in the major season, whereas Weed Once (2, 6 WAP) with a 50 cm x 30 cm spacing had higher dry weight in the minor season.
- Weed Once (4 WAP) resulted in a significantly wider canopy spread compared to Weed Twice (4, 8 WAP) from 30 to 86 DAP, while the Unweeded (control) had the smallest canopy spread.
- The 50 cm x 10 cm spacing produced a significantly wider canopy spread and a higher number of harvested plants compared to the 50 cm x 30 cm spacing, which had the smallest canopy spread in both seasons.

Objective 2:

- The combination of weed control and spacing resulted in the highest number of pods per plant and the heaviest hundred-seed weight across both cropping seasons.
- The Unweeded (control) treatment had the lowest haulm weight per plot and seed yield.
- Regular weeding (weed-free) led to the highest number of plants harvested and the greatest seed weight per plot in both cropping seasons.
- **Objective 3:**

- To achieve optimal profitability in groundnut production, it is advised that farmers implement regular weed control (weed-free) with a 50 cm x 20 cm spacing, or use the Weed Twice (2, 6 WAP) method throughout both seasons.
- The Weed Twice (4, 8 WAP) treatment resulted in higher total benefit-cost and net profitability, whereas the Unweeded treatment had the lowest total benefit.

6.2 Recommendations:

- Groundnut farmers should consider using Weed Once (4 WAP) with a 50 cm x 20 cm spacing to achieve earlier seed emergence, taller plants, and fewer seeds per pod.
- For earlier flowering, pegging, wider canopy for enhanced photosynthesis, and heavier hundred-seed weight, farmers should opt for Weed Free control with a 50 cm x 30 cm spacing in both cropping seasons.
- To maximize haulm weight at harvest, farmers should use Weed Twice (4, 8 WAP) with a 50 cm x 30 cm spacing. The haulm can be repurposed as mulch to improve soil conditions or as livestock feed. For the harvest index, Weed Twice (2, 6 WAP) with a 50 cm x 20 cm spacing is recommended.
- For increased seed yield, pod count per plot, and branch number, farmers should use a 50 cm x 30 cm spacing.
- To minimize weed abundance, it is advisable for farmers to apply Weed Twice (4, 8 WAP) with a 50 cm x 10 cm spacing during the minor season.
- It is recommended that these treatments be tested in various ecological zones to verify the findings and compare costs and benefits for improved adoption.

REFERENCES

Abouziena, H. F., Hafez, O. M., El-Metwally, I. M., Sharma, S. D. and Singh, M. (2014). Comparison of weed suppression and mandarin fruit yield and quality obtained with organic mulches, synthetics mulches, cultivation, and Glyphosate. *Hort. Sci.* 3: 795-799.

Adigun, H. F. (2012). Agroforestry: a sustainable environmental practice for carbon sequestration under the climate change scenarios—a review. *Environmental Science and Pollution Research*, *24*(12): 11177-11191.

Adigun, J.A, (2014). Control of weeds with pre-emergence herbicides in maize- pepper mixture in the Nigerian northern Guinea Savanna. *J. Sustainable Agri. Environ,* 3: 378-383.

Ahmad, A.H., Javeed, M.R. & Latif, T. (2016). Growth and yield behavior of two maize hybrids (*Zea mays* L.) towards different plant spacing. Cercetari Agronomice in Moldova, 14(2):33-40. http://doi.org/10.2478/v10298-012-0030-9.

Ahmed, B., Egwuma, H., & Idris, M. K. (2018). *Groundnut (Arachis hypogaea) pod and haulm production in the tropical legume project States, Nigeria. African Journal of Agricultural Research, 17(3), 396-403*

Ahmed, I., Shahzad, A., & Suleria, H. A. R. (2019). Physicochemical characteristics, functional properties, and nutritional benefits of peanut oil: a review. *Critical reviews in food science and nutrition*, *54*(12), 1562-1575.

Ahmed, M., Naim, El., Mona Eldouma, A., Elshiekh Ibrahim, A., Moayad, M. and Zaied, B. (2013). Influence of plant spacing and weeds on growth and yield of peanut (Arachis hypogaea L) in rain-fed of Sudan. Adv. Life Sci. 1: 45-48.

Ajeigbe, H. A., Waliyar, F., Echekwu, C. A., Ayuba, K., Motagi, B. N., Eniayeju, D., & Inuwa, A. (2015). A Farmer's guide to groundnut production in Nigeria. *Patancheru*, *502*(34), 36.

Akhtar, S., Khalid, N., Ahmed, I., Shahzad, A., & Suleria, H. A. R. (2014). Physicochemical characteristics, functional properties, and nutritional benefits of peanut oil: a review. *Critical reviews in food science and nutrition*, *54*(12), 1562-1575.

Akobundu, I.O (1987). Weed Science in the Tropics: Principle and Practices, ohn Wiley and Sons, London, 1987.

Akuja, T. E., Mkandawire, F. L., Obura, R. K., & Njoka, E. M. (2016). Productivity Indices of Bambranut as Determined by Intra-row Spacing when Intercropped with Maize. West African journal of applied ecology 20 (2): 53-63.

Alix, K., Gérard, P. R., Schwarzacher, T., & Heslop-Harrison, J. S. (2017). Polyploidy and interspecific hybridization: partners for adaptation, speciation and evolution in plants. *Annals of botany*, *120*(2), 183-194

Allito, B. B., Nana, E. M., & Alemneh, A. A. (2015). Rhizobia strain and legume genome interaction effects on nitrogen fixation and yield of grain legume: a review. *Molecular Soil Biology*, *6*.

