UNIVERSITY FOR DEVELOPMENT STUDIES

RESPONSE OF MUTANT SOYBEAN (*Glycine max* L) GENOTYPES TO DROUGHT AND HIGH SOIL TEMPERATURE IN THE GUINEA SAVANNA AGROECOLOGY OF GHANA

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FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCES

DEPARTMENT OF CROP SCIENCE

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BY

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AUGUST, 2022

DECLARATION

I, hereby declare that this thesis is the result of my original work and that no part of it has been presented for a degree in this university or elsewhere. The work of others, which served as sources of information for this study, has been duly acknowledged in the references.

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Supervisors

We, hereby declare that the preparation and the dissertation/thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies.

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Dr. Shirley Lamptey ……………. ……………………….

(Co-Supervisor**)** **(Signature)** **(Date)**

DEDICATIONS

This thesis is dedicated to my father, Mr. Boabeng Solomon, and mother, Mrs. Vida Mensah, who have always supported me and held me in their thoughts and prayers throughout my life.

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God be praised for his divine wisdom, grace, courage, security, compassion, and encouragement during this work and my time at this university.

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ABSTRACT

The Department of Crop Science in the University for Development studies has produced mutant soybean genotypes with improved agronomic traits. A Series of evaluations of these mutant genotypes have been carried out at different agro-ecological zones in Ghana and high-yielding mutants such as 150 Gy, 200 Gy, 250 Gy, and 300 Gy have been identified. The present study used the above genotypes as planting material for the studies in the dry season and rainy seasons of the year 2020 to evaluate them for tolerance to abiotic stresses such as heat and drought. Two experiments were conducted for this research study. One experiment was conducted in the dry season (pot), and the other was in the rainy season carried out in the field. The design used 5×5×4 and 5×4×2 factorial experiments laid out in Randomized Complete Block Design with three replication in pot and field studies, respectively. The factors involved in the pot experiment were Genotypes (150 Gy, 200 Gy, 250 Gy, 300 Gy, and standard check-Jenguma) and, water application (100 %, 80%, 60%, 40%, and 20 %), where the and Mulching (0 t/ha, 20 t/ha 40 t/ha and 60 t/ha of rice straw). Two seeds per pot were planted and the temperature was recorded at every three-day interval. Two planting dates were used in experiment II which was carried out on the field. The first planting was done on the 17th of June and the second plating was done 17th of July, 2020. For each planting date, the plots were measured 5 m × 4 m. Results from data on water use efficiency, growth, and other agronomic traits were collected and analyzed using the GenStat (12 edition) and means were separated using Least Significance Difference (LSD) at 5% after evaluation both in the pot and in fields studies. The observed variations in the growth, yield, and other traits of these genotypes revealed that mutagenesis had a significant effect on these mutant genotypes. The 200 Gy and 250 Gy as the best performing genotype. The finding of this study observed a significant ($P < 0.05$) . different in the level of mulch, different applications, and the planting date. The results further revealed a significant ($P < 0.05$) . different among the interaction of genotypes, heat, and drought stress. Mutants 150 Gy, 200 Gy, and 250 Gy were observed to be tolerant to drought and heat. Early planting of these genotypes mulched with 20-40 t/ha mulch produced outstanding results in term growth and grain yield. I, therefore, recommend that further studies should be carried out in different agroecology to evaluate the mutant soybean genotypes for tolerance to drought and heat stress.

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CHAPTER ONE

INTRODUCTION

1.1 Background

For many years, soybean (*Glycine max* L) has been referred to as the world's most important economic oilseed crop (M. Singh *et al.*, 2022). To add to the importance of refined soybeans, they are a major source of both vegetable and protein feed oil (Bellaloui et al., 2010). In the family Leguminoaceae, the crop is classified as papillionaceae. As a result of its high great nutritional value and use as a protein supplement, it has earned the name "Golden Bean" of the twentieth century. With a projected worldwide cultivation area of 108.75 million ha, it is currently the world's top oilseed crop, with 268 million tonnes produced and 2.5 tonnes ha^{-1} produced in 2012-13 (Jadhav *et al.*, 2014). Even though soybeans provide macronutrients and minerals, they also include secondary metabolites, including phytoestrogen isoflavones (Hasanah *et al.*, 2015). It's possible to modify soybeans by using either *A. tumefaciens or A. rhizogenes*. However, neither technique is flawless. However, *A. tumefaciens* alterations are usually ineffective (Ko *et al.*, 2006).

Considered a predictor for future climate change adaptation of crops is their resiliency to adverse weather conditions such as drought, excessive heat, and temperature variations during grain filling (Cutforth *et al.*, 2007). Drought-stressed soybean (*Glycine max* L) plants use a variety of methods to survive. Drought avoidance, drought escape, and drought tolerance can all be grouped under one heading (Turner *et al.*, 2001). Breeding for drought tolerance in crops will be difficult to achieve unless subjected to stress for some years to permit straight selection for yield. Therefore, a field deprived of good moisture-holding capacity, soil uniformity, and a reasonable drought each year is significant but is unfortunately very tough to achieve results (Pathan *et al.,* 2007).

There is doubt with regard to drought responses of crop plants as they are genetically and physiologically complex. An additional responsibility that has been given less attention is canopy wilting (Lawlar and Cornic, 2002). Preliminary symptom (Carter *et al.,* 2006) indicates that soybean genotypes differ in how rapidly canopy wilting occurs under water stress. The mechanisms discussing canopy wilting differences among soybean genotypes are only partially understood. One major mechanism determining genotypic differences in wilting appears to be related to soil moisture conservation even before drought stress becomes severe (King *et al.,* 2009). Hong and Vierling, (2000) reported that organisms implore an ancient and conserved adaptive response to attain thermotolerance to normally lethal temperatures. Achievement of thermotolerance is expected to be of particular significance to plants that experience day-to-day temperature fluctuations and are incapable of escaping to more favorable environments. Drought and soil heat could be accounted for about a 40 % reduction in soybean yield (Specht *et al.*, 2001). Soybean plants exhibit different water use efficiency (WUE) from one genotype to another depending on hybrid characteristics, especially under drought conditions. The crop uses approximately 450–700 mm of water throughout the growing season (Dogan *et al.*, 2011)

1.2 Problem statement and justification

Crop growth has been negatively impacted by the recent abrupt weather change. First, as the ambient temperature rises, the rate of crop development expedites, shortening the total plant life cycle. Because of this, the crop grows smaller, has shorter reproductive cycles, and produces less overall. It also spends less time in the field accumulating biomass. Second, as the temperature rises, plant respiration rates rise as well, resulting in less net assimilate accumulation. Rainfall reduction as predicted by climate change negatively affect soil water replenishment and availability, especially due to agricultural drought (low water storage capacity) (Ogunkanmi *et al.*, 2021).

According to literature sources, the combined effect of high temperature and drought has negative effects on yield and grain number than either factor acting alone (Prasad *et al.*, 2011). Jumrani and Bhatia, (2018), observed that soybean seeds sown at high temperatures of 38 and 42 ^{0}C resulted in yield reductions of 42 and 64 %, respectively

Poor soybean crop establishment, inappropriate planting depth, use of unimproved seeds, low soil fertility, and lack of effective nodulation have been reported as major constraints in soybean production in Ghana (Lawson *et al.*, 2009). Other factors such as drought stress, high soil and atmospheric temperatures, and disease and pest infestation all result in low production of soybean. In general, variations in crop yield are projected with yield transfer functions derived from dynamic crop simulation models as defined by Parry *et al.*, (2004).

A Series of evaluations of some mutant soybeans in the Crop Science Department have been conducted and high-yielding mutants have been produced. Earlier studies on these genotypes in three agro-ecological zones in Ghana produced stable but desirable agronomic traits such as high yielding, early maturity, and resistance to shattering of pods. In the Guinea Savanah agroecology of Ghana, factors such as drought or moisture stress, high temperature, and low atmospheric humidity affect crop production leading to poor crop yield (Osakabe *et al.*, 2014). In such conditions, resistance to abiotic stress is becoming one of the most desired traits of crops. However, a new variety selection is difficult due to the wide range of plant stress responses with overlapping functions between their components creating complex mechanisms of resistance (Bartels and Sour, 2004).

The present study would help and results would indicate which genotypes would tolerate drought and/or heat. Therefore, the information generated on these genotypes would determine which of the high-yielding mutant would be most unstable for cultivation in the study area where soil heat and drought stress bedevil the production of crops

1.3 Main objective

- Study the influence of abiotic stress on growth and yield as well as the production of soybean

1.4 Specific objectives

Determine the water use efficiency of mutant genotypes and valuation of them for tolerance to

- Drought stress
- Heat tolerance

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and distribution

Despite the crop's significance for the global economy, there is no information in the archaeological record on how the soybean came to be a valuable resource and, eventually, a domesticated plant. Instead, phylogenetics and historical records have provided information about the origin of the soybean, showing that it was domesticated in East Asia and developed into a significant crop by the Zhou Dynasty (about 2500 BC) in Chin (Crawford *et al.,* 2011). Soybean’s existence was not known until after the Chinese-Japanese war of the mid-1890s that this crop was cultivated in China locally (Cannon, 2017). The world’s attention was later drawn to soybean crops following shipments to Europe in 1908 (Gibson and Benson, 2005).

. Present-day Georgia in the United States was the first state to document soybean in 1765. It is estimated that the United States provided two-thirds of global soybean demand in 1970, as a result of an increase in soybean production. The increase in soybean production in South America has propelled Brazil and Argentina to become the world's second and third-largest soybean producers, respectively. The cultivation of soybeans began in Africa in the late 1800s, however, nothing is known about the countries to which it was initially introduced to the continent (Shurtleff and Aoyagi, 2007).

However, they speculated that the crop would have been grown near the eastern coast of Africa since the region had long dealt with the Chinese before the arrival of the

Europeans. There are different reports as to when the crop was introduced in Ghana. While Shurtleff and Aoyagi, (2007) gave 1909 as the date for its introduction in Ghana, (Plahar, 2006) gave 1910. Reporters intended to convince local farmers to grow the crop as a food supplement and as a viable export product. Between 1909 and 1956, 40 kinds were grown in 17 annual trials scattered over 12 places from Asuansi on the coast to Tono on Ghana's northern border. Tests conducted up to 1942 had poor outcomes, but yields improved as trial officers became more adept at managing their crops. In the early 1950s, some trials produced yields of 1,457 kg ha^{-1} Shurtleff and Aoyagi, (2007). Plant-based protein from soybeans is the 4th most significant food crop on earth.

2.2 Drought tolerance

Drought is the most difficult abiotic factor to overcome when it comes to crop production. Drought is the most difficult abiotic factor to overcome when it comes to crop production (Tuberosa and Salvi, 2006). Drought, which is caused by insufficient rainfall and/or changing precipitation patterns, is the most overwhelming abiotic factor limiting crop output, according to Toker *et al.* (2007). Plant growth is restricted in a major amount of the world's agricultural area due to drought. Drought stress is known to be a problem for soybeans, especially at critical stages of development. Plant growth is restricted in a major amount of the world's agricultural area due to drought. Drought stress is known to be a problem for soybeans, especially at critical stages of development. (Liu *et al.*, 2004). Inhibition of growth is the most common indication of water stress damage, and it demonstrates a decrease in dry matter yield (Le Thiec and Manninen, 2003).

According to Mouss (2011), water deficit has become the supreme devastating abiotic stress inhibiting plant growth and development. The available moisture and the soil moisture balance in the soil will change as the global climate changes, and the frequency of regional droughts will increase. There are many morphological, physiological, and molecular responses in many agricultural plants that allow them to adapt to adverse climatic conditions, such as water scarcity. It is more efficient to use rainfall and irrigation water; nevertheless, irrigation system adaptation is region-specific and would result in a large increase in soybean production costs (Kebede *et al.*, 2014).

As a result of the quantitative inheritance of the trait, a faulty physiological foundation of yield in water-limited settings, and technological restrictions for systematic phenotyping, soybean breeding was formerly hindered by drought tolerance issues in soybeans. As a result of quantitative inheritance of the trait, a faulty physiological basis for yield in water-limited settings, and technological restrictions for systematic phenotyping, drought tolerance in soybean crop breeding was previously hindered. (Sinclair, 2011).

Drought has a well-documented impact on soybean, causing morphological alterations in the vegetative plant as well as a decrease in seed quantity and quality. Methods for analyzing quantitative and qualitative morphological criteria have been described. Drought has a well-documented impact on soybean, causing morphological alterations in the vegetative plant as well as a decrease in seed quantity and quality. Methods for evaluating quantitative and qualitative morphological criteria have been described (Ku *et al.*, 2013). As a response to soybeans' reliance on rainfall, the most significant factor limiting production is the advent of severe drought conditions during another stage of crop growth and development (Joshi *et al*., 2009).

The imbalanced water conditions may significantly increase biomass output and yield, as well as improve soybean quality. Because of the limited moisture content in the soil, reducing moisture leads to a reduction in photosynthesis, which results in a drop in soybean dry matter production. The imbalanced water conditions may significantly increase biomass output and yield, as well as improve soybean quality. Because of the limited moisture content in the soil, reducing moisture leads to a reduction in photosynthesis, which results in a drop in soybean dry matter production. (Iqbal *et al.*, 2019).

It has taken many measures to combat the detrimental effects of drought stress on soybeans, including agricultural practices, as well as genetic improvement (Turner, 2000). It is tactically essential to cultivate drought-tolerant soybean varieties to maintain yield gains. It is tactically essential to cultivate drought-tolerant soybean varieties to maintain yield gains (Devi *et al.*, 2014). It's preferable to concentrate on translating features that improve yield stability rather than drought resistance when it comes to soybean production when it comes to drought tolerance. Bean plants have a higher tolerance for drought because they can use water more efficiently during the growing season and maintain physiological activity until maturity.

It's preferable to focus on translating features that improve yield stability rather than drought resistance when it comes to soybean production when it comes to drought tolerance. Soybean crops' ability to absorb available water more efficiently during the growing season and to maintain physiological activity until maturity enhances drought tolerance. Importance should be given to traits that improve yield stability over those that promote drought resistance in soybean farming. Soybean crops' ability to absorb available water more efficiently during the growing season and to maintain physiological activity until maturity enhances drought tolerance (Ye *et al.*, 2020). Several evaluation methodologies based on root and shoot growth rates have been used to effectively observe the drought tolerance potential of soybean cultivars in stressed and non-stressed situations according to Cattivelli *et al* (2008). It has been emphatically established by Shao *et al* (2008) that the length of the root is one of the principal traits that assist plants to tolerate inadequate water conditions.

The response of soybean roots to drought stress varies by cultivar and is dependent on soil bio-physiochemical parameters as well as the drought stress's timing relative to the growth stage. (Bengough *et al.*, 2011). Soybean root architecture, which includes branching density, root angle and depth, and biomass partitioning, could be adversely influenced (Wijewardana and Reddy, 2019). Plant breeding programs have proven to be a beneficial complement to suitable farm management strategies in reducing the negative effects of drought. (Manavalan *et al.*, 2009). About 40% reduction in soybean yield has been estimated as a result of drought (Ye *et al.*, 2020).

Every year, drought reduces global soybean production by more than half (Wang *et al.*, 2003). The impact of drought on soybean production is determined by the severity, length, and timing of stress relative to the growth stage of the soybean crop (Brar *et al.*, 1990). Soybean is highly susceptible to drought stress during the reproductive period (Wijewardana *et al.*, 2018). Long-term severe water stress during the vegetative growth stage, however, can result in considerable production reductions for plants.

As a result of high soil moisture stress, chlorophyll decreased by 24%, but carotenoids increased by 38%. As a result of soil moisture stress, chlorophylls are assumed to be depleted, which is caused by chlorophyll degradation, pigment photo-oxidation, and insufficient chlorophyll synthesis. Due to the reduced light absorption by chloroplasts, photochemical damage to PS II in water-stressed situations would be prevented (Wijewardana *et al.*, 2019).

Early vegetative soybean development and establishment are severely hampered by soil moisture stress. There is a direct correlation between drought stress and leaf development during the vegetative growth stages. Soil moisture stress tolerance has been linked to various growth and developmental characteristics including node number, plant height, internode length, and leaf area expansion (Desclaux *et al.*, 2000; Ku *et al.*, 2013; Khan *et al.*, 2014).

Stomatal closure may result from drought stress, which reduces CO_2 availability in leaves and inhibits carbon fixation, exposing chloroplasts to excessive excitation energy, which may increase the generation of reactive oxygen species, which can induce oxidative stress (Reddy *et al.*, 2004).

2.3 Heat tolerance

The effects of heat stress on cell function are complicated, signifying that several procedures are involved in thermotolerance. Approximately, most of these processes may be explicit to basal thermotolerance meanwhile others may be induced during attained thermotolerance, and many may be involved in both. Increased temperatures are described to hurt membrane-linked processes as a result of modifications in membrane fluidity and permeability (Larkindale *et al.,* 2005).

Soybean seed yield is limited by heat stress during reproductive stages, including pollination and seed development. There are complex relationships between temperature, drought, and carbon dioxide in the future climate, but the consistency of the estimates on how these stressors would affect soybean output is unknown (Chebrolu *et al.,* 2016).

It has been found by Alsajri *et al* (2019) that temperature fluctuates in a crop production structure geographically and rapidly over the growing season, with each activity and the developmental component of the crop falling within a definite specific temperature optimum. Some plants have different responses to environmental stimuli based on their processes or cultivars. An estimated 27 % loss in yield occurs when plants are exposed to temperatures of 35°C for 10 hours during the day (Mohammed *et al.,* 2007).

An estimated 27 % loss in yield occurs when plants are exposed to temperatures of 35°C for 10 hours during the day. Greenhouse gas emissions are expected to rise between 1.5

to 11°C by 2100 (Stainforth *et al.*, 2005), which could lead to significant reductions in soybean yield in the future.

Various environmental factors influence seedlings' emergence in plants, such as temperature, soil moisture, soil physical features, and seed quality. When water and nutrients are at their optimal levels and seeds germinate and emerge, temperature plays an important role in influencing the growth rates of plants regardless of other stress factors. As a rule, plant species differ in their sensitivity to temperature. There were differences in temperature sensitivity between cultivars and hybrids (Castiel, 2010; Wijewardana *et al.*, 2015). Due to the high temperatures, seed germination and growth vigor were reduced. Due to the high temperatures, seed germination and growth vigor were reduced (Egli *et al.*, 2005). The authors found that higher temperatures during the seed filling period in the field harmed the germination of soybean seeds. The temperature has a significant impact on seed weight and canopy placement. Modi and Asanzi (2008) showed that soybean seeds produced at low temperatures (20/10°C Day/Night) were heavier, while seeds produced at high temperatures (30/20°C Day/Night) were lighter.

Therefore, it is appropriate to screen for genetic material that is more tolerant of high-temperature stress, which is urgently needed to ensure soybean production's sustainability. Experimenting with growing plants in high-temperature circumstances throughout their life cycle will help us better understand their responses and adaptations (Jumrani and Bhatia, 2014). Soybean is a facultative short-day plant that requires a short photoperiod to blossom. Photoperiod impacts not only the phenological and physiological development of soybean but also the morphological structures of the soybean. A photoperiod-dependent seed filling period and corresponding harvest maturity time exist. When day length and temperature fluctuate, soybeans respond accordingly (Bita and Gerats, 2013).

Plant growth, as well as the number of flowers and seeds per pod, is reduced by the high temperatures (Tubiello *et al.*, 2007; Canci and Toker, 2009). During flowering, heat stress can cause pollen sterility and impaired seed set. Temperatures above 37.2 °C significantly reduced pod production, while temperatures above 29.4 °C resulted in fewer pods. Heat stress has the largest impact on soybean production during the R5 growth stage. Daytime temperatures of 32.8-35.6 ^{0}C during seed fill result in fewer seeds per plant, while daytime temperatures of greater than 29.4 °C during seed fill can result in lower soybean weight. High nighttime temperatures can lead to inefficient respiration and a decrease in the net amount of dry matter accumulated by plants. Respiration increases rapidly with temperature, approximately doubling for every 10.6 degrees Celsius increase (Onat *et al.*, 2017). High temperatures (>30 °C) have been found to limit the amount of anther dehiscence and pollen shedding, as well as pollen grain germination on the stigma, pollen tube elongation, and in-vivo pollen germination (Fahad *et al.*, 2015, 2016).

Plant productivity is reduced as a result of many physiological damages caused by high temperatures, such as scorching of leaves, stem scorching (and subsequent leaf abscission), and leaf senescence (and subsequent leaf aging) (Vollenweider and Günthardt-Goerg, 2005). Hypocotyl and petiole lengthening are common morphological responses to shade avoidance in many situations (Hua, 2009; Tian *et al.*, 2009). High temperatures, on the other hand, decrease plant growth by influencing the shoot net absorption rates and, thus, the total dry weight of the plant (Wahid and Shabbir, 2005).

Additionally, heat increases the formation of reactive oxygen species, which in turn damages chlorophyll and the photosynthetic mechanism (Camejo *et al.*, 2006; Guo *et al.*, 2007). Heat stress decreases a plant's photosynthetic and respiratory activity by boosting chlorophyllase activity and decreasing the amount of photosynthetic pigment (Todorov *et al*., 2003; Sharkey and Zhang, 2010). For reproductive success, a decrease in photosynthesis will eventually lead to a drop in energy stores leading to plant malnutrition, resulting in limited resource availability for reproduction (Young *et al.*, 2004; Sumesh *et al.*, 2008).

Biosynthesis and metabolite compartmentalization is disrupted by high-temperature stress in plant tissues (Maestri *et al.*, 2002). A high temperature alters the activity of carbon metabolism enzymes, starch accumulation, and sucrose synthesis by down-regulating particular genes in carbohydrate metabolism (Ruan *et al.,* 2010). Among the primary metabolites accumulating in response to heat stress are proline, glycine betaine, or soluble sugars (Wahid and Close, 2007). Many plant species accumulate other osmolytes, such as sugar alcohols (polyols) or tertiary and quaternary ammonium compounds (Sairam and Tyagi, 2004; Rao *et al.*, 2006).

All of these physiological processes are affected by high temperatures: photosynthesis, primary/secondary metabolism, lipid, and hormone signaling, and many others. There are several proteins, membranes, and cytoskeleton components that are affected by heat stress. However, pollen grain production has a greater impact on reproductive growth. In addition, heat causes a metabolic imbalance and the accumulation of harmful by-products, such as ROS, which impede plant vegetative and reproductive development and significantly affect fruit set and quality (Bita and Gerats, 2013).

2.4 Mulching

One of the common conservative measures is mulching, which provides a protective layer over the soil surface and conserves moisture, as well as regulating temperature and controlling weeds. Growing conditions are improved as well as a variety of stressors are alleviated by it (Macilwain, 2004). Using mulch can minimize soil evaporation by up to 50%, according to Colorado State University (Waskom and Neibauer, 2010). Mulch in the garden can thus potentially save the gardener a significant amount of water and money. Glab and Kulig (2008) concluded that mulching is one of the major agronomic practices that supply the soil with both organic and nutrient.

An accumulation of 15 cm of leaf mulch in the soil can increase organic matter, phosphorus, magnesium, and cation exchange capacity. An accumulation of 15 cm of leaf mulch in the soil can increase organic matter, phosphorus, magnesium, and cation exchange capacity (Athy *et al.*, 2006). Mulching stimulates the soil moisture regime (Zegada-Lizarazu and Berliner, 2011) by regulating evaporation from the soil surface, improving infiltration and soil-moisture retention, and easing condensation of water at night due to temperature reversals (Acharya *et al.*, 2005). Mulching has a significant impact on the crop's water use efficiency (Sarkar and Singh, 2007), while available water capacity and total porosity are significantly increased. The incidence of soil erosion is minimized by mulch by the reduction of the impact of raindrops, while organic residue can also slow surface run-off and improve infiltration (Mulamba and Lal, 2008). The growth, survival, and photosynthesis of plants from semi-arid regions are highly affected by water stress as a result of water deficits, which are associated with high temperatures and high light stress (Chaves *et al.*, 2002).

To conserve water, nutrients, and carbohydrates, plants respond to stresses such as soil drying by closing stomatal pores (Wilkinson and Davies, 2002). Mulching increases the total intake of water due to the formation of loose soil surfaces. The raindrops on mulched soil do not seal the particles as they do on the soil without mulch. The effect of the sealing of soil particles from raindrops results in more loss of water through erosion (Marigowda and Srinivasan, 2020). Straw mulch has been reported to cause either a decrease, an increase, or a negligible effect on soil temperature. For instance, straw mulch during the over-wintering period can improve soil thermal regime according to Lou *et al* (2011). Mulching conserves soil and water, enhances soil structure and organic matter content, adds cations to the soil, changes soil temperature, and restores the productivity of degraded land, according to numerous scientific studies (Srivastava *et al.*, 1993). Mulching decomposes raindrop energy and hence reduces soil detachment. It also ensures infiltration by preventing surface sealing and lowering runoff and soil loss. Mulching decomposes raindrop energy and hence reduces soil detachment. Infiltration is also ensured by preventing surface sealing and reducing runoff and soil loss (Adekalu *et al.*, 2007). Plastic film mulching is one of the many mulching methods that increase soil surface temperature by manipulating the heat balance and thus increasing soil temperature, as well as having a significant impact on crop emergence (Aniekwe *et al.*, 2004).

2.5 Fertilizer application

Nitrogen, phosphorus, and potassium are macronutrients that are known to be important in promoting plant development and yield (Mohamed *et al.*, 2011). While nitrogen fertilizer is unlikely to be utilized in soybean crop production, it has been stated that soybean plants' ability to fix atmospheric N_2 to meet nitrogen needs and create maximum yields is insufficient. While nitrogen fertilizer is unlikely to be utilized in soybean crop production, it has been stated that soybean plants' ability to fix atmospheric N_2 to meet nitrogen needs and create maximum yields is insufficient (Wesley *et al.*, 1998). According to several field research reports, the usage of integrated mineral fertilizer and organic manure is the only way to achieve high and sustained crop yields. By converting inorganic nitrogen to organic forms, the complementary application of organic and inorganic fertilizers increases nutrient synchronicity and decreases losses (Jaja and Barber, 2017).

Incorporating organic and inorganic fertilizers into the soil to use land continually for agricultural production, according to Basso and Ritchie (2005) would provide many benefits for improving the chemical and physical status of the soil, resulting in improved crop output. Compost, farmyard manure (FYM), slurry, worm castings, urine, peat, green manure, dried blood, bone meal, fish meal, and feather meal are examples of organic fertilizers (Haynes and Naidu, 1998).

Mineral elements are found in both organic and inorganic fertilizers, which plants need for proper growth and development. Essential mineral elements, which are divided into micro and macro-categories, are required in optimal proportions. Plant growth and development are influenced by nitrogen, phosphorus, and potassium (Yagoub *et al.*, 2012). It was also discovered that using organic manures in conjunction with fertilizers meets the micronutrient requirements of soybeans (Joshi *et al.*, 2000). Some Rhizobium stains that fix atmospheric nitrogen (N) in the nodules have an antagonistic effect on soil-borne diseases (Ganesan *et al.*, 2007).

In general, fertilizer application has improved crop production significantly; yet, fertilizer management in present farmers' practices is not always in line with crop needs (Zhang *et al.*, 2009). Phosphate (P) has become a critical plant macronutrient for most life processes in soybean or leguminous plants, including photosynthesis, metabolism, root development, flower, fruit, and seed generation. The phosphorus nutrient is a vital ingredient that plants require in considerable amounts. Chemical fertilizers are the most important phosphorus suppliers in arable soils, even though 75 to 90% of phosphorus is fixed in the soil by iron, calcium, and aluminum. Phosphate (P) has become a vital plant macronutrient for most life processes in soybean or leguminous plants, including photosynthesis, metabolism, root development, flower, fruit, and seed generation. The phosphorus nutrient is a vital ingredient that plants require in considerable amounts. Chemical fertilizers are the most important phosphorus suppliers in arable soils, even though 75 to 90% of phosphorus is fixed in the soil by iron, calcium, and aluminum (Turan *et al.*, 2006). Phosphorus is another vital component that limits plant growth when it is not available (Fernandez *et al.*, 2007). For this reason and others, it's important to address the problem of phosphate-solubilizing bacteria (Fernandez *et al.*, 2007). Studies have demonstrated that P can increase root nodule weight and number while also improving pod quality.

Rhizobium inoculation has been demonstrated to considerably increase soybean grain production in experiments (Ahiabor, 2014; Ronner *et al.*, 2016a) and genotypes and phosphorus fertilizers have positive impacts on soybean productivity (Nwoke *et al.*, 2005), no study has endeavored to scrutinize the possible impact that improvements in the above elements can contribute to enhancing soybean yields in smallholder systems to date. Moreover, the soybean's reaction to these nutrients has been exceedingly varied in recent years (Ronner *et al.*, 2016; Thilakarathna and Raizada, 2017).

To increase soybean yields, nitrogen fertilizer must be applied (Umeh *et al.*, 2011) it has always been questioned whether legumes, like soybeans, do not require fertilizer N because they can fix atmospheric nitrogen to use. To maximize soybean production, N fixing may not be enough, according to Gan *et al.* (2003). The flowering stage is the optimal time to apply N top dressing, since it increases seed yield by 19 and 21 % to no top dressing (Gan *et al.*, 2003), Through its influence on a wide range of agronomic and quality characteristics, nitrogen enhances yields. In general, soybean plants grew taller and accumulated more dry matter per plant (Manral and Saxena, 2003).

Several studies have found that any gaps or shortages in crop nitrogen demand and nitrogen supply from nitrogen fixation must be made up for by N uptake from other sources (Salvagiotti *et al.,* 2008). Even though nitrogen is a mobile nutrient, if the overall N supply does not meet soybean requirements, the crop will remobilize N stored in the upper leaves and other parts of the plant to the grain, resulting in early leaf fall, which reduces the canopy's photosynthetic capacity and thus limits yield potential (Salvagiotti *et al.,* 2008). Several studies have demonstrated that the application of nitrogen fertilizer, notably as a starter for soybeans has been shown to promote and improve growth and production (Giller *et al.,* 2001; Tahir *et al*., 2009). N-fixation may not be sufficient to meet plant requirements in the early stages of plant growth and development if the plant is still growing and developing. Seeds have a high photosynthetic requirement during the pod filling stage, which could contribute to nodule senescence.