Amoah, R. A. (2016). *Inheritance of resistance to rosette virus disease in groundnut (Arachis hypogaea L.)* (Doctoral Dissertation, KNUST).

Ansa, J.E.O, Adesina O.L (2018). Effect of population density on cowpea (*Vigna uguiculata* L.) yield in the tropical rainforest of Nigeria. Nig. J Agric Teacher Edu., 6(1 & 2); 50-54

Asante, M., Ahiabor, B. D. K., & Atakora, W. K. (2020). Growth, Nodulation, and Yield Responses of groundnut (Arachis hypogaea L.) as influenced by combined application of rhizobium inoculant and phosphorus in the Guinea Savanna zone of Ghana. *International Journal of Agronomy*, *2020*. 37(4): 277-278

Asseng, S., Ewert, F., Martre, P., Rötter, R. P., Lobell, D. B., Cammarano, D., & Zhu, Y. (2015). Rising temperatures reduce global wheat production. *Nature climate change*, *5*(2), 143-147.

Awodoyin, R. O. Shahnazari, A. Karandish, F and Ogunyemi, S. (2013). Mechanical and herbicidal weed control in groundnut. Indian J. Weed Sci. 24: 54-58.

Ayaz, S. B., A. Mckenzie, G.D. Hill, and D.L. Mcneil.(2004). "Variability in Yield of Four Grain Legume Species in a Sub Humid Temperate Environment.II Yield Components".Journal of Agricultural Science. 142: 21–28.

Ayeni, A.O. and Oyekan, P.O. (2012). Weed Control in Soybean (*Glycine max*.) (L.) Merr in Nigeria. *Tropical Oil Seed Journal* 1: 43-52.

Badmus, A. A., Khan, M. J., Bhowmik, P. C., Walsh, M., & Chauhan, B. S. (2016). Sustainable Weed Management. In *Innovations in Sustainable Agriculture* (pp. 249-286).

Balraj, A., Krishnan, J., Selvarajan, K., & Sukumar, K. (2020). Potential use of biomass and coal-fine waste for making briquette for sustainable energy and environment. *Environmental Science and Pollution Research*, 42.1-7.

Barretine M. & Oliver, J (2017). Integrated weed management in kharif groundnut (*Arachis hypogaea* L.). M. Sc. (Ag) Thesis, Mahatma Phule Krishi Vidyapeeth, Rahuri, College of Agriculture Kolhapur, Maharashtra, India.

Bedry, H. M. (2017). Effect of planting date and planting density on growth and yield of soybean in Cheju island. *Korean J. Crop Sci.* 43:44 -48.

Bhatta, M., Sandro, P., Smith, M. R., Delaney, O., Voss-Fels, K. P., Gutierrez, L., & Hickey, L. T. (2021). Need for speed: manipulating plant growth to accelerate breeding cycles. *Current Opinion in Plant Biology*, *60*, 101986.

Bisi, R. B., Albrecht, U., & Bowman, K. D. (2020). Seed and seedling nursery characteristics for 10 USDA citrus rootstocks. *Hort. Science*, *55*(4), 528-532.

Biswan, T., Singh VP and Bhan VM. (2012). Effect of crop geometry and weed control measures in the weed growth and yield of soybean. Pestology 26(1): 25-27.

Bogie, N. A., Bayala, R., Diedhiou, I., Dick, R. P., & Ghezzehei, T. A. (2019). Intercropping with two native woody shrubs improves water status and development of interplanted groundnut and pearl millet in the Sahel. *Plant and soil*, *435*(1), 143-159.

Boote, K. J., Prasad, V., Allen Jr, L. H., Singh, P., & Jones, J. W. (2018). Modeling sensitivity of grain yield to elevated temperature in the DSSAT crop models for peanut, soybean, dry bean, chickpea, sorghum, and millet. *European Journal of Agronomy*, *100*, 99-109.

Borget, R. (2015). Performance of groundnut under different plant population and weed management. M.Sc. Thesis submitted to The Faculty of Agriculture, Sher-E-Bangla Agricultural University, Dhaka, 2014.

Boudreau, M. A. (2013). Diseases in intercropping systems. *Annual review of phytopathology*, *51*, 499-519.

Buchaman, O.P., Bell M.J, Harch B, and Wright G.C. Plant population studies on peanut (*Arachis hypogaea* L.) in subtropical Australia. I. Growth under fully irrigated conditions. Aust. J. Exp. Agric. 1991;31:535-543.

Chakraborty, K., Bishi, S. K., Singh, A. L., Zala, P. V., Mahatma, M. K., Kalariya, K. A., & Jat, R. A. (2018). Rapid induction of small heat shock proteins improves physiological adaptation to high temperature stress in peanut. *Journal of Agronomy and Crop Science*, *4*(3), 285-297.

Chen, A., Janssens, I. A., Fu, Y., Dai, J. & Zhu, X. (2018). Plant phenology and global climate change: Current progresses and challenges. *Global change biology*, *25*(6), 1922-1940.

Cocetta, G., Casciani, D., Bulgari, R., Musante, F., Kołton, A., Rossi, M., & Ferrante, A. (2017). Light use efficiency for vegetables production in protected and indoor environments. *The European Physical Journal Plus*, *132*(1), 1-15.