Temperature, moisture, and soil pH all influence soybean nitrogen response. Nitrogen fertilizer can increase total dry matter production, allowing the plant to produce more pods, seeds, and ultimately grain yields (Caliskan *et al.,* 2008). Ezekiel-Adewoyin (2014) also found that nitrogen injection at either the vegetative or flowering stage resulted in a 44 % and 16 % increase in the pod and crop biomass, respectively (Gan *et al*., 2004) the use of nitrogen fertilizer on soybeans at different stages of its growth to increase its yield. On the other hand, Schmitt et al (2001), have disputed this claim that soybean fertilized with mineral N resulted in high grain yield and oil content. Barker and Sawyer (2005) also added that N application to soybean at a particular growth stage might not be advisable. The use of N fertilizer in soybean cannot be taken out completely; so, factors such as time of application, fertilizer type, rate of application and environment, etc. must be a consideration before conclusions can be drawn on these controversies.

Potassium completes a primary function in the directive of the movement of water into plant cells. Even though potassium may not be part of many enzyme structures, it activates over 60 enzymes, especially enzymes that are used in respiration and photosynthesis (Taiz and Zieger, 2002). On the other hand, the usage of organic manures in conjunction with fertilizers has been shown to meet the nutritional requirements of soybeans (Dadi *et al.*, 2019). Nitrogen (N) is fixed by certain symbiotic N_2 fixing Rhizobium stains in the nodules, which has an antagonistic effect on soil-borne diseases (Gopalakrishnan *et al.*, 2015)

Biofertilizers are those that are made from non-synthetic organic resources such as plant and animal by-products; rock powder; seaweed; inoculants; sludge; animal manures and plant residues (Jones, 2012) generated by the drying, cooking, and composting processes (Dadi *et al.*, 2019), chopping, Grinding and Fermentation (Mario *et al.*, 2019) possibly a different procedure (Thanaporn and Nuntavun, 2019). Bio-fertilizers not only provide soil nutrients and organic matter but also increase the size, biodiversity, and activity of the soil's microbial community. They also have an impact on soil structure and nutrient turnover (Albiach *et al.*, 2000). Micronutrient requirements for soybean can be met by using organic manures in conjunction with fertilizers, according to research (Joshi *et al.*, 2009). There is also evidence that the combined application of inorganic and organic manures improves soybean growth and yield compared to the use of only one of the two according to Lourduraj (2000).

An important nutrition source is incorporating organic materials into the soil. These materials contain nitrogen, phosphorous, and magnesium which are released through mineralization (Fairhurst, 2012). While organic matter and nutrients, mostly nitrogen and phosphorus, are abundant in this material, improper treatment or use could have severe negative environmental repercussions. If properly handled, it can potentially replace partial or chemical fertilization (Juan *et al.*, 2014). Not only do organic fertilizers provide the soil with organic matter and nutrients, but they also improve the soil's microbial population as well as its physical, biological, and chemical qualities (Albiach *et al.*, 2000).

Plant nutrients can also be obtained from compost and vermicomposting, which are well-known sources of plant nutrition. Plant nutrients can also be obtained from compost and vermicomposting, which are well-known sources of plant nutrition. (Manivannan *et al.*, 2009; Shehata and El-Helaly, 2010). Fertilizers like vermicompost and compost are used as a means of improving soil properties such as water-holding capacity, stiffness, and structure (Wells *et al.*, 2000). Physico-chemical and biological features of deteriorated or poor fertility soil can be recovered, and they can also provide a substantial source of soil N-P-K to help plants grow better (Baziramakenga and Simard, 2001). The right application of compost in soil (root rot of beans) limits the development of disease and generates vigorous plants, according to Cespedes et al (2006). Application of nutrients, especially organic manures, not only increases output but also improves soil health (Sushila and Giri, 2000) as well as ensures a sustainable farming system (Tiwari *et al.*, 2002) simply because it is a major supplier of soil organic material. Several activities in the soil ecosystem are affected by organic matter, including nutrient cycling and soil structure development as well as carbon sequestration, water retention, and energy delivery to microorganisms (Lakaria *et al.*, 2011).

Soil organic matter is the most important factor in soil fertility, formation, soil biology, and physical and chemical properties of soil, which in turn affects crop output (Walker *et al*., 2004). Plants benefit from mineral fertilizer application when there are organic resources present in the soil. In outre, organic inputs provide nutrients that aren't only available in the form of mineral fertilizers. Soil organic matter is replenished by creating a favorable rhizosphere, which increases the availability of phosphorus for plant uptake and alleviates problems such as soil acidity (Fairhurst, 2012). This means that soil carbon sequestration improves as the agroecosystem becomes more stable (Kuppusamy *et al*., 2016).

Soil organic matter and soil enzymes are significantly affected by management measures such as straw mulching or integration, fertilization, irrigation, and tillage (Muhammad *et al.*, 2018). Tabo *et al*. (2007) proposed adding and incorporating organic fertilizer to soil to improve soil structure and increase its capacity to hold appropriate moisture and nutrients. To enhance soil fertility in intensive agricultural systems, biodegradable compost has been touted as one of the most promising methods of doing so. To enhance soil fertility in intensive agricultural systems, compost created from organic waste has been touted as one of the most promising methods of doing so (Adediran *et al.*, 2003; Summer, 2000). Organic fertilizer must be applied in vast quantities to crops to be effective due to its poor nutritional makeup (Akanbi et al., 2007).

In contrast to soil treatment, foliar fertilization allows for faster consumption of nutrients and faster repair of detected deficiencies (Fageria *et al.*, 2009). Foliar application of urea enhanced soybean grain production between 6 and 68% over the control, according to Oko *et al.* (2003). It is also important to note that the effect of fertilization throughout different phases of soybean growth has an impact on grain production (Mallarino *et al.*, 2001).

To increase soil texture, water retention, drainage, and aeration, organic or inorganic matter is added to the soil. Soil that is sandy or rocky requires additions to improve the texture and increase water retention. Clay soils must be amended to increase texture, aeration, and drainage, as well as to improve soil structure. A wide range of soil amendments are available (Rana, 2018). Among the causes that have contributed to poor soil, productivity is loss of soil organic matter and nutrients, limited water infiltration, and low water holding capacity of soils (Nweze *et al.*, 2020).

In the same way, biochar increases soils' ability to absorb plant nutrients (Liang *et al.*, 2006) decreasing the number of nutrients that are leached from the soil. According to research, biochar can reduce soil bulk density and enhances soil cation exchange capacity, nutrient cycling, and plant-available water retention. The addition of biochar to soil is expected to boost both nutrient and water use efficiency, increasing crop output as a result (Glaser *et al.*, 2001; Liang *et al.*, 2006).

2.6 Nodulation and Biological Nitrogen Fixation

Microorganisms in the soil fix nitrogen in leguminous plants through a process called biological nitrogen fixation (Gregoire, 2003). Associating rhizobia with legumes is the is very essential in agriculture. Plants benefit from the rhizobium-legume relationship because they can transform air nitrogen into forms that can be used by plants (Jensen and Hauggaard-Nielsen, 2003). Biological nitrogen fixation (BNF) is a cost-effective and environmentally sound method of increasing crop output, minimizing external nitrogen inputs, and improving the quality of soil resources, reducing reliance on mineral fertilizers, which can be expensive and inaccessible to smallholder farmers. Biological N fixation also has economic, environmental, and agronomic benefits, according to Silva and Uchida, (2000), and might be employed to a greater extent as an alternative to manufactured fertilizers.

Soybean and other legume crops show potential in this area. According to Solomon *et al*. (2012), legumes such as soybean can get between 50 and 80 % of their nitrogen requirements via BNF. However, according to Sanginga (2002), contemporary promiscuous soybean genotypes cannot meet all of their need for growth and seed development alone by N_2 fixation. BNF is an important source of nitrogen for farmers that use little or no fertilizer, particularly when growing legumes like soybeans (Smaling *et al*., 2008). BNF was described as an additional advantage by Rinnofner *et al.* (2008) in the context of legume capture crops.

There is a symbiotic relationship between rhizobia and a host-specific legume in the BNF process, and it is critical to crop growth because it allows atmospheric nitrogen molecules to be converted directly into plant-useable forms (Hopkins and Hüner, 2009). It is estimated that per year, roughly 31014 g of N_2 is transformed into ammonium nitrate (NH_4^+) (Rees *et al.*, 2005). Microorganisms typically convert N_2 to NH_4^+ and $NO3^-$ (Dogan *et al.*, 2011).

As a sustainable supply of nitrogen, biological nitrogen fixation in plants may reduce our current requirement for industrial nitrogen production. Even in the advanced world, where agricultural productivity remains dependent upon the use of more productive types and hybrids, inorganic nitrogen application is on the rise (Mahmud *et al*., 2020). N_2-fixing plants, according to Graham and Vance (2000), require more phosphorus than plants receiving mineral N fertilizer due to the development of nodules and associated signal transduction pathways, and the presence of phospholipids in bacteroids. It is therefore possible to improve nodulation with the use of phosphorus fertilizer (Abbasi *et al*., 2010).

Bradyrhizobium japonicum, according to Okogun *et al.* (2005), maybe rare in Ghanaian soils since soybeans are an exotic crop. Moreover, Bradyrhizobia populations are erratic in soils where soybeans have never been planted, therefore nodulation of soybean may require specific Bradyrhizobium species for successful N_2 fixation.

Legumes must, however, establish a symbiotic connection with rhizobia bacteria to fix nitrogen. In addition to boosting agricultural output, increasing the quantity and efficiency of nitrogen fixation could cut fertilizer costs. To optimize this symbiosis, it may be important to improve the selection of the host and the rhizobia involved. A 10

% improvement in nitrogen fixation from better cultivars of legumes can be achieved by improving the genetic capability of the plants to fix nitrogen according to Giller and Cadisch (1995).

This occurs when host plants emit flavonoids and microbes at the time of nodulation This protein recognizes flavonoids and initiates Nod factor synthesis through the use of products from several genes that code for this protein (Date and Halliday, 1987). The nod factor, on the other hand, initiates early nodulation activities.

When it comes to leguminous crops, N production is determined by a variety of factors, including the soil type, crop development circumstances, and management approaches (Jensen and Hauggaard-Nielsen, 2003).

Through their ability to build a bridge between the roots and soil, mycorrhizae improve crop yield and improve fertilizer efficiency (University of Washington, 2006). An organic fertilizer, mycorrhiza (of the Endogone family) is a mutually beneficial interaction between mycorrhizal fungi and higher plants.

Soybeans will remobilize N stored in leaves to the grain if the total N supply does not match their needs, which reduces the canopy's photosynthetic capability and decreases output potential. Van-Kessel and Hartley (2000) also propose that N_2 fixation increases in high-yielding situations because nitrogenase, which is located in the nodules, will change its activity based on demand from the legume.

It was found by Anne Sophie *et al*. (2002) that mineral N in the soil reduced symbiotic nitrogen fixation, however, it was only relevant to the commencement of nodulation and N2 fixation at early vegetative growth if the concentration was low.

Soybean exhibits a high requirement for nitrogen up to 80 kg N per 1000 kg of soybean grain for optimal development and grain productivity, according to studies on N_2 fixation in soybean using different techniques (Ronner *et al.*, 2016). From 0 to 450 kg N ha^{-1}, soybeans can fix nitrogen from the environment (Giller, 2001). BNF can provide 60 to 70 % of the soybean's N requirements in suitable settings for N fixation. (Herridge *et al.*, 2008) while the rest could come from the soil's nitrogen stock. In contrast, Mapfumo *et al.* (2011) found that BNF in impoverished soils, which are widespread in smallholder farming systems in Sub-Saharan Africa, can be as low as 5 kg N ha^{-1}. Even for legume crops, this would suggest a need for nitrogen fertilizers.

When inoculated with a suitable strain of rhizobia, a soybean nodule forms approximately 10 days after sowing and grows about 3mm until about 20 days after planting, when the nodules begin to fix nitrogen (Sato *et al.*, 2001).

2.7 Biomass accumulation

In both the field and the greenhouse, nitrogen application influenced shoot biomass at harvest, with TSP plots having the most biomass. Similar gains in soybean shoot biomass production have been found in other trials using TSP fertilizer (Asia *et al.*, 2005). Katulanda, (2011) also found that nitrogen application at either the vegetative or flowering stage increased pod and crop biomass by 44 and 16 %, respectively.

Furuhata *et al.* (2011) proposed that increasing the availability of nitrogen (N) in the soil may help to mitigate the growth loss caused by excess water. As a result of lower leaf area development, biomass accumulation under excess water appears to be reduced in the early stages of plant growth. One way to do this is by increasing the number of plants in the area. Soybean dry weight was shown to rise only with the addition of N fertilizer in both years by Córdova *et al*. (2020)

Plants in severe asymmetric competition, according to Yang *et al.*, (2019), allocate more of their biomass to plant components that give them a competitive edge in accessing resources in scarcity (such as moisture and light). In this way, plants may allocate more assimilates to below-ground tissues (such roots) and structural supports (e.g., stems and petioles). The asymmetric competition resulted in the out competition of the weaker plants, resulting in favorable morpho-physiological reactions in the vigorous plants (Mellendorf, 2011). Koester *et al.* (2014) also discovered that contemporary soybean cultivars had more efficient canopies that intercepted light, turned light energy into aboveground biomass, and partitioned biomass into seeds. Plants accumulate biomass either by increasing the number of cells or by expanding the number of cells (Matte Risopatron *et al.*, 2010).

Plant architecture and biomass can be improved by dissecting the regulatory network that controls cell wall biosynthesis (Gonzalez *et al.*, 2012). Plant cell wall polymers, which are a substantial component of plant biomass, have also received a lot of attention in recent years. During plant growth and stress, the nature and number of these polymers in the cell wall change (Zhong and Ye, 2007). A better knowledge of these microorganisms' role in improving abiotic stress tolerance and increasing biomass output in plants is, however, required (Pump and Conrad, 2014). Diverse bacterial species, belonging to different genera, have been proven in numerous studies to contribute to host plant tolerance against various abiotic stimuli, resulting in increased biomass (Grover *et al.*, 2011).

2.8 Water use efficiency

The water usage efficiency (WUE) of a plant can be expressed as the quantity of biomass accumulated per unit of water used. As a well-known physiological feature, water usage efficiency in soybeans has been linked to drought tolerance (Hatfield and Dold, 2019). There is some evidence that WUE can contribute to crop productivity during drought, according to Wright *et al.* (1994). It was also found that in a drought environment, WUE and total biomass production were positively connected. According to him, a crop plant's WUE should only improve yields provided a high harvest index is maintained.

Since the 1950s, global water consumption has risen, but freshwater supply has decreased (Gleick, 2003). Due to population growth, half a billion people will live in nations that are water-stressed or water-scarce by 2030. About 80% of the water used in the world is used in irrigation agriculture (Molden *et al.*, 2013). Demand for irrigation water to support agricultural production and home and industrial needs will increase as the world's population and income expand. Around 9 billion people are expected to live on the planet by 2050, according to projections.

40 % of the world's food is produced on only 19 % of the world's agricultural area that is irrigated (Molden, 2007) such that there have been significant socio-economic gains (Evenson and Gollin, 2003). Food security in the future will depend on the availability of water for agriculture. Due to an increase in non-agricultural water demand, such as urban and industrial usage together with increased environmental concerns, irrigation water demand has been scrutinized more closely and food security has been put at risk. Already, water scarcity has become a major issue in many regions of the world (Fedoroff *et al.*, 2010). There is also a growing public concern that food security has significant environmental footprints (Khan and Hanjra, 2009). Growing irrigation water demands over the past several decades have resulted in altered river flow patterns, a reduction in land cover, and consequently a decline in stream water quality.

Breeding for high seed output and drought tolerance is currently a major focus of research. It is important to have a high water use efficiency (WUE) that results in high yields per unit rainfall in many production systems and is typically related to crop drought resistance (Richards et *al.*, 2002). However, identifying high-yielding crop cultivars with better WUE is complicated since WUE linked with reduced water use typically results in lower yields (Blum, 2005). WUE expansion in crop breeding projects could be useful only if it is linked to high biomass and/or yield; one way to achieve this would be to select WUE based on enhanced biomass output rather than reduced water use (Specht *et al.*, 2001). Water use efficiency (WUE) was increased in soybean in water-limited conditions, although the physiological mechanisms are not well understood. Drought stress is often detected and responded to by the plant's roots first (Fenta *et al.*, 2014).

Traditionally, water use efficiency (WUE) concentrates on inefficiency under drought situations and ignores evaluations of how efficiently the agricultural system uses water when it is ample (Lobell *et al.*, 2014) through the flow of water by evaporation, drainage, and runoff.

2.9 Mutagenesis

Mutation breeding is the act of producing genetic variability by chemical and physical mutagenesis to produce new types (Lundqvist *et al.*, 2012). The efficiency of gamma radiation in improving plant growth, seed quality, cooking time, and physiological processes are closely related to the dose levels used (Lima *et al.*, 2011). It was found that Gamma radiation at 0.4% KGy resulted in the largest increase in the plant growth and seed output of Okra in comparison to other radiation doses. There has been very little usage of gamma radiation in the breeding of high-yield soybean cultivars (Lima *et al.*, 2011). A study published by Addai and Safo-Kantanka (2006) subjected three soybean varieties to differing levels of gamma radiation (0, 50, 100, 150, 200, 250, and 300 Gy). 250 Gy was shown to have a 50% reduction in emergence percentage and seedling height when compared to the control (zero Gy). Thereby determining the best dose for induced mutation in each of the genotypes that were studied.

Breeding for mutations has become a popular method in plant breeding in recent years as a means of increasing crop varieties' genetic diversity, biochemical composition, and growth and development characteristics. Recombinant and transgenic breeding technologies are the other two mainstays of modern plant breeding. GMOs and conventional breeding methods are out of the question because of their risks and costs, whereas mutation breeding procedures are safe and relatively inexpensive (Jain, 2010).

Mutations are responsible for all genetic changes in any creature, including plants. (Kharkwal, 2012). Variation is used as a raw material by natural selection, and it is also a driving factor in evolution. Although spontaneous mutations are uncommon and unpredictable, they are more difficult to utilize in plant breeding attempts (Lonnig, 2005). For several traits, mutant variants with large and minor phenotypic implications arise using this strategy (Kharkwal, 2012). Mutation breeding is the technique of using chemical and physical mutagenesis to create genetic heterogeneity to create new types. It is now a pillar of modern plant breeding, alongside recombinant breeding and transgenic breeding (Shu *et al.*, 2012).

Genetic diversity for crop breeding and functional investigation of a specific gene, on the other hand, comes from several mutant alleles. The process of discovering people with a target mutation is the most important part of mutant breeding, and it involves two primary steps: test-for-mutants and confirm-for-mutants (Forster and Shu, 2012).

To improve soybeans, one of the most important technologies is mutation breeding. Effective and efficient mutagens must be selected to ensure the high frequency of desirable mutants (More and Borkar, 2016). It's been proven that gamma rays are more cost-effective than other ionizing radiations due to their ease of accessibility as well as their penetration power. Because of the high penetration strength of the gamma rays, they can be used to improve a wide range of plant species (Moussa, 2006b).

It is estimated that there are at least 3212 mutant species, according to FAO and IAEA statistics from 2011. Gamma and X-rays are the most commonly employed physical mutagens (Mba *et al*., 2012; Mba and Shu, 2012). The fact that these programs are easy to use plays a major part in their spread. Coriander is one of the plants that has benefited from the use of gamma radiation treatments (Salve and More, 2014), tomato (Sikder *et al*., 2013), Anthurium (Puchooa, 2005), and mungbean (Sangsiri *et al*., 2005). In the Urd bean study, this is evident (*Vigna muno* L.) The use of gamma rays at low doses was more effective in 2010, however, mutant plants can only be obtained when it is combined with sodium azide (Makeen and Babu, 2010). When used in vitro, the radiation approach is a powerful tool for creating variety and rapid mutant growth, as well as obtaining disease-free mutants. There have been effective applications of this mixture on date palms, apples, sweet potatoes, and pineapple (Fao *et al*., 2001).

Asexual hybridization and mutagenesis have successfully recombined the required genes from the existing accessible gene pool and related plant species, resulting in new cultivars with desirable features such as high yield, and abiotic, and biotic stress resistance. Caused mutations are used for plant breeding to increase the number of varieties that are available. The frequency of spontaneous mutations is extremely low, making it difficult for plant breeders to take advantage of them. One of the key advantages of mutation breeding is the ability to identify mutants with various features. Mutant variants have a considerably better chance of surviving in climates that are subject to rapid shifts in temperature. Before any new cost-effective techniques are discovered that are publicly available without too many constraints, using nuclear technology to develop new types under changing climate circumstances would be the optimum way (Jain, 2010).

Mutagenic populations had significantly higher phenotypic and genetic coefficients of variation and heritability estimates in the broad sense, Kumar and Dubey, (2001) reported. According to Pavadai *et al*. (2010), mutagen-treated plants had higher variability, heritability, and genetic progress as a percent of mean than untreated plants for all generations studied.

However, genetic improvement depends on the amount of genetic diversity in the population (Herwibawa *et al*., 2014). As a result, there are several ways to create mutation and intentionally enhance diversity. These include chemical mutagens like sodium azide or ethyl methanesulfonate as well as physical mutagens like gamma rays and neutron radiation (Sikora *et al.*, 2011). When used in conjunction with selective breeding, induced mutation can be a very successful technique to discover new features in animals. Selective breeding combined with induced mutations is the only way to uncover new traits (Chen *et al*., 2016). Identifying gene function requires the use of mutants (Zhu *et al*., 2005; Gabrielson *et al.*, 2006) model and non-model plant species have been successfully employed to study gene function (Cui *et al.*, 2013). Plant genomes can be mutated in a variety of ways, including chemical, radiation, and transformation-induced mutagenesis.

This means that most mutation research includes examinations of how chromosome breaking occurs, what types of aberrations occur, and what genetic consequences result from those aberrations (Gobinath and Pavadai, 2015).

2.10 Varieties of soybean have already been released

It was in 2003 that the Savanna Agricultural Research Institute of Ghana (SARI) released the Jenguma soybean variety to increase soybean output in Ghana's northern area. A part of the Council for Scientific and Industrial Research (CSIR) program in Ghana, SARI is based in Nyankpala, Ghana. In the local Lobi dialect, 'Jenguma' means 'wait for me', hence the variety name. Tax 1445-2E is the most extensively farmed soybean variety in Ghana and has an official designation of Tax 1445-2E (Salifu, 2003). It was developed to survive the harsh climate of the region. As a result of its high oil and pod shatter-resistance, Jenguma is also effective against *Striga hermonthica*, a weed that hampers agricultural performance and production in Ghana. (Fosu *et al.*, 2012). It has great nutritional and economic worth, as it contains 40% protein and 20% oil, and it is also useful for industrial uses.

Other media maturing soybean varieties found in Ghana include "Salintuya-1," "Anidaso," and "Quarshie" (101-110 days). The Nangbaar type matures quickly, usually in less than 100 days, but the “Jenguma” variety matures slowly (110-115 days). Salintuya-1 and Anidaso have grain yields of 1.2 – 1.8 t/ha (12 – 18 bags/ha), Nangbaar is 1.5 – 2.5 t/ha (15-25 bags/ha), and Jenguma has a grain output of 1.7 – 2.8 t/ha (17-28 bags/ha) (Asafo-Adjei *et al.*, 2005). Afayak, also described as TGX 1834-5E, is a Striga-resistant variety with a maturity period of 110-115 days and a potential yield of

2.0-2.2 t/ha Jenguma has an average plant height of 65 cm and takes 45 days to flower 50% of the time, according to Denwar and Mohammed (2008)

Since 2002, the Soybean Breeding and Seed Systems Program has successfully bred, developed, and released improved high-yielding, early maturing, and rust-resistant soybeans with support from the Ministry of Agriculture, Animal Industry, and Fisheries - Vegetable Oil Development Project (MAAIF - VODP), Alliance for a Green Revolution in Africa (AGRA), and Regional Universities Forum for Agricultural Development (RUFORUM). Maksoy 1N and Namsoy 4M (2004), Maksoy 2N (2008), Maksoy 3N (2010), Maksoy 4N and Maksoy 5N are the variations in order of release (2013). Simultaneously, seed multiplication and dissemination, as well as capacity-building, have been done to boost soybean yield, raise soybean income, and encourage local production to address protein deficiency among smallholder households.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site

The research was carried out in Nyankpala, which is part of the Guinea Savanna agro-ecological zone. With Average annual rainfall was 1,092 mm and widespread from April to November, the area enjoys unimodal rainfall (Awuni *et al.*, 2020)

Rainfall in this region begins in April-May and peaks in July and September. It drops precipitously in October and has no rain in November (Lawson *et al.*, 2013). According to the United States Development Agency method of categorization, the soil in the study area is an Alfisol, while according to the Ghana System of classification, it is a savanna Ochrosol. The soil is a brown, well-drained sandy loam free of concretions, very shallow with a hardpan beneath the top few centimeters, and belongs to the Nyankpala Series, which was formed from Voltaian sandstone (Awuni *et al.*, 2020)

Temperatures are relatively constant throughout the year ranging between 25 ^{0}C and 32.4 ^{0}C with a mean monthly minimum temperature of 23.1 ^{0}C and a mean monthly maximum temperature of 324 ^{0}C. Similarly, relative humidity figures for the study area show high humidity from May to October with a mean monthly minimum relative humidity of 53% and a mean monthly maximum relative humidity of 80% (Tangonyire, 2019).

Vitellaria paradoxa, Parkia biglobosa, Acacia albida, Anogeissus leiocarpus, Adansonia digitata (baobab), Tamarindus indica, Mangifera indica, and Ceiba *pentandra* are the most prevalent tree species that are dispersed and typically protected (Abubakari, 2012)

Table 1: Rainfall, temperature, and relative humidity during the 2019/2020 cropping season at the experimental site.

Month	Rain Freq.	Total Rainfall (mm)	Average Rainfall (mm)	Temperature (°C)		Relative Humidity (%)	
				Minimum	Maximum	Minimum	Maximum
January	0	0	0	19.78	37.00	29.06	56.23
February	0	0	0	21.58	38.11	26.72	52.55
March	3	95.4	31.8	26.83	37.96	46.94	73.61
April	0	0	0	25.86	35.70	59.17	84.17
May	6	98.7	16.45	25.52	34.92	62.52	88.52
June	14	257	18.36	24.60	31.75	68.00	93.00
July	8	336.4	42.05	24.21	29.93	73.16	93.03
August	9	240.2	26.69	23.58	30.20	73.48	92.71
September	14	256.7	18.34	23.78	30.65	73.87	94.80
October	10	133.9	13.39	23.39	32.45	71.58	93.87
November	0	0	0	21.82	36.42	49.80	87.87
December	0	0	0	21.64	37.18	41.32	78.58

3.2 Agronomic practices

3.2.1 Planting materials

Mutant soybean genotypes from the Department of Crop Science of the University for Development Studies were used for the study. Two experiments were carried out. One of the experiments (Experiment I) was set up during the drying season of 2020 in pots and the other experiment (Experiment II) was carried out in the field during the rainy season of 2020.

3.2.2 Experiment I

The factors involved were Genotypes (150 Gy, 200 Gy, 250 Gy, 300 Gy, and standard check-Jenguma) and, water application (100 %, 80 %, 60 %, 40 %, and 20 % WUE), where the WUE of soybean is 700 mm (Dogan et al., 2011) and Mulching (0 t/ha, 20 t/ha 40 t/ha and 60 t/ha of rice straw). Treatment combinations of the above factors were replicated 3 times in RCBD

3.2.3 Experiment II

Five levels of genotypes (150 Gy, 200 G, 250 Gy, and 300 Gy Jenguma as a check) were planted using two planting dates (17th of June and 17th July, 2020.). Four levels of mulching (0 ton/ha, 20 ton/ha 40 ton/ha, and 60 ton/ha of rice straw were used. For each planting date, the plots were measured 5 m × 4 m. The alleys between the plots were 0.50 m whilst 1 m was allowed between replications. The planting distance was 50 cm × 20 cm.

3.2.4 Land preparation

The experimental sites were ploughed with a tractor in June 2020. The sites were manually leveled after ploughing and demarcations were made using a tape measure and garden pegs. The blocks and plots were labeled accordingly.

3.2.5 Planting

Experiments I (pot experiment) was planted on the 5th of March 2020 and Experiment II (field studies) which consisted of two plantings were planted on the 17th of June and 17th of July, 2020, for the first and second planting dates respectively.

3.2.6 Water application

Water application at four levels was made three times within the week.

3.2.7 Mulching

Both Experiment I (pot experiment) and experiment II (field experiment) were mulched with rice straw two weeks after planting. The soil temperature was recorded at every three-day interval.

3.2.8 Weed control

Weeds were controlled on the 3rd, 6th, and 9th weeks after planting by hoeing and handpicking. No insect pests were observed.

3.2.9 Harvesting

Depending on the variety, soybeans were due to be harvested 3-4 months after planting. The maturity of soybean was determined through the yellowing and dropping of the lower and the upper leaves. Harvesting was carried out by hand. The soybean was uprooted and piled into smaller heaps when it reached maturity. After that, the heaps were relocated to a tarpaulin on the ground. After that, the plants were threshed by pounding the mound with sticks until the pods broke open and the beans spilled out. Winnowing was used to remove the beans from the chaff.

3.3 Experimental design

The design used 5×4×2 factorial experiments laid out in Randomized Complete Block Design (RCDD) with three replication in field studies.

3.4 Determination of water use efficiency of soybean

Harvesting plants and estimating the dry weight of the vegetative portion of grain were used to determine water use efficiency. Because the roots required to be rinsed clean of soil, the roots and shoots were picked separately. They were bagged and dried down to constant weight using a forced air drier set at 80° C. The WUE of the plants was calculated as the total dry matter (roots and shoots combined) divided by the water used

3.5 Data collection

The following parameters were recorded: percentage emergence, plant height, number of leaves, number of nodules, days to 50% flowering, days to maturity, soil moisture, a score of prevalence/susceptibility to common soybean diseases, soil/aerial temperature of the experimental fields, and weather parameters (relative humidity, rainfall, temperature), number of pods per plant, pod length, number of pods per plant, number of pods per plant, number of pods per plant, number of pods per plant, number of pods per plant, number of pods per plant, number.

3.5.1 Plant height

The height was recorded at weeks 3, 6, 9, and 12 after planting. Measurements were made from the base of the shoot to the growing tip of the shoot from five selected plants.

3.5.2 Number of leaves

Leaves numbers were recorded from the 3, 6, 9, and 12 weeks after planting from the selected plant.

3.5.3 Leaf area index

Both the length and width of leaves were recorded and the LAI was computed for 3, 6, 9, and 12 weeks after planting. The Leaf area index was computed as follows:

(TLA) = Leaf length * leaf width

$$\text{Leaf Area Index (LAI)} = \frac{\text{TLA} \times \text{nLv} \times \text{constant}}{\text{PD}} \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where:

LAI is the Leaf Area Index

TLA is the Total Leaf Area

nLv is the number of Leaves

PD is the planting Distance

LAI constant =0.69 for soybean plant as described by Konadu, (2014)

3.5.4 Nodule count

Two plants were randomly uprooted for their nodules to be counted and recorded.