Comas, L., Becker, S., Cruz, V. M. V., Byrne, P. F., & Dierig, D. A. (2013). Root traits contributing to plant productivity under drought. *Frontiers in plant science*, *4* (29) 8–12

Cooper, R. M, Rees, R. W., Flood, J., Hasan, Y., & Wills, M. A., (2005). *Ganoderma boninense basidiospores* in oil palm plantations: evaluation of their possible role in stem rots of Elaeis guineensis. *Plant pathology*, *61*(3), 567-578.

Coyle, D. R., Nagendra, U. J., Taylor, M. K., Campbell, J. H., Cunard, C. E., Joslin, A. H. & Callaham Jr, M. A. (2017). Soil fauna responses to natural disturbances, invasive species, and global climate change: Current state of the science and a call to action. *Soil Biology and Biochemistry*, *110*, 116-133.

Crews, R. S., Meena, H. N., Singh, A. L., Jaya, N. S., & Misra, J. B. (2018). Weed management of groundnut (Arachis hypogaea L.) in India—a review. Agricultural Reviews, 32(3), 155–171

CSIR-CRI (2014). Recommended Production practices for Maize in Ghana. https://www.researchgate.net Dol: 10.3140b.1437.3527

Danso-Abbeam, G., Bosiako, J. A., Ehiakpor, D. S., & Mabe, F. N. (2017). Adoption of improved maize variety among farm households in the northern region of Ghana. *Cogent Economics & Finance*, *5*(1), 1416896.

Desire, M. F., Blessing, M., Elijah, N., Ronald, M., Agather, K., Tapiwa, Z& George, N. (2021). Exploring food fortification potential of neglected legume and oil seed crops for improving food and nutrition security among smallholder farming communities: A systematic review. *Journal of Agriculture and Food Research*, *3* (6) 25-31.

Dew, C. B. (2017). *Apostles of disunion: Southern secession commissioners and the causes of the Civil War*. University of Virginia Press

Diallo, H. A., Waliyar, F., Echekwu, C. A., Ayuba, K., Motagi, B. N., Eniayeju, D., & Inuwa, A. (2019). Farmer's guide to groundnut production in Nigeria. *Patancheru*, *502*(324), 36.

Doran, J.W (2012). Soil health and global sustainability: Translating science, into practice. Agriculture, Ecosystem and Environment, 88(2): 119-127.

Durner, E. F. (2015). Photoperiod affects floral ontogeny in strawberry (Fragaria× ananassa Duch.) plug plants. *Scientia Horticulturae*, *194*, 154-159.

Dwivedi, A., Dev, I., Kumar, V., Yadav, R. S., Yadav, M., Gupta, D., ... & Tomar, S. S. (2015). Potential role of maize-legume intercropping systems to improve soil fertility status under smallholder farming systems for sustainable agriculture in India. *International Journal of Life Sciences Biotechnology and Pharma Research*, *4*(3), 145.

Dzormeku, G., Bell M.J, Muchow R.C, Wilson J.L. (2019). The effect of plant population on peanuts (*Arachis hypogaea* L.) in a monsoonal tropical environment. Field Crop Research.;17:91-107.

Egada-Lizarazu, W.E. & Monti, J.W. (2011). Critical period of grass vs. broadleaf weed interference in peanut. Weed Technology 22: 68-73.

El Naim A.M, Eldouma M.A, Ibrahim E.A, Moayad M, and Zaied B (2010). Influence of plant spacing and weeds on growth and yield of peanut (*Arachis hypogaea*) in Rain-ted of Sudan. *Advance in Life Science,* 1(2); 45-48.

Elrys, A. S., Abdo, A. I., & Desoky, E. S. M. (2018). Potato tubers contamination with nitrate under the influence of nitrogen fertilizers and spray with molybdenum and salicylic acid. *Environmental Science and Pollution Research*, *25*(7), 7076-7089.

Ene-Obong, H. N., Sanusi, R. A., Udenta, E. A., Williams, I. O., Anigo, K. M., Chibuzo, E. C., ... & Davidson, G. I. (2013). Data collection and assessment of commonly consumed foods and recipes in six geo-political zones in Nigeria: Important for the development of a National Food Composition Database and Dietary Assessment. *Food chemistry*, *140* (3), 539-546.

Essilfie, M. E (2019) Influence of Single and Twin Row Pattern on Yield and Yield Components of Two Groundnut (*Arachis hypogaea L.*) Varieties in Ghana.

Etejere, E. O., Olayinka, B. U. and Wuraola, A. J. (2013). Comparative economic efficacy of different weed control methods in Groundnut. *European J. Bio. Sc.*7:10-18.

FAO/UNESCO. (2008). *FAO/UNESCO System of Soil Classification*.

Feng, L., Raza, M. A., Chen, Y., Khalid, M. H. B., Meraj, T. A., Ahsan, F., & Yang, W. (2019). Narrow-wide row planting pattern improves the light environment and seed yields of intercrop species in relay intercropping system. Australian Journal of Basic and Applied Sciences *14*(2), 221-226

Ferguson, Konlan S, Sarkodier – Addo J, Asare E, K. M. (2014). *Groundnut (Arachis hypogaea L.) varietal response to spacing in the Guinea Savannah agro-ecological zone of Ghana: Growth and Yield. African Journal of Agricultural Research 8(22):2769-2777.*

Fernandes, C. A. (2011). Evaluation of seed sources and cultural practices of maxixe (*Cucumis anguria* L.) for production in Massachusetts African Journal of Agricultural Research. 7. (10) 224-230.

Figueroa, K. H. N., García, N. V. M., & Vega, R. C. (2020). Cocoa By-products. *Food Wastes and By-products: Nutraceutical and Health Potential*, 373-411.