3.5.5 Days to 50% flowering

The number of days for individual plants to produce flowers till half of the total plant population on each field flowered was recorded.

3.5.6 Biomass accumulation

The shoot and root biomass of the soybean plant was measured. The fresh weights of the root and shoot were recorded after they were separated. They were subsequently dried for 24 hours at 80°C in the oven, and their dry weights were recorded as well. The dried samples' root and shoot dry weights were calculated by weighing them again.

The dry weights were determined as follows according to Fallis, (2013)

$$\mathrm{DMY(kg/ha)} = TFW(kg) \times \frac{1000\ (m^2/ha)}{H\ (m^2)} \times \frac{SDW\ (kg)}{SFW\ (kg)} \quad \ldots\ldots\ldots\ldots\ldots\ (2)$$

Where:

DMY is the dry matter yield

TFW is the total fresh weight

SFW is the shoot fresh weight

SDW is the shoot dry weight

Root-Shoot ratio (dry weight) was also given by:

$$RS = \frac{\mathrm{RDW}}{\mathrm{SDW}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

Where:

RS is the root-shoot ratio

SDW is the shoot dry weight

RDW is the root dry weight

3.5.7 Soil moisture

Soil moisture was measured every two days by tensiometers pre-calibrated for this soil type for the field.

Similarly, soil temperature was measured every alternate day using stainless steel Fisher brand bi-metal dial thermometers, having a stem length of 20.3 cm, a gauge diameter of 4.5 cm, and an accuracy of 1.0% of dial range at any point of the dial.

3.5.8 Days to maturity

The number of days it took for each genotype and the standard check to reach maturity were recorded.

3.5.9 Number of pods per plant

A random selection was done at harvest where five plants were selected from each plot and their pods were counted for averages to be computed.

3.5.10 Number of seeds per pod

Ten pods were selected randomly at harvest from each plot. The seeds from each sampled pod were counted and their averages were recorded.

3.5.11 Hundred seed weight

A hundred seeds from each treatment combination were selected and weighted using an electronic balance. The weights were recorded in grams.

3.5.12 Total grain yield

Seeds obtained from each experimental unit were weighed using an electronic balance and later converted to tons per hectare. The grain yield per hectare for each treatment was determined as follows according to Fallis, (2013)

$$TGY\ (kg/ha) = \frac{GYM\ (g)}{H\ (m^2)} \times \frac{10000\ (m^2/ha)}{1000\ (g/kg)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Where:

TGY is the final grain yield,

GYM is the grain yield from each pot

H is the area of the pot.

3.6 Data analysis

The data for all the parameters collected in the study were subjected to ANOVA. Means were separated using Least Significance Difference (LSD) at 5%. Results were presented in tables and graphs

CHAPTER FOUR

RESULTS

4.1 Experiment I

4.1.1 Soil temperature

The temperature of the soil varied significantly ($P < 0.05$) between the various mulching levels. The plots without much recorded the highest soil temperature in March but increased in April but decline from May to June (Figure 1).

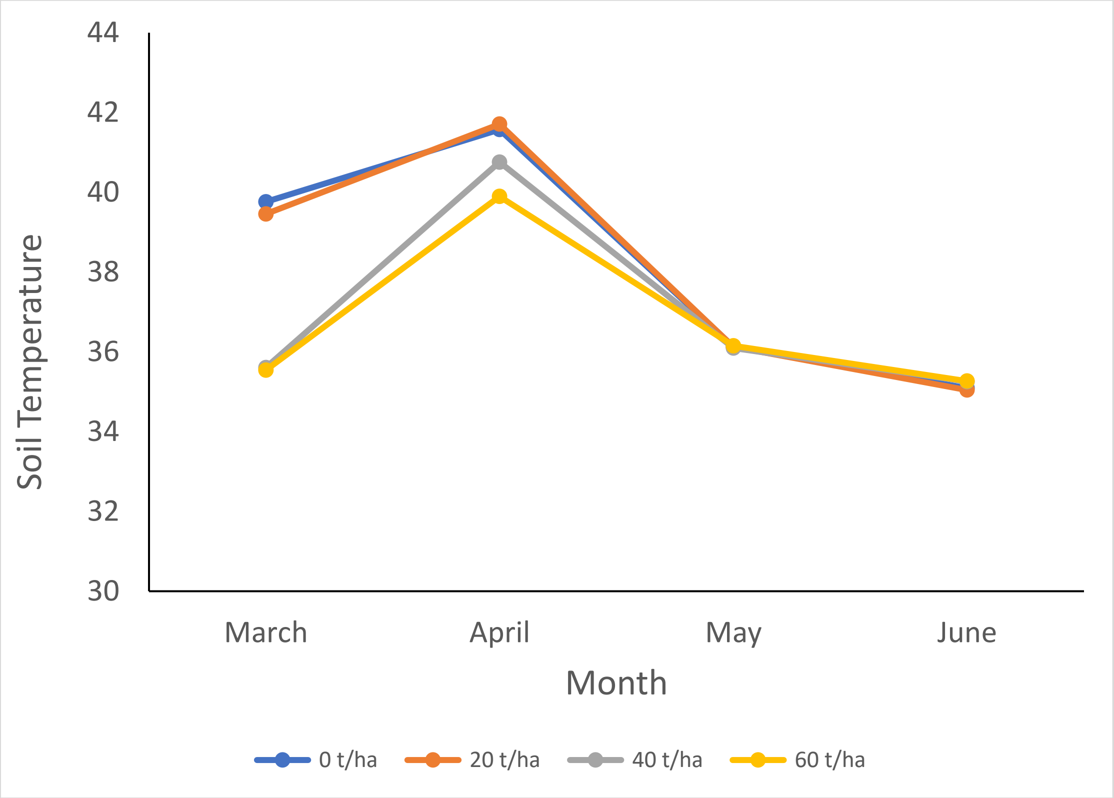

Figure 1: Variation in soil temperature from March to June

4.1.2 Chlorophyll

A significant difference ($P < 0.05$) was observed for the genotypes × water application × mulching for chlorophyll content. The Genotypes 150 Gy applied with 60 % WUE without mulch recorded the highest chlorophyll content followed by the same genotype applied with 40% WUE with 60 t/ha of mulch while the 200 Gy applied with 60 % WUE of water without mulch recorded the lowest of chlorophyll content (Table 2)

However, the single effects, genotype, water application, and mulching did not differ significantly ($P > 0.05$).

Table 2: Genotypes × water application ×mulching for chlorophyll content (spad unit) during the dry season of 2020

		Mulching			
Genotypes	Water application (% WUE)	0 t/ha	20 t/ha	40 t/ha	60 t/ha
Jenguma	20	24.10	11.07	34.72	32.07
	40	21.60	26.17	28.68	21.93
	60	32.13	22.43	33.75	13.50
	80	19.83	30.28	35.72	33.27
	100	23.82	31.00	35.03	21.00
150 Gy	20	23.13	24.00	34.30	34.68
	40	22.63	11.83	35.30	35.93
	60	38.30	12.80	32.88	31.60
	80	24.40	21.77	24.13	25.27
	100	24.43	22.47	32.70	34.15
200 Gy	20	19.23	13.00	24.07	35.83
	40	34.27	12.73	20.03	31.17
	60	7.00	33.33	24.77	21.70
	80	20.03	22.17	33.98	19.43
	100	34.80	33.83	31.90	20.07
250 Gy	20	33.40	21.47	20.82	20.73
	40	7.30	20.80	19.75	35.63
	60	17.45	28.48	20.52	23.00
	80	33.73	22.90	32.37	30.07
	100	18.50	20.68	11.97	16.97
300 Gy	20	23.33	13.67	34.33	12.29
	40	24.97	23.13	23.58	32.08
	60	23.97	23.87	32.97	34.63
	80	33.80	22.17	21.10	36.60
	100	32.57	22.00	34.17	32.63
LSD (0.05) = Genotypes × water application × mulching = 23.840					

4.1.3 Leaf area index

There was significant ($P < 0.05$) variation for mulch for leaf area index 6WAP. The crops treated with 60 t/ha mulching recorded the highest leaf area index followed by those treated with 40 t/ha whereas the crops that were not mulched recorded the lowest leaf index (Figure 2).

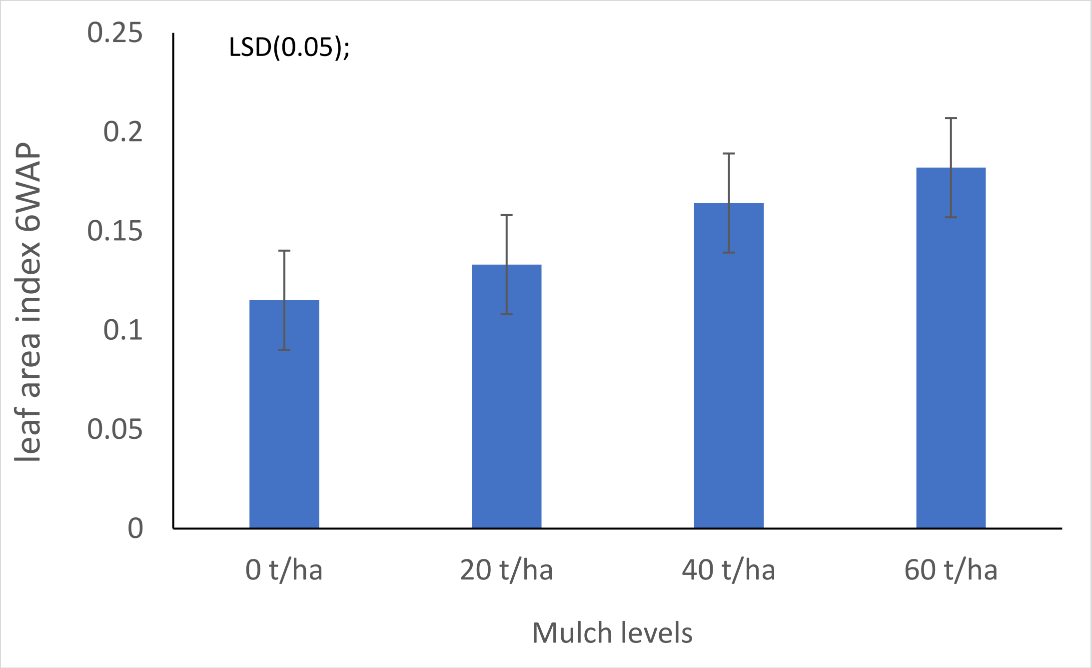

Figure 2: Leaf area index of soybean (*Glycine max* L. Merrill) genotypes during the dry season of the 2020

Among the water application rates, there was a significant difference ($P < 0.05$) in the leaf area index. Plants with 60% water application recorded a higher leaf area index as compared to the plants treated with the other water application level (Figure 3)

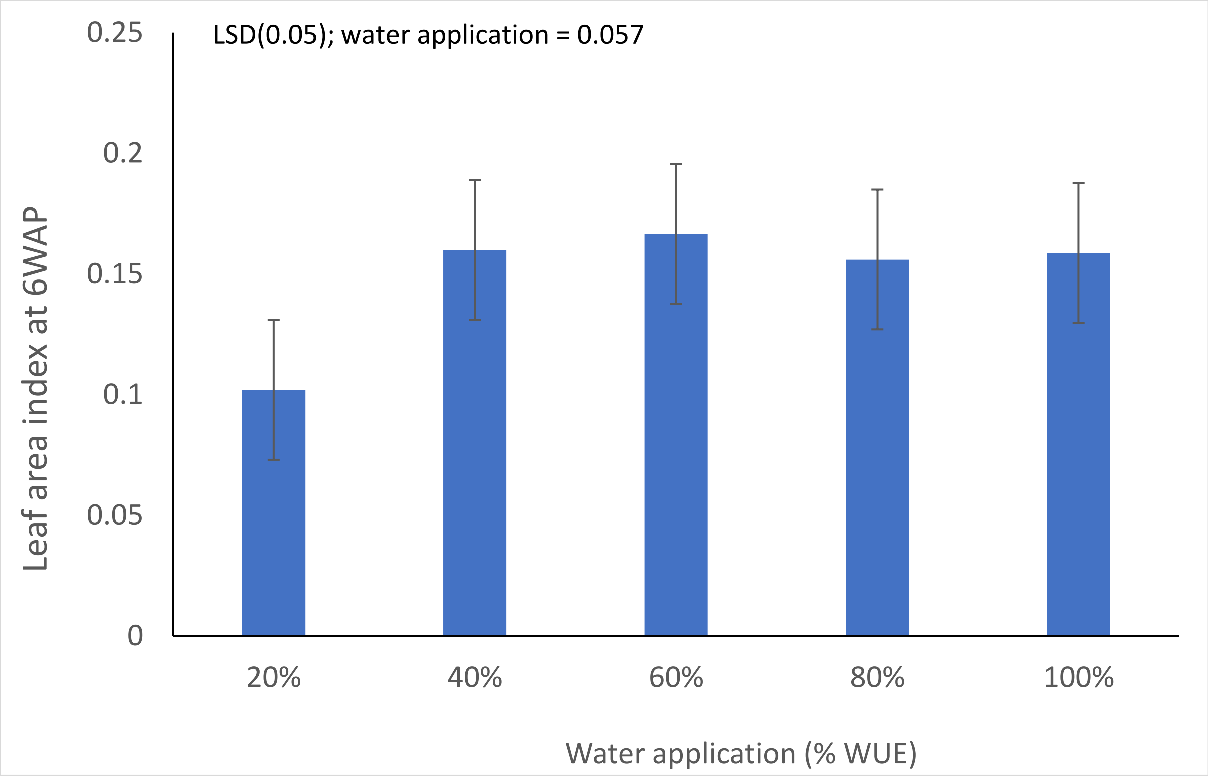

Figure 3: Leaf area index of water application (WUE) soybean (*Glycine max* L. Merrill) genotypes during the dry season of 2020

The interaction for genotypes, water application, and mulching for leaf area index varied significantly ($P < 0.05$) . The 150 Gy applied with 40 % WUE and with 60 ton/ha mulching recorded the highest leaf area index followed by 300 Gy applied with 60 % water application with 60 t/ha. However, plants from the 150 Gy with 100% water application and mulched with 40 t/ha recorded the lowest leaf area index (Table 3)

Table 3: Genotypes × water application ×mulching for leaf area index 6 WAP during the dry season of 2020

Genotype	Water application (% WUE)	Mulching			
		0 t/ha	20 t/ha	40 t/ha	60 t/ha
Jenguma	20	0.15	0.12	0.05	0.12
	40	0.15	0.32	0.26	0.25
	60	0.17	0.02	0.25	0.14
	80	0.13	0.13	0.28	0.23
	100	0.11	0.25	0.32	0.16
150 Gy	20	0.08	0.15	0.11	0.22
	40	0.00	0.05	0.22	0.44
	60	0.15	0.16	0.28	0.21
	80	0.13	0.23	0.00	0.12
	100	0.14	0.12	0.02	0.12
200 Gy	20	0.04	0.05	0.07	0.25
	40	0.22	0.20	0.26	0.15
	60	0.20	0.15	0.13	0.19
	80	0.13	0.03	0.11	0.11
	100	0.17	0.24	0.22	0.13
250 Gy	20	0.11	0.16	0.12	0.16
	40	0.00	0.11	0.14	0.23
	60	0.12	0.42	0.16	0.04
	80	0.23	0.12	0.33	0.26
	100	0.07	0.23	0.08	0.18
300 Gy	20	0.02	0.03	0.15	0.00
	40	0.10	0.11	0.03	0.18
	60	0.10	0.10	0.19	0.35
	80	0.17	0.11	0.09	0.18
	100	0.21	0.03	0.25	0.29
LSD (0.05) = Genotypes × water application × mulching = 0.1277					

4.1.4 Leaf Area Index 12WAP

The leaf area index 12 weeks after planting varied significantly (P <0.05) for the main effects of genotype. Jenguma in week 12 after planting recorded an extremely higher leaf area index than the improved genotypes. The 150 Gy also recorded the second-highest leaf index whereas the 200 Gy, 250 Gy, and 300 Gy recorded the lowest (Figure 4).

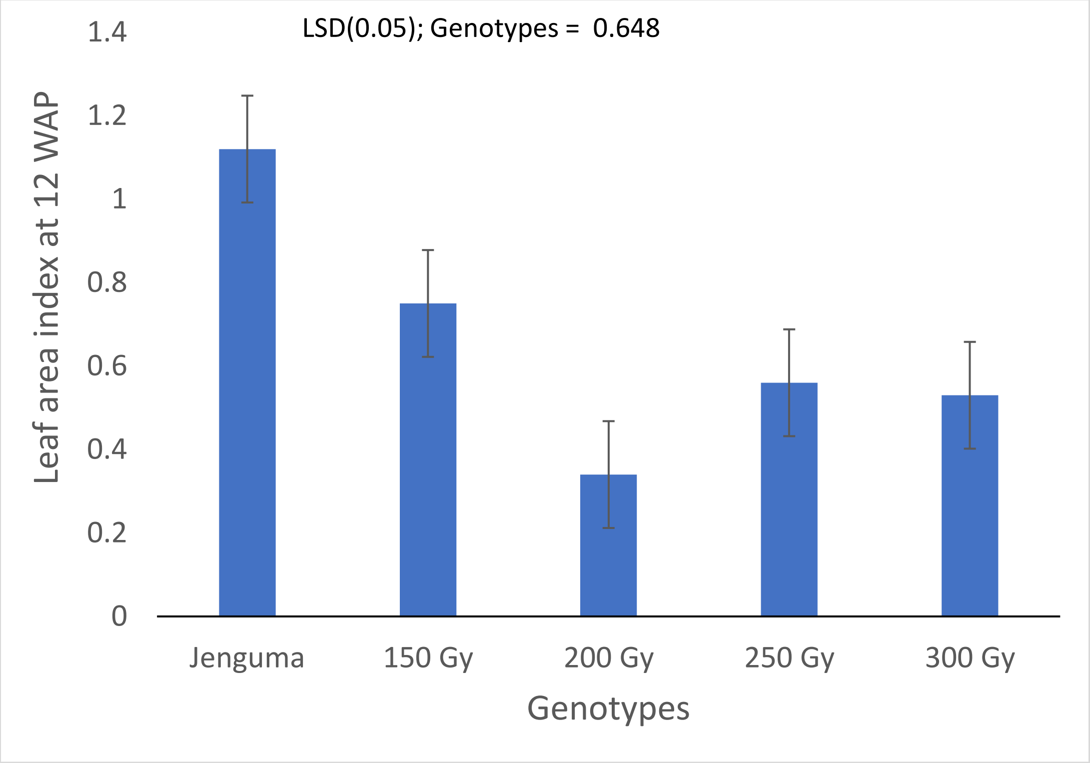

Figure 4: Leaf area index at 12 WAP of soybean (*Glycine max* L. Merrill) genotypes during the dry season of 2020.

The interaction between the Genotype and mulching also showed significant variation for leaf area index. Jenguma with no mulch recorded the highest leaf area index followed, by the 150 Gy with no mulch while the 200 Gy without mulch recorded the lowest leaf area index (Table 4)

Table 4: Interaction of soybean genotypes and mulch for leaf area index during the dry season of the 2020 cropping season

	Mulching			
Genotype	0 t/ha	20 t/ha	40 t/ha	60 t/ha
Jenguma	1.85	0.86	1.11	0.64
150 Gy	1.59	0.28	0.78	0.34
200 Gy	0.17	0.24	0.67	0.30
250 Gy	0.32	0.77	0.63	0.52
300 Gy	0.75	0.30	0.45	0.62
LSD (0.05) =Genotypes × Mulching = 0.295				

4.1.5 Number of leaves

The number of leaves of the genotypes varied significantly ($P < 0.05$) . The mutant 250 Gy at weeks 3 and 6 after planting recorded the highest height. However, a different result was observed at weeks 9 and 12 where the Jenguma took the lead as 250 Gy declined. The 200 Gy at weeks 9 and 12 after planting recorded the lowest number of leaves (Figure 5).

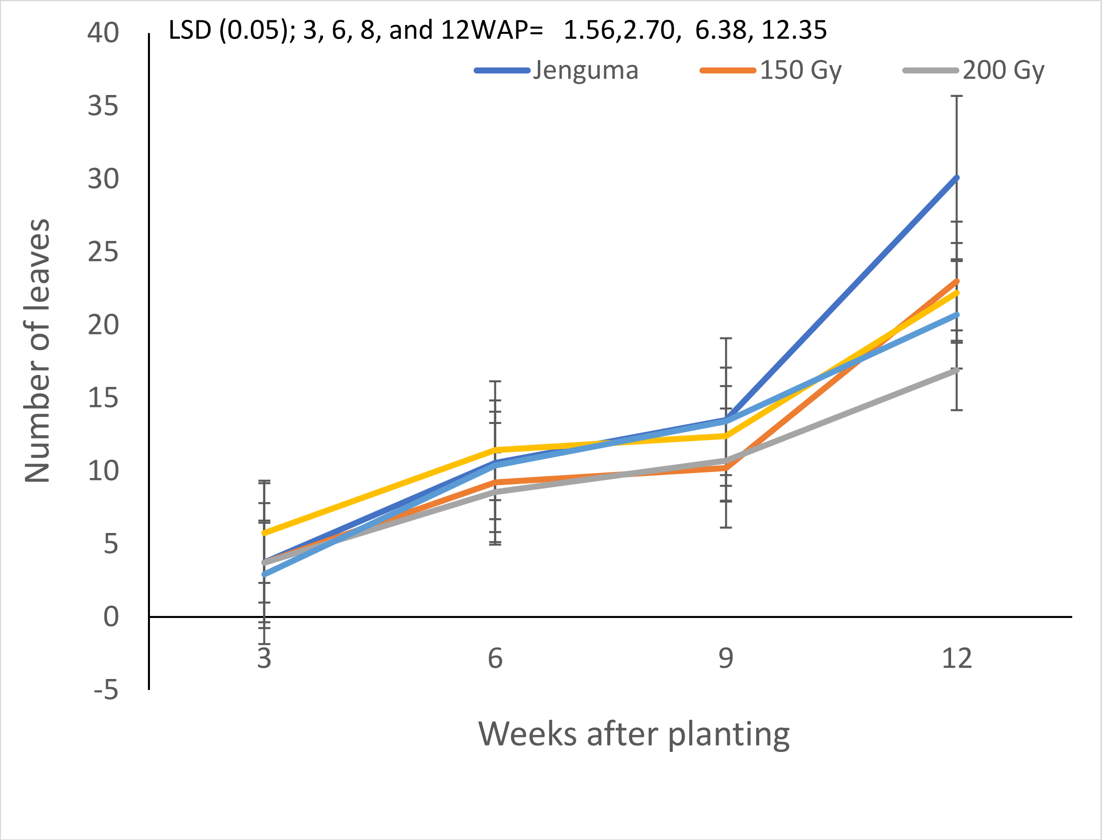

Figure 5: Leaf number of soybean (*Glycine max* L. Merrill) genotypes during the dry season of 2020

Variation was significant ($P < 0.05$) for the interaction of genotypes, water application, and mulching for the number of leaves at 3 weeks after planting. The highest number of leaves were recorded by 200 Gy applied with % WUE without mulch, followed by 250 Gy applied with 100 % and mulched at 60 ton/ha, and Jenguma without mulching applied with 40 % of the required water (Table 5).

Table 5: Soybean genotypes × mulching for number of leaves during the dry season of the 2020 cropping season

Genotype	Water application (% WUE)	Mulching 0 t/ha	20 t/ha	40 t/ha	60 t/ha
Jenguma	20	2.67	1.33	1.37	5.33
	40	0.30	6.00	3.00	2.33
	60	3.67	6.67	3.67	3.67
	80	2.67	5.67	6.00	2.67
	100	7.33	5.00	4.33	1.33
150 Gy	20	3.50	2.67	7.33	3.00
	40	0.00	0.00	8.37	2.67
	60	0.10	1.33	7.33	9.33
	80	7.00	4.33	0.67	7.67
	100	1.33	3.00	3.00	5.33
200 Gy	20	6.67	1.33	0.67	0.67
	40	6.33	2.67	6.67	0.0
	60	0.00	0.67	2.67	6.67
	80	0.00	3.33	7.67	2.67
	100	10.67	7.67	3.67	3.67
250 Gy	20	2.67	6.67	5.33	10
	40	3.67	3.67	2.67	9.67
	60	4.00	7.00	6.33	3.33
	80	4.67	2.67	3.00	6.67
	100	8.33	8.00	6.67	10.0
300 Gy	20	0.00	4.33	4.67	0.00
	40	3.33	6.33	0.00	3.00
	60	3.00	1.33	4.00	5.00
	80	1.00	4.00	3.33	2.33
	100	4.67	2.00	0.00	6.00
LSD (0.05) =Genotypes × water application × mulching = 2.980					

The interaction for genotypes, water application, and mulching showed significant variation ($P < 0.05$) for the number of leaves. The 250 Gy applied with 100 % water with 20 ton/ha mulched recorded the highest number of leaves followed by the 250 Gy at the same rate of mulch applied with 60 % WUE and Jenguma applied with 40 % WUE with 20 t/ha while 300 Gy applied with 100% with 20 ton/ha mulch recorded the lowest number of leaves (Table 6)

Table 6: Genotypes × mulching ×water application for the number of leaves during the dry season of 2020

Genotype	Water application	Mulching			
	(% WUE)	0 t/ha	20 t/ha	40 t/ha	60 t/ha
Jenguma	20	11.00	9.67	3.67	8.00
	40	7.00	19.67	10.67	10.33
	60	11.33	3.33	12.00	12.00
	80	7.67	8.00	16.33	12.67
	100	8.33	17.33	12.00	10.00
150 Gy	20	5.33	9.67	8.67	13.67
	40	0.00	5.00	13.00	17.33
	60	11.33	6.33	16.67	16.33
	80	7.17	12.33	0.00	12.00
	100	9.33	9.00	2.00	9.00
200 Gy	20	4.67	5.00	5.67	14.00
	40	14.67	0.00	13.67	6.33
	60	0.00	9.67	9.67	16.00
	80	7.67	1.67	7.00	10.00
	100	11.33	15.67	12.67	5.67
250 Gy	20	9.33	13.00	15.33	10.33
	40	6.00	8.00	6.67	13.00
	60	9.33	19.67	11.33	4.00
	80	14.67	11.67	16.67	14.00
	100	5.00	20.00	12.33	8.00
300 Gy	20	3.33	10.25	11.00	0.00
	40	13.00	5.00	3.67	14.00
	60	8.67	6.67	15.33	18.67
	80	10.00	11.67	9.67	13.00
	100	15.67	2.67	18.00	17.33

LSD (0.05) =Genotypes × water application × mulching = 12.067

The interaction between water application and mulching differed significantly ($P < 0.05$) . Plant from 60 % application of the required water for soybean mulched at 40 t/ha recorded the highest number of leaves whereas the 20% water application at 20 t/ha of mulch and 40 % of water application at 40 ton/ha recorded the lowest number of leaves (Table 7)

Table 7: Genotypes × mulching ×water application for number of leaves during the dry season of the 2020 cropping season

	Mulching			
Water application (% WUE)	0 t/ha	20 t/ha	40 t/ha	60 t/ha
20	27.45	20.10	32.74	33.69
40	33.07	27.45	20.10	32.74
60	33.69	33.07	45.87	20.47
80	41.20	21.20	38.6	38.93
100	23.73	25.00	26.67	22.93

LSD (0.05) =Genotypes × mulching = 5.396

4.1.6 Days to 50% flowering

A significant difference ($P < 0.05$) was observed in water application for days to 50% flowering. Crops applied with 80 % WUE of soybean took a smaller number of days to flower while the crops applied with 100 % water application to a greater number of days to reach 50% flower (Figure 6)

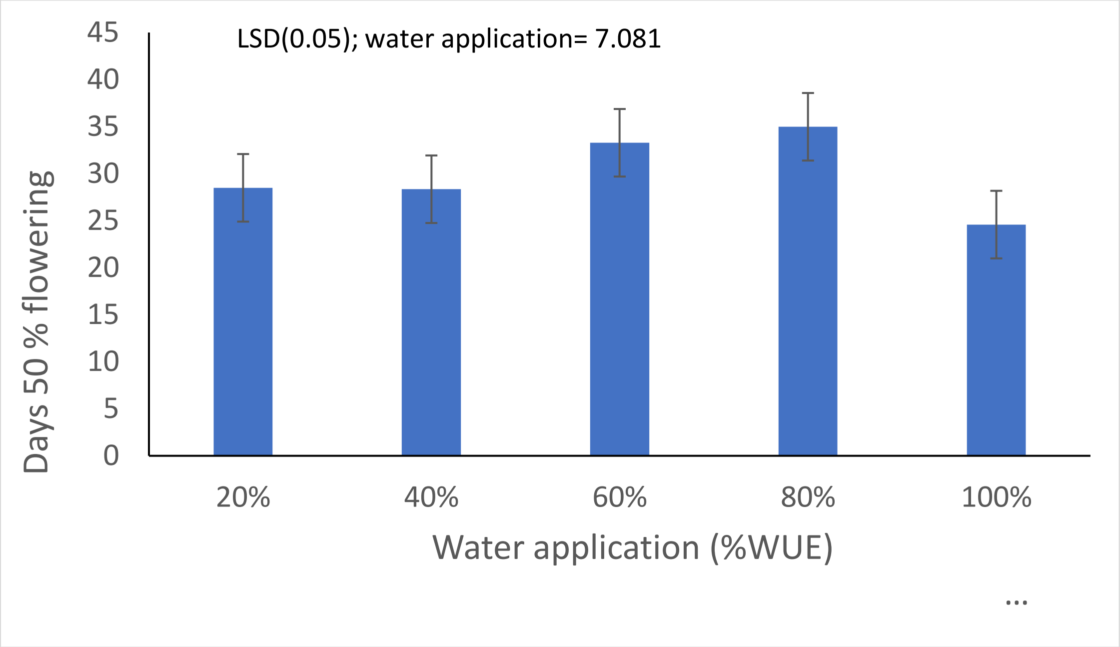

Figure 6: Days to 50% flowering of soybean (*Glycine max* L. Merrill) genotypes during the dry season of 2020

The interaction among genotypes, mulching, and water application varied significantly ($P < 0.05$) for days to 50 % flowering. The Jenguma at 40 t/ha rate of mulch applied with 60 % WUE required the most days to reach 50 percent flowering of genotypes, whereas the 200 Gy treated with % WUE without mulch took the least number of days to reach 50 % flowering of genotypes (Table 8).