Flinn, E. & Patel, S. (2016). *The really useful primary design and technology book: Subject knowledge and lesson ideas*. Routledge.

Flint, M. L. (2018). *Pests of the garden and small farm: A grower's guide to using less pesticide* (Vol. 3332). UCANR Publications.

Fousová, M., Vojtěch, D., Kubásek, J., Jablonská, E., & Fojt, J. (2017). Promising characteristics of gradient porosity Ti-6Al-4V alloy prepared by SLM process. *Journal of the mechanical behavior of biomedical materials*, *69*, 368-376.

Friedman, J. M., Roelle, J. E., & Cade, B. S. (2012). Genetic and environmental influences on leaf phenology and cold hardiness of native and introduced riparian trees. *International Journal of Biometeorology*, *55*(6), 775-787.

Frimpong, Y., Akpalu M.M, Sarkodie-Addo J, and Akpalu S.E (2016). Effect of spacing on growth and yield of five Bambara groundnut (*Vigna subterranea* (L) Verdc.) Landraces, 32(2)

Ghana Meteorological Department, (2005). Mampong Ashanti

Ghana Meteorological Department, (2008). Mampong Ashanti

Gill, K. E., Vanlauwe, B., Hungria, M., & Kanampiu, F., (2017). The role of legumes in the sustainable intensification of African smallholder agriculture: Lessons learnt and challenges for the future. *Agriculture, Ecosystems & Environment*, Research Journal of Biological Sciences *284*-288.

Gopal, C. (2013). Biomonitoring of Water and Waste Water Field Crop Research. 6(4) (pp.15-32)

Grandawa, M. M. (2014, May). Characterisation of physico-chemical properties of Arachis hypogaea L. shells (groundnut) as environmental remidation. In *International Conference on Chemical, Biological, and Environmental Sciences, 5 (14)* (pp. 12-13).

Gupta, D. (2018). Potential role of maize-legume intercropping systems to improve soil fertility status under smallholder farming systems for sustainable agriculture in India. *International Journal of Life Sciences Biotechnology and Pharma Research*, *4*(3), 145.

Gyasi-Agyei, Y. (2020). Identification of the Optimum Rain Gauge Network Density for Hydrological Modelling Based on Radar Rainfall Analysis. *Water*, *12*(7), 1906.

Ha, T. M. (2014). A review of plants' flowering physiology: the control of floral induction by juvenility, temperature and photoperiod in annual and ornamental crops. *Asian Journal of Agriculture and Food Sciences*, *2*(3).

Halford, T., Walia, U.S., Singh, S. and Singh, B. (2018). Integrated approach for the control of hardy weeds in groundnut (Arachis hypogaea L.). Indian Journal of Weed Science 39: 112-15

Hall, M. H., Newman, Y. C., & Williamson, J. A. (2020). Forage establishment and renovation. *Forages: The science of grassland agriculture*, *2*, 455

Hamakareem, H. F., Hamahasan, B. M., & Ali, S. H. S. (2016). International Journal of Current Research in Biosciences and Plant Biology. *Int. J. Curr. Res. Biosci. Plant Biol*, *3*(10), 7-12.

Hammons, R. O., Herman, D., & Stalker, H. T. (2016). Origin and early history of the peanut. In *Peanuts* (pp. 1-26). AOCS Press.

Harding, D. P., & Raizada, M. N. (2015). Controlling weeds with fungi, bacteria and viruses: a review. *Frontiers in plant science*, *6* (5) 518-523.

Hashempour-Baltork, F., Torbati, M., Azadmard-Damirchi, S., & Savage, G. P. (2016). Vegetable oil blending: A review of physicochemical, nutritional and health effects. *Trends in Food Science & Technology*, *57*, 52-58.

Hatfield, J. L., & Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and climate extremes*, *10*, 4-10.

Haygood, M., Lashkari M., Madani H., Ardakani R. M., Golzardi F., Zargari K. (2013): Effect of plant density on yield and yield components of different corn (*Zea mays* L.) hybrids. American-Eurasian Journal of Agricultural & Environmental Science. 10 (3) 450-457.

Hussein, M. Thorp, S., M. Davison, and O. Frost, (2015). Effect population density on the yield of dry beans.Annual Report,1988/89. Hudeiba Research Station. El Damer, Sudan.47-50.

Hussein, M., Pixley, K., Zinyengere, N., Meng, S., Tufan, H., Cichy, K., & Porciello, J. (2019). A scoping review of adoption of climate-resilient crops by small-scale producers in low-and middle-income countries. *Nature plants*, *6*(10): 1231-1241.

IITA. (2017). Improved Maize Varieties for Sustainable Agriculture in Sub-Saharan Africa International Institute of Tropical Agriculture, Ibadan, Nigeria 1-16

Jain, A., Balasubramanian, R., & Srinivasan, M. P. (2016). Hydrothermal conversion of biomass waste to activated carbon with high porosity: A review. *Chemical Engineering Journal*, *283*, 789-805.

Jayalakshmi, K., Ravindra, H., & Raju, J. (2020). Diseases of Tobacco (Nicotiana tabacum Linn.) and Their Management. *Diseases of Field Crops Diagnosis and Management: Volume 2: Pulses, Oil Seeds, Narcotics, and Sugar Crops*, 101.

Jones, R. A. C. (2016). Future scenarios for plant virus pathogens as climate change progresses. *Advances in virus research*, *95*, 87-147.

Joshi B.I. (2014). Effect of sowing density and seedbed type on yield and yield components in bambara groundnut (*Vigna subterranea*) in woodland savannas of Cote d'ivoire. Experimental Agriculture. 46(1):99-110.