Table 8: Genotypes × mulch ×water application for days to 50 % flowering during the dry season of the 2020 cropping season

		Mulching			
Genotype	Water application (% WUE)	0 t/ha	20 t/ha	40 t/ha	60 t/ha
Jenguma	20	37.57	30.40	36.80	38.13
	40	36.96	37.57	45.45	36.80
	60	38.13	36.96	62.00	15.67
	80	40.33	21.67	38.67	58.00
	100	35.67	35.00	34.00	0.00
150 Gy	20	23.00	32.30	31.43	33.07
	40	32.29	23.00	32.30	31.43
	60	33.07	32.29	53.00	19.00
	80	57.00	30.67	17.33	49.33
	100	52.00	19.33	33.00	36.67
200 Gy	20	32.97	21.25	29.90	33.46
	40	29.96	32.97	21.25	29.90
	60	33.46	29.96	36.67	15.67
	80	15.67	33.67	50.67	32.00
	100	47.33	35.67	35.00	0.00
250 Gy	20	22.23	19.63	32.97	31.90
	40	31.52	22.23	19.63	32.97
	60	31.90	31.52	39.00	15.67
	80	54.33	20.00	52.67	16.00
	100	20.67	14.00	15.67	17.33
300 Gy	20	21.47	27.30	32.58	31.90
	40	34.63	21.47	27.30	32.58
	60	31.90	34.63	38.67	36.33
	80	38.67	0.00	33.67	39.33
	100	15.00	21.00	15.67	60.67
LSD (0.05) =Genotypes × water application × mulching =31.669					

4.1.7 Vigor

The interaction for scoring for the vigor of the soybean genotypes showed significant variation ($P < 0.05$) . Jenguma applied 80 % WUE of 60 t/ha recorded the highest in terms of scoring of vigor as compared to other treatment combinations (Table 9)

Table 9: Genotypes × mulch ×water application for scoring for vigor during the dry season of 2020

Genotype	Water application (% WUE)	Mulching			
		0 t/ha	20 t/ha	40 t/ha	60 t/ha
Jenguma	20	0.20	0.00	0.16	0.50
	40	0.36	0.23	0.36	0.00
	60	0.16	0.40	0.20	0.63
	80	0.36	0.00	0.23	0.63
	10	0.20	0.40	0.43	0.00
150 Gy	20	0.16	0.16	0.20	0.30
	40	0.23	0.16	0.40	0.43
	60	0.56	0.00	0.40	0.00
	80	0.30	0.36	0.40	0.36
	10	0.00	0.20	0.32	0.56
200 Gy	20	0.00	0.20	0.20	0.20
	40	0.32	0.00	0.39	0.40
	60	0.00	0.23	0.20	0.43
	800	0.23	0.20	0.43	0.26
	10	0.30	0.20	0.20	0.00
250 Gy	20	0.20	0.20	0.20	0.20
	40	0.00	0.36	0.34	0.20
	60	0.00	0.43	0.36	0.16
	80	0.56	0.16	0.40	0.16
	10	0.16	0.39	0.39	0.39
300 Gy	20	0.16	0.36	0.36	0.00
	40	0.20	0.36	0.00	0.55
	60	0.20	0.43	0.43	0.39
	80	0.39	0.00	0.32	0.23
	10	0.00	0.40	0.36	0.56
LSD (0.05) =Genotypes × water application × mulching = 0.238					

4.2 Experiment II

4.2.1 Plant height

The plant height of the soybean genotypes varied significantly ($P < 0.05$) . Jenguma recorded the highest height. This was followed by the mutant 150 Gy and 250 Gy recorded the lowest plant height (Figure 7).

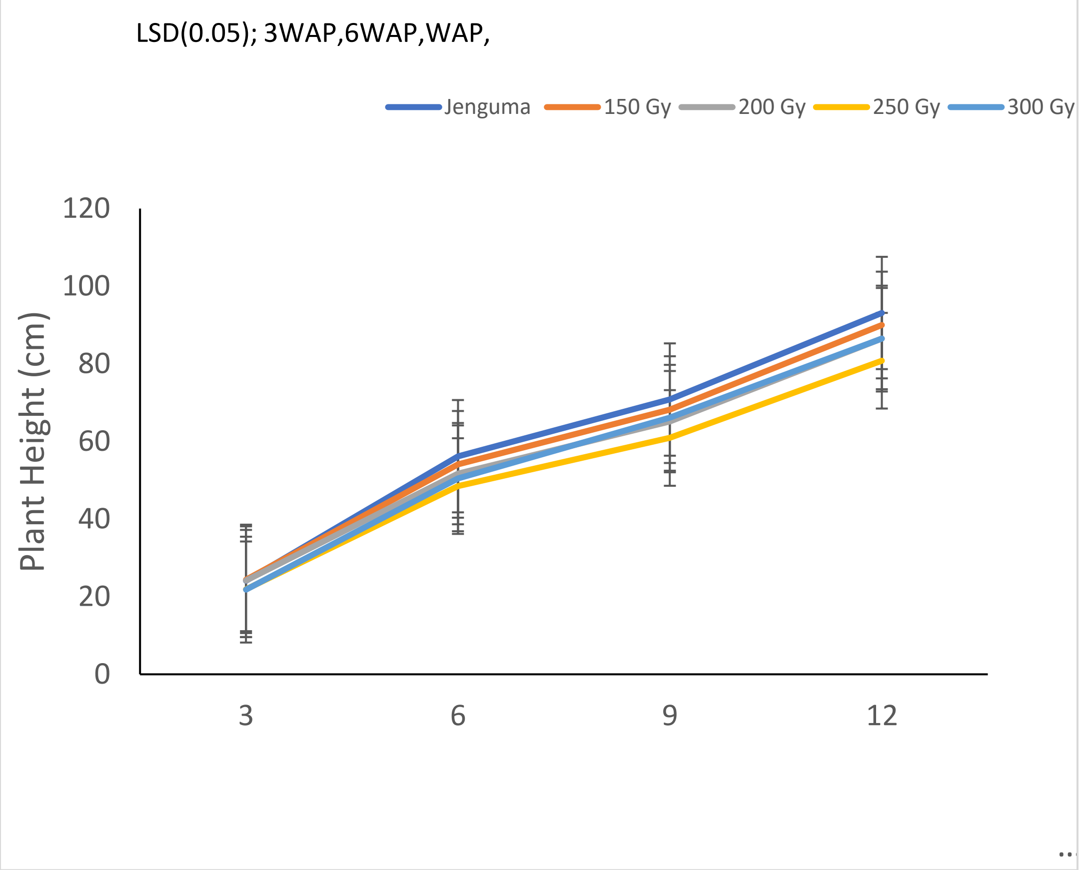

Figure 7: Plant height of soybean (*Glycine max* L. Merrill) genotypes during the rainy season of 2020.

Interaction of soybean genotype and planting date for plant height at week 3 after planting varied significantly ($P < 0.05$) . The 150 Gy recorded the highest plant height during the first planting while the Jenguma recorded the highest for the second planting. Generally, the soybean genotypes planted firstly recorded higher plant height as compared to genotypes from the second planting (Figure 8).

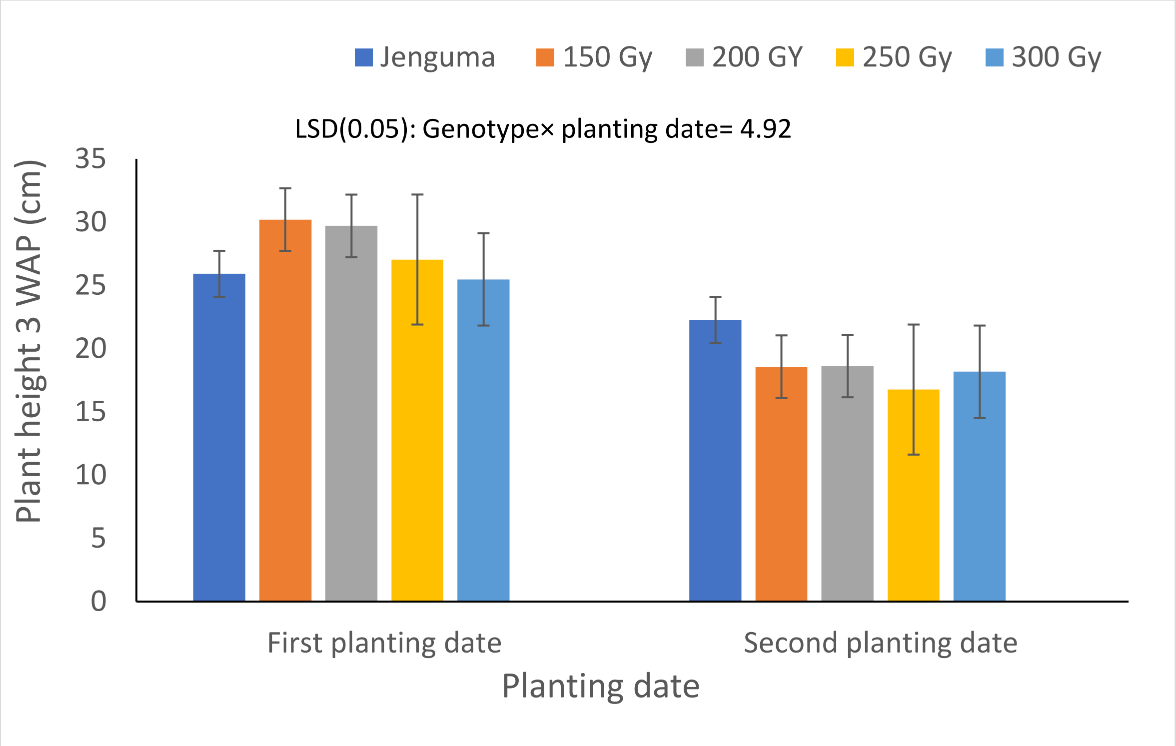

Figure 8: Interaction of soybean genotype and planting date for plant height evaluated at the field during the rainy season of 2020.

The genotype × planting date × mulching for plant height planting varied significantly ($P < 0.05$) . Jenguma with 40 ton/ha mulch for the first planting 6 weeks after planting recorded the highest plant height while the 200 Gy with 40 ton/ha of mulch from the second planting recorded less in of the height of the soybean (Table 10).

Table 10: Interaction of soybean genotype, mulching, and planting date for plant height during field experimentation of the 2020 cropping season

		Week after planting			
		3		6	
Genotype's	Mulching	First planting	Second planting	First planting	Second planting
Jenguma	0 t/ha	22.17	21.17	73.1	56.1
	20 t/ha	32.64	18.39	92.1	53.2
	40 t/ha	24.67	31.80	95.6	53.6
	60 t/ha	24.17	17.73	90.5	52.4
150 Gy	0 t/ha	32.30	16.91	86.0	53.1
	20 t/ha	33.23	19.87	80.3	65.3
	40 t/ha	27.60	19.17	81.0	52.5
	60 t/ha	27.67	18.33	81.6	45.8
200 Gy	0 t/ha	28.39	19.10	61.5	44.1
	20 t/ha	25.23	18.40	75.2	76.8
	40 t/ha	35.93	16.55	85.9	47.3
	60 t/ha	29.23	20.43	75.3	54.6
250 Gy	0 t/ha	23.18	15.19	76.5	64.3
	20 t/ha	27.19	18.45	63.2	33.2
	40 t/ha	32.63	15.27	62.7	45.3
	60 t/ha	25.17	18.13	77.9	63.9
300 Gy	0 t/ha	26.40	17.51	88.9	42.1
	20 t/ha	22.27	19.72	80.8	49.1
	40 t/ha	28.73	19.99	76.4	56.1
	60 t/ha	24.47	15.47	89.1	45.9

LSD (0.05); Genotype × mulching × planting dates; 3WAP and 6WAP=9.84; 25.25

genotype × mulching for plant height at week 3 after planting showed variation ($P < 0.05$) . Jenguma with 40 t/ha mulched recorded the highest. However, the 300 Gy with 60 ton/ha mulch was recorded least (Table 11).

Table 11: Interaction of soybean genotype and mulching for plant height at week 3 after planting during field experimentation of the 2020 cropping season

Genotypes	Mulching			
	0 t/ha	20 t/ha	40 t/ha	60 t/ha
Jenguma	21.67	25.51	28.23	20.95
150 Gy	24.60	26.55	23.38	23.00
200 GY	23.74	21.82	26.24	24.83
250 Gy	19.18	22.82	23.95	21.65
300 Gy	21.95	20.99	24.36	19.97
LSD (0.05): Genotype × mulching =4.92				

4.2.2 Number of leaves

There was a significant difference ($P < 0.05$) in the number of leaves for soybean genotypes. The 150 Gy recorded the highest followed by the 200 Gy whiles 250 Gy at all week after planting recorded the lowest number of leaves ().

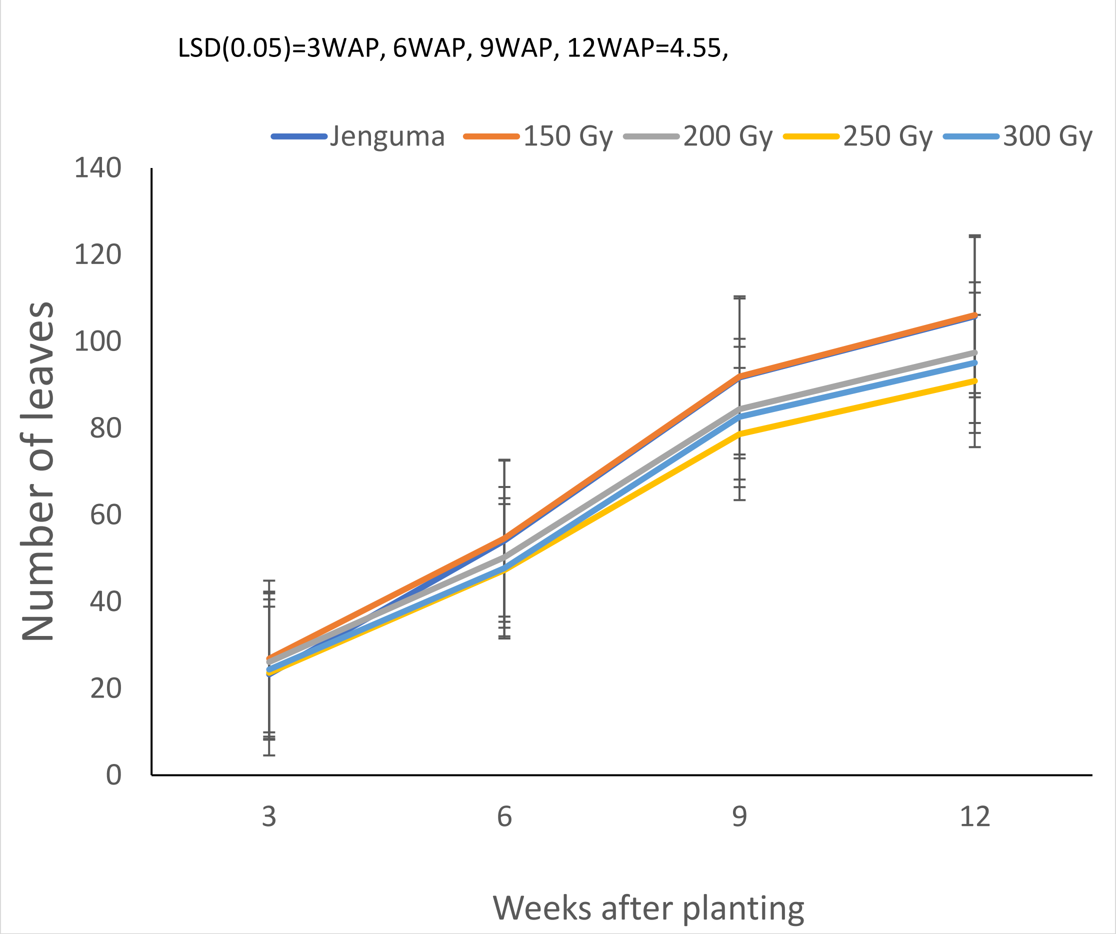

Figure 9: Plant leaf number of soybean (*Glycine max* L. Merrill) during the rainy season of 2020.