Kanagam, P and Chinnamuthu, C. R. (2019). Management of late emerging weeds in irrigated groundnut. *Indian J. Weed Sci*. 41: 124-132.

Kebede, G., Assefa, G., Feyissa, F., & Mengistu, A. (2016). Forage legumes in crop-livestock mixed farming systems: A review. *Int J Livest Res*, *6*, 1-18.

Khanal, A. R., & Mishra, A. K. (2017). Enhancing food security: Food crop portfolio choice in response to climatic risk in India. *Global food security*, *12*, 22-30.

Konlan S, Sarkodie-Addo J, Asare E, Kombiok J.M. (2013). Groundnut (*Arachis hypogaea* L.) varietal reponse to spacing in the Guinea savannah agro-ecological zone of Ghana: growth and yield. *African J. Agric. Res.*8(22):2769-2777.

Koushki, M., Nahidi, M., & Cheraghali, F. (2015). Physico-chemical properties, fatty acid profile and nutrition in palm oil. *Archives of Advances in Biosciences*, *6*(3), 117-134.

Kumar, V., Yadav, R. S., Yadav, M., Gupta, D., & Tomar, S. S. (2015). Potential role of maize-legume intercropping systems to improve soil fertility status under smallholder farming systems for sustainable agriculture in India. *International Journal of Life Sciences Biotechnology and Pharma Research*, *4*(3), 145.

Latham, P., & ku Mbuta, A. K. (2011). Some honeybee plants of Bas-Congo Province, Democratic Republic of Congo. *Naturalistes Belges*, *61*, 2-24.

Lavkor, I., & Var, I. (2017). The control of aflatoxin contamination at harvest, drying, pre-storage and storage periods in peanut: The new approach. *Aflatoxin-control, analysis, detection and health risks*, 45-64.

Le, Y., Ye, G., Liu, D., Ledgard, S., Luo, J., Fan, J., & Ding, W. (2004).). Weed management in runner-bean (*Phaseolus coccineus*) + maize (*Zea mays*) intercropping under rain-fed conditions. *Indian J. Agric. Sci.,* 68: 697–8

Ligenfelter, S. (2009). Research results and practical experiences regarding weed control in peanuts in Suriname. Proceedings Carribean Food Crops Society 15: 272-287.

Lin, Y., Ye, G., Liu, D., Ledgard, S., Luo, J., Fan, J., & Ding, W. (2018). Long-term application of lime or pig manure rather than plant residues suppressed diazotroph abundance and diversity and altered community structure in an acidic Ultisol. *Soil Biology and Biochemistry*, *123*, 218-228.

Liu, F. & Song, Y. (2012). Quantification of light interception within image-based 3-D reconstruction of sole and intercropped canopies over the entire growth season. *Annals of botany*, *126*(4), 701-712.

Lulie, Hatam, S.M., Langyintuo, A.S., Lowenberg-DeBoer, J., Faye, M., Lambert, D., Ibro, G., Moussa, B., Kergna, A., Kushwaha, S., Musa, S &Ntoukam, G. (2015).Cowpea supply and demand in West and Central Africa.*Field Crop Research* 82 (2003): 215-231. (alsoaailable at www.sciencedirect.com).

Makarova, O., Makarov, V., Gasparyan, S., Napris, Z., & Shemyakin, A. (2020). *Methodological approach to grain yield planning. In E3S Web of Conferences (Vol. 175, p. 01003). EDP Sciences.*

Makinde M., and Alabi, Y., (2012). Studies on plant spacing of peanut. Tech. Bull. Facult. Hortic. (Ghib University). 6, 164-150.

Malliga, P., Bela, R. B., & Shanmugapriya, N. (2020). Conversion of textile effluent wastewater into fertilizer using marine cyanobacteria along with different agricultural waste. In *Biovalorisation of Wastes to Renewable Chemicals and Biofuels*. Elsevier. pp. 87-111.

Marais, M., Swart, A., Fourie, H., Berry, S. D., Knoetze, R., & Malan, A. P. (2017). Techniques and procedures. In *Nematology in South Africa: a view from the 21st century* (pp. 73-117). Springer, Cham.

Martínez-Hidalgo, P., Galindo-Villardón, P., Trujillo, M. E., Igual, J. M., & Martínez-Molina, E. (2014). Micromonospora from nitrogen fixing nodules of alfalfa (Medicago sativa L.). A new promising Plant Probiotic Bacteria. *Scientific reports*, *4*(1), 1-11.

Mattera, J., Romero, L. A., Cuatrín, A. L., Cornaglia, P. S., & Grimoldi, A. A. (2013). Yield components, light interception and radiation use efficiency of lucerne (Medicago sativa L.) in response to row spacing. *European Journal of Agronomy*, *45*, 87-95.

Mehmud, M., Sadarov M., Haddadi H. M. (2016): Study of tillage, plant pattern and plant densities on kernel yield and its component of maize in Iran. *International Journal of Agriculture and Crop Sciences. 5*. (15.) 1682 -1686.

Mkandwire, R. W., & Likoswe, A. A. (2015). The effect of intercropping cotton with legumes on crop yields and yield components. *Agronomy Journal*, *8*, 41-46.

Mohale, K. C., Belane, A. K., & Dakora, F. D. (2014). Symbiotic N nutrition, C assimilation, and plant water use efficiency in Bambara groundnut (*Vigna subterranea* L. Verdc) grown in farmers' fields in South Africa, measured using 15 N and 13 C natural abundance. *Biology and fertility of soils*, *50*(2), 307-319.

Mohapatra, H. A. (2015). Studies on weed management in irrigated groundnuts (*Arachis hypogaea* L). in Sudan. Ph.D. Thesis. Faculty of Agricultural Sciences, University of Gezira, Wad Medani, Sudan,

Mokhtar W.J. (2001). A Farmer's guide to groundnut production in Nigeria. *Patancheru*, *502*(324), 36.

Mondal, M., Gunri, S. K., Sengupta, A., & Kundu, R. (2018). Productivity enhancement of rabi groundnut (*Arachis hypogaea* L.) under polythene mulching and rhizobium inoculation under new alluvial zone of West Bengal. *Int. J. Curr. Microbiol. Appl. Sci*, *7*, 2308-2313.

Morrison F.R., Summerfield, R.J. and Neves, M.C. (2002). Nitrogen nutrition of cowpea [*Vigna unguiculata* (L.), Walp]: Effects of timing of inorganic nitrogen application.Trop. Agric. (Trinidad), 58:1-12.

Mubarak,U. (2004). Evaluation of different varieties, seed rates and row spacing of Groundnut, planted under agro-ecological conditions of Malakand Division. *J. Interacad.;*9:178-183.

Namatsheve, T., Cardinael, R., Corbeels, M., & Chikowo, R. (2020). Productivity and biological N 2-fixation in cereal-cowpea intercropping systems in sub-Saharan Africa. A review. *Agronomy for Sustainable Development*, *40*(4), 1-12

Nanduri, K. R., & Dakheel, A. J. (2015). Manual of seed production of salt tolerant crops. *International Center for Biosaline Agriculture, Dubai*.

Noorhosseini, S. A., Soltani, A., & Ajamnoroozi, H. (2018). Simulating peanut (*Arachis hypogaea* L.) growth and yield with the use of the Simple Simulation Model (SSM). *Comput Electron Agric*, *145*, 63-75.

Norman, W., Ansa, E., Joseph Etim & Okon H. (2016). Effects of groundnut spacing on yield and weed control in the rainforest Agro-Ecological zone of Nigeria. Journal of Agricultural Research. 4(12):374-377.

Odeleye, D., Haricharan Reddy K, Arun Kumar J.S, Gautam Ghosh. T (2017). Effect of plant spacings on the yield and yield attributes of groundnut varieties. 79-81.

Onasanya, O. O., Hauser, S., Necpalova, M., Salako, F. K., Kreye, C., Tariku, M., & Pypers, P. (2021). On-farm assessment of cassava root yield response to tillage, plant density, weed control and fertilizer application in southwestern Nigeria. *Field Crops Research*, *262*-265.

Onat B, Bakal H, Gulluoglu L, and Arioglu H. (2016). The effects of row spacing and plant density on yield and yield components of peanut grown as a double crop in mediterranean environment in Turkey. *Turkish Journal of Field Crops.* 22(1): 71-80.

Ortega, D. L., & Tschirley, D. L. (2017). Demand for food safety in emerging and developing countries: a research agenda for Asia and Sub-Saharan Africa. *Journal of Agribusiness in Developing and Emerging Economies* 2. (5) 4680-4683

Otieno, D. (2019). *Metagenomic Analysis of Groundnut (Arachis Hypogaea L.) RNA Viruses in Gem and Matayos Sub-counties, Western Kenya* (Doctoral dissertation, University of Nairobi).

Oudhia A. (2014) Effect of chemical weed control of soybean (*Glycine max* L.) field in Mongolia. Asian Journal of Plant Sciences. 3. (2.) 203-206.

Pandey, P., Irulappan, V., Bagavathiannan, M. V., & Senthil-Kumar, M. (2017). Impact of combined abiotic and biotic stresses on plant growth and avenues for crop improvement by exploiting physio-morphological traits. *Frontiers in plant science*, *8*, 537.

Pandian, K., Subramaniayan, P., Gnasekaran, P., & Chitraputhirapillai, S. (2016). Effect of biochar amendment on soil physical, chemical and biological properties and groundnut yield in rainfed Alfisol of semi-arid tropics. *Archives of Agronomy and Soil Science*, *62*(9), 1293-1310.

Panth, M., Hassler, S. C., & Baysal-Gurel, F. (2020). Methods for management of soilborne diseases in crop production. *Agriculture*, *10*(1), 16.

Paulsen, M. R., Kalita, P. K., & Rausch, K. D. (2015). Postharvest losses due to harvesting operations in developing countries: a review. In *2015 ASABE Annual International Meeting* (p. 1). American Society of Agricultural and Biological Engineers.

Phogat, V., Pitt, T., Stevens, R. M., Cox, J. W., Šimůnek, J., & Petrie, P. R. (2020). Assessing the role of rainfall redirection techniques for arresting the land degradation under drip irrigated grapevines. *Journal of Hydrology*, *587*-595.

Piao, S., Liu, Q., Chen, A., Janssens, I. A., Fu, Y., Dai, J. & Zhu, X. (2019). Plant phenology and global climate change: Current progresses and challenges. *Global change biology*, *25*(6), 1922-1940

Popescu, A., Stoian, E., & Șerban, V. (2019). The EU-28 milk sector trends in the period 2009-2018. *Scientific Papers. Series" Management, Economic Engineering in Agriculture and Rural Development"*, *19*(4), 261.

Prasad, V., Allen Jr, L. H., Singh, P., & Jones, J. W. (2010). Modeling sensitivity of grain yield to elevated temperature in the DSSAT crop models for peanut, soybean, dry bean, chickpea, sorghum, and millet. *European Journal of Agronomy*, *100*, 99-109.

Qutbudin, I., Shiru, M. S., Sharafati, A., Ahmed, K., Al-Ansari, N., Yaseen, Z. M., & Wang, X. (2019). Seasonal drought pattern changes due to climate variability: case study in Afghanistan. *Water*, *11*(5), 1096

Rajbhandari, R., Lashkari, A. M., Eldouma, M. A., Abdalla, A. E., (2013). Effect of weeding frequencies and plant population on vegetative growth characteristic in groundnut (*Arachis hypogaea* L.) in North Kordofan of Sudan. Int. J. Appl. Biol. Pharmaceut. Technol. 1(3), 1188-1193.

Rębilas, K., Klimek-Kopyra, A., Bacior, M., & Zając, T. (2020). A model for the yield losses estimation in an early soybean (Glycine max (L.) Merr.) Cultivar depending on the cutting height at harvest. *Field Crops Research*, *254*, 107846

Reddy A, and Whiting C. (2018). Groundnut in Eastern Africa 1981-1990. In: Nigam SN, editor. Groundnut–a global perspective. ICRISAT, Patancheru, India.;89-95.

Reddy, M. T., Pandravada, S. R., Sivaraj, Ntrajan & Sunil, Neel A. M. (2016). Characterization of Indian landrace germplasm and morphological traits desirable for designing a customer-driven variety in okra (Abelmoschus esculentus L. Moench). *Journal of Global Agriculture and Ecology*, *6*(1), 7-34

Rees, R. W., Flood, J., Hasan, Y., Wills, M. A., & Cooper, R. M. (2016). *Ganoderma boninense basidiospores* in oil palm plantations: evaluation of their possible role in stem rots of Elaeis guineensis. *Plant pathology*, *61*(3), 567-578.

Rokon, G. M., Khan, M. M. H., Bahadur, M. M., Shanto, M. H., Alam, M. K., Hussain, J & Halder, J. (2019). Leaf Clipping and Population Density Effects on Green Fodder and Grain Yield for Hybrid Maize (Zea mays) in Bangladesh. *Journal of Plant Breeding and Genetics*, *7*(2), 55-62.

Roy, W.T., Karim, F.M. and Rashid, M.M. (2012). Performance of groundnut under different plant population and weed management. M.Sc. (Ag) Thesis, Sher-e-Bangla Agricultural University, Dhaka.

Salem, J.M., Prasart Dogkeaw & Prasit Jina, (2017). Weed control in rainfed peanut (*Arachis hypogaea* L.) production in Northern Thailand. *Thai Journal of Agricultural Science* 9: 51-65.

Santo, K. G. (2011). *Growth and yield response of groundnut (Arachis hypogyaea L.) to weeding regime and plant spacing* (Doctoral dissertation, KNUST).

Schlecht E, Buerkert A, Tielkes E, Bationo A (2006). A critical analysis of challenges and opportunities for soil fertility restoration, Sudano- Sahelian West Africa. nutrient cycling in Agroecosystems, 76(2);,109- 136.

Shahein, A. A., Darkwa, A. A., & Ocloo, G. K. (2014). Yield and productivity of component crops in a maize-soybean intercropping system as affected by time of planting and spatial arrangement. *ARPN Journal of Agricultural and Biological Science*, *6*(9): 50-57

Shamshiri, R. R., Ibrahim, B., Ahmad, D., Man, H. C., & Wayayok, A. (2018). An overview of the system of rice intensification for paddy fields of Malaysia. *Indian J. Sci. Technol*, *11*, 18.

Shanwad, U. K., Agasimani, C. A., Aravndkumar, B. N., Shuvamurth, S. D., Surwenshi, A. and Jalageri, B. R. (2011). Integrated weed management (IWM): A long time case study in groundnut –wheat cropping system in Northern Karnataka. *Res. J. Agri. Sci.* 1: 196-200.

Shinde, G. C., More, S. R., Pawar, S. V., & Nimbalkar, C. A. (2019). Genetic variability and association study for different traits in F5 progenies of groundnut. *Journal of Pharmacognosy and Phytochemistry*, *8*(5), 1497-1500.

Shokes E., & Melouk, R. (2015). Improving global production and use of peanuts: Annual report, Peanut CRSP. University of Georgia, Griffin, USA.

Singh, A. L. (2011). Physiological basis for realizing yield potentials in groundnut. *Advances in plant physiology*, *12*, 131-242.

Singh, R. K., Pandey, S. K., & Chattopadhyay, A. (2020). Detection and Diagnosis of Seed-Borne and Seed-Associated Nematodes. In *Seed-Borne Diseases of Agricultural Crops: Detection, Diagnosis & Management*. Journal of Agricultural & Environmental Science. 10. (3.) (pp. 201-229). Springer, Singapore.

Singh, S (2019). Nitrogen Management in Baby Corn: A Review. *Current Journal of Applied Science and Technology*, Agron. Journal V (4) P1-11.

Skoko, B.C. and Zivanovic, B. (2015). Effect of weed management practices on weed control, growth attributes, yield and economics in Rabi groundnut (*Arachis hypogaea L*.). Int. J. Plant Protec., 8: 307-312.

Slattery, R. A., VanLoocke, A., Bernacchi, C. J., Zhu, X. G., & Ort, D. R. (2017). Photosynthesis, light use efficiency, and yield of reduced-chlorophyll soybean mutants in field conditions. *Frontiers in Plant Science, 8*, 549.

Smýkal, P., Coyne, C. J., Ambrose, M. J., Maxted, N., Schaefer, H., Blair, M. W & Varshney, R. K. (2015). Legume crops phylogeny and genetic diversity for science and breeding. *Critical Reviews in Plant Sciences, 34*(1-3), 43-104

Son, N. T., Chen, C. F., Chen, C. R., & Guo, H. Y. (2020). Classification of multitemporal Sentinel-2 data for field-level monitoring of rice cropping practices in Taiwan. *Advances in Space Research, 65*(8), 1910-1921.

Sreelatha P, Sudhakar P, Umamahesh V, Subramanyam D, Vasanthi RP (2008). Variability in growth and yield attributes among different growth habits of groundnut genotypes. International Journal of Current Microbiology and Applied Sciences. 8(6):1066-1071

Sukhadia, N. M., Ramani, B. B., Asodaria, K. B. and Modhwadia, M. M. (2015). Comparative efficacy of pre and post emergence herbicide application in spreading groundnut. Indian J. Weed Sci. 30: 163

Sulikowska, A., Ustrnul, Z., & Czekierda, D. (2017). Variability of growing degree days in Poland in response to ongoing climate changes in Europe. *International journal of biometeorology*, *61*(1), 49-59.

Sweet M., Z. Y., Minotti N.T and Mbagwu R. (2014). Fertilizer requirements for wheat and maize in China: The Quefts approach. *Nutr. Cycling Agro ecosyst., 74:* 245-258.

Sweet, P., G. & Minotti Y.B. (2019). Studies on crop-weed competition and chemical weed control in groundnut. Madras Agricultural Journal 63: 454-457

Sweet, P., G. & Minotti Y.B. (2019). Studies on crop-weed competition and chemical weed control in groundnut. Madras Agricultural Journal 63: 454-457

Tawaha, R and Turk,S.E.(2004) plant density effects on seed yield components of beans. Crop Sc. 17 (4) 478-489.

Taylor, K. W. (Ed.). (2015). *Voices from the second republic of South Vietnam (1967–1975)* (No. 65). Cornell University Press.

Tazbian, F. (2016). *Survey, Damage Assessment and Biology Study of Saw-Toothed Grain Beetle, Oryzaephilus Surinamensis* (Doctoral Dissertation, Department of Entomology, Sher-E-Bangla Agricultural University, Dhaka.).

Thellen, K.D. (2016) Interaction between row spacing and yield: Why it works. Online Crop Management; 2006. Accessed: August 2009. DOI:10.1094/CM--0227-03-RV. Available:https://www.plantmanagementnetwork.org / pub/cm/research/2006/peanut.

Thwala B.N and Ossom W. (2019). Phenotyping cowpeas for adaptation to drought. *Frontiers in physiology*, *3*, 155.

Tijani. E. (2011). Cultural weed management. Non-Chemical Weed Management: Principles, Concepts and Technology, Wallingford, UK: CAB International, 35-48.

Tijani-Eniola H (2001) Influence of intra-row spacing and weeding regime on the performance of cowpea [Vigna unguiculata (L) Walp]. Nigerian J of Weed Sci. 14:11-15

Tippe, D. E., Rodenburg, J., Schut, M., van Ast, A., Kayeke, J., & Bastiaans, L. (2017). Farmers' knowledge, use and preferences of parasitic weed management strategies in rain-fed rice production systems. *Crop protection*, *99*, 93-107.

Tisdale, P. and Nelson, Q. (2015). Weed management practices and their influence on weed growth and yield of groundnut. Pestology. 14: 18-21.

Tittonell, P., & Giller, K. E. (2013). When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research*, *143*, 76-90.

Tripathi R and Singh, A., (2011). Effect of different periods of weed free maintenance on crop weed competition in groundnut (*Arachis hypogaea* L.). Indian Journal of Weed Science 17: 9-14

Turner, N. C. (2019). Imposing and maintaining soil water deficits in drought studies in pots. *Plant and Soil*, *439*(1), 45-55.

Wang, X., Zgadzaj, R., Fazel, N., Li, Z., Yi, S. A., Zhang, X & Downer, M. C. (2013). Quasi-monoenergetic laser-plasma acceleration of electrons to 2 GeV. *Nature comunications*, *4*(1), 1-9.

Wani, S. P., Anantha, K. H., & Garg, K. K. (2017). Soil properties, crop yield, and economics under integrated crop management practices in Karnataka, southern India. *World Development*, *93*, 43-61.

Weerarathne, L. V. Y., Marambe, B., & Chauhan, B. S. (2017). Intercropping as an effective component of integrated weed management in tropical root and tuber crops: A review. *Crop protection*, *95*, 89-100.

Weiss, J.W. (2013). Critical period of grass vs. broadleaf weed interference in peanut. Weed Technology 22: 68-73.

Yadava, P. and and kurnar T. (2011). Weed management practices and their influence on weed growth and yield of groundnut. Pestology. 14: 18-21.

Zegada-Lizarazu, W., & Monti, A. (2011). Energy crops in rotation. A review. *Biomass and bioenergy*, *35*(1), 12-25.

Zhang, Y., Liu, H., Liu, S., Zhai, L., & Yin, C. (2015). Row ratios of intercropping maize and soybean can affect agronomic efficiency of the system and subsequent wheat. *PloS one*, *10*(6), e0129245.

Zhao, D., Yu, Y., Shen, Y., Liu, Q., Zhao, Z., Sharma, R., & Reiter, R. J. (2019). Melatonin synthesis and function: evolutionary history in animals and plants. *Frontiers in endocrinology*, *10*, 249.