Significant variation was observed among planting dates ($P < 0.05$) . Plants from the first planting recorded the highest number of leaves for both 3 and 6 weeks after planting but the opposite result was observed at 9 and 12 weeks after planting where the soybean genotypes from the second planting recorded the highest in terms of the number of leaves (Figure 10).

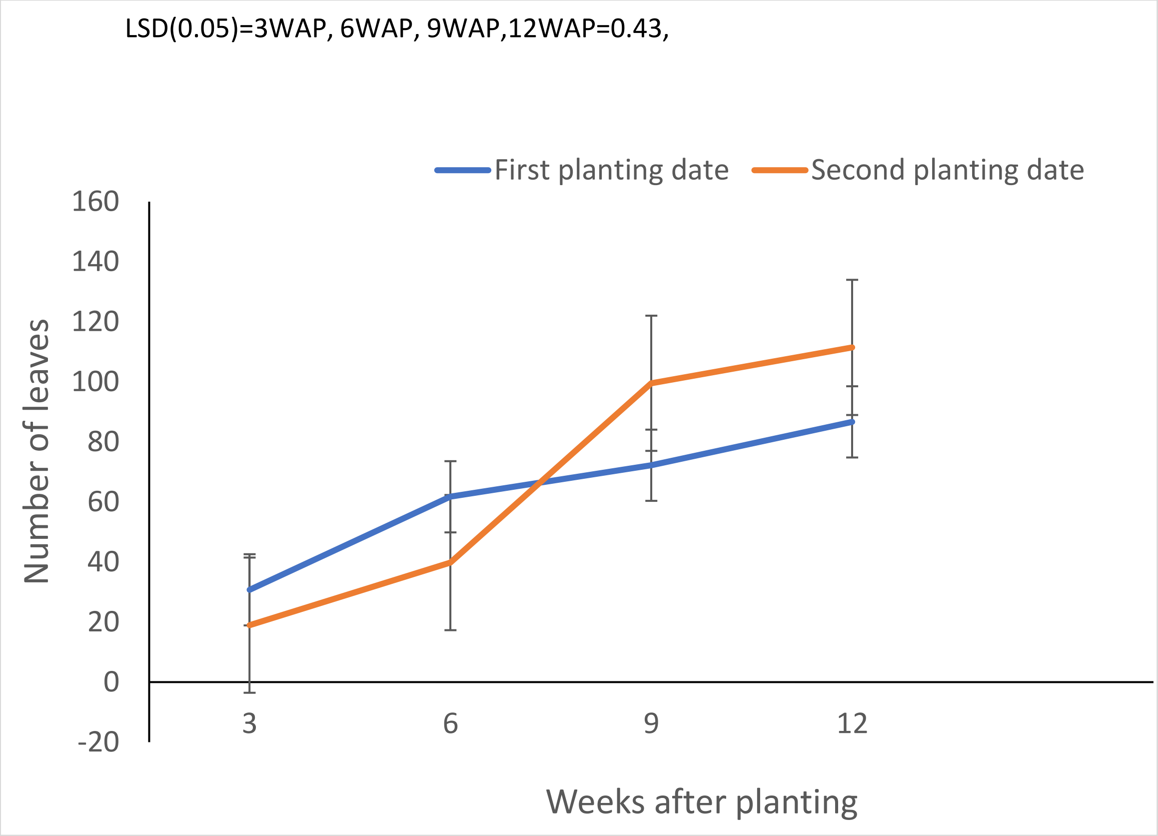

Figure 10: Number of leaves of soybean (*Glycine max* L. Merrill) during the rainy season of 2020

A significant difference ($P < 0.05$) was observed in the interaction between the soybean genotypes and the planting dates for the number of leaves of the soybean genotypes 3 weeks after planting. Plants from 150 Gy and 200 Gy from the first planting recorded the highest number of leaves. Generally, plants from the first planting performed better than those plants from the second planting for the number of leaves (Figure 11).

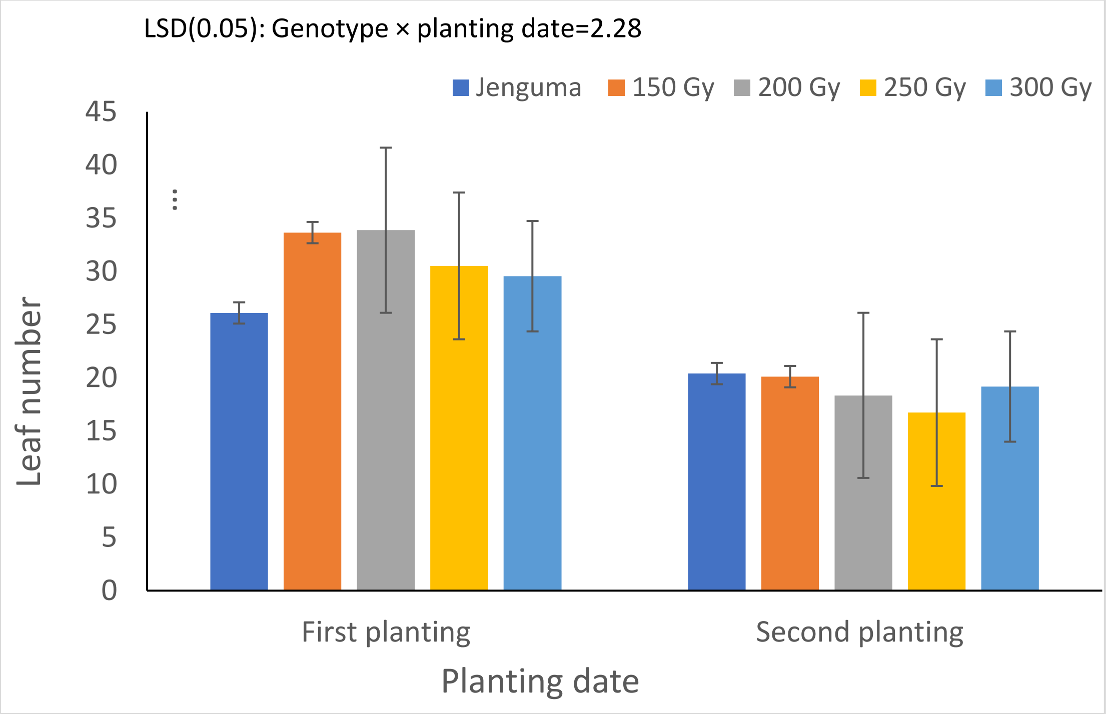

Figure 11: Interaction of soybean (*Glycine max* L. Merrill) genotype and planting date for the number of leaves of the 2020 cropping season.

The interaction between the soybean genotypes and mulching at 6WAP showed significant variation ($P < 0.05$) . Plants from the 150 Gy with 40 ton/ha mulch recorded the highest number of leaves followed by those from 200 Gy while 250 Gy with 0 ton/ha mulch recorded the lowest number of leaves (Table 12).

Table 12: Genotype × mulching for number of leaves at 6WAP for the rainy season of the year 2020

Genotypes		Mulching		
	0 t/ha	20 t/ha	40 t/ha	60 t/ha
Jenguma	49	54.01	62.27	50.98
150 Gy	52.75	61.3	54.69	49.51
200 Gy	45.66	44.22	58.83	52.22
250 Gy	48.8	47.16	43.04	50.06
300 Gy	48.74	40.59	53.47	48

LSD (0.05): Genotype × mulching=17.46

The interaction between the soybean genotypes and the date of plating differed significantly ($P < 0.05$). The plants planted first performed much better than the genotypes from the second planting for the number of leaves. However, statistically, there was no variation observed among the plants from the second planting (Figure 12).

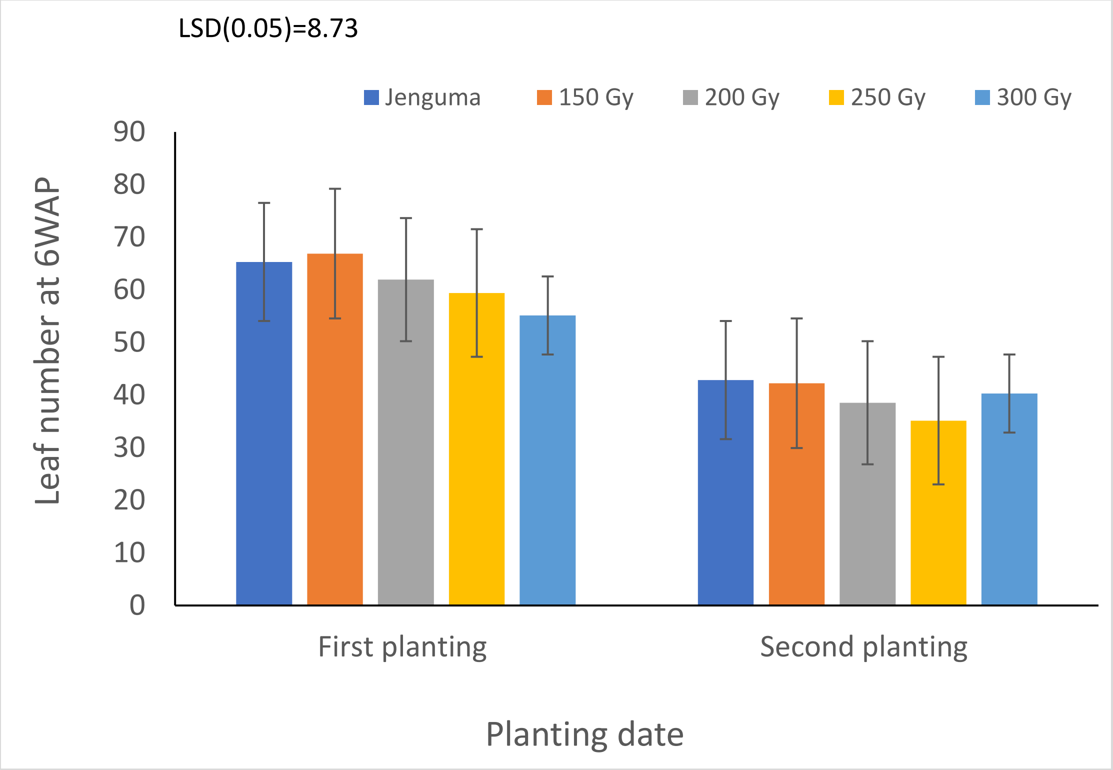

Figure 12: Interaction of soybean (*Glycine max* L. Merrill) genotype and planting date for the number of leaves during the rainy season of 2020.

The interaction between the soybean genotypes and the planting dates at 6 weeks after planting was significant ($P < 0.05$) . Jenguma at the second planting date recorded the highest number of leaves followed by the 150 Gy for the same planting date while the 300 Gy planted first recorded the lowest number of leaves (Figure 13).

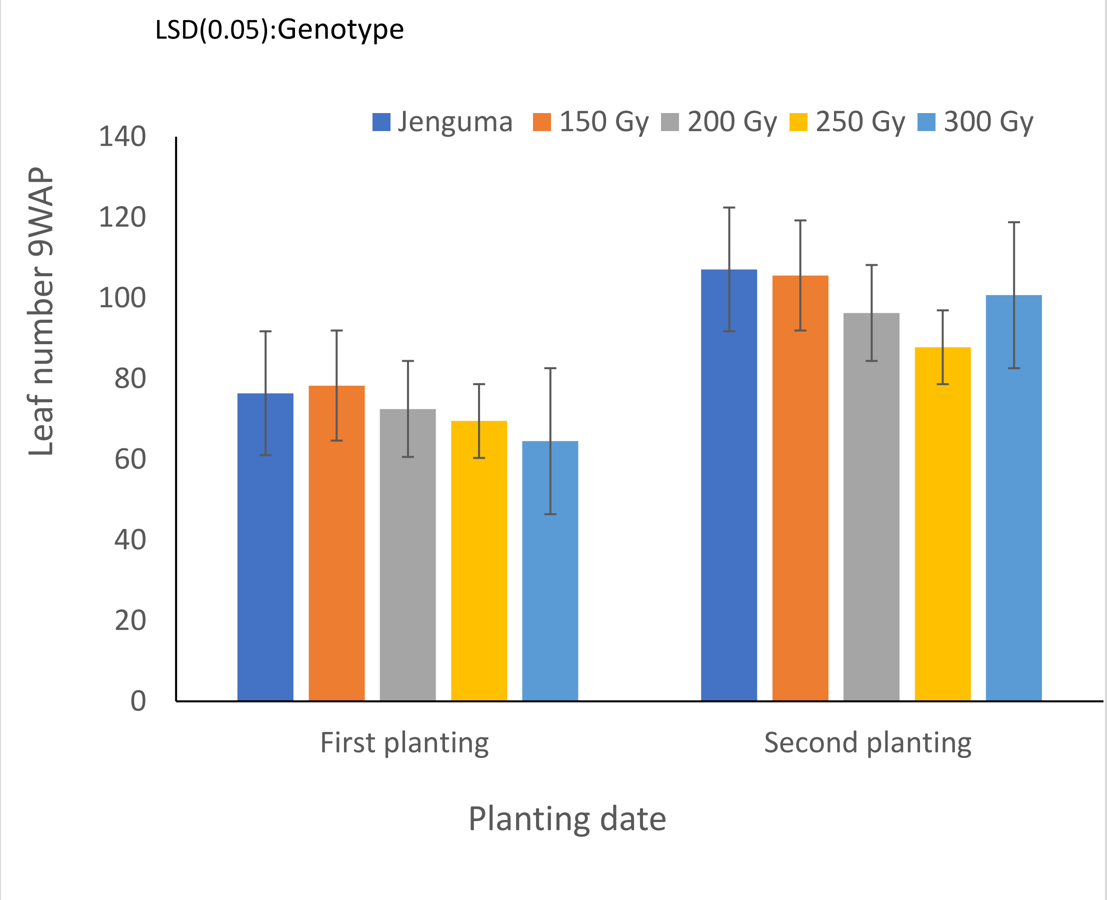

Figure 13: Interaction of soybean genotype (*Glycine max* L. Merrill) and planting date for the number of leaves during the rainy season of the year 2020

The variation was significant ($P < 0.05$) for the interactions of soybean genotypes, mulching, and planting dates for leaf number. The 150 Gy at the second planting date with 40 t/ha recorded the highest number of leaves (Table 13).

Table 13: genotype, × mulching, × planting date for the number of leaves during the rainy season of 2020

		Weeks after planting							
		3		6		9		12	
Genotypes	Mulching	First	Second	First	Second	First	Second	First	Second
Jenguma	0 t/ha	22.73	19.87	56.28	41.72	65.80	104.30	79.00	116.80
	20 t/ha	34.80	18.87	68.40	39.62	80.00	99.00	96.00	110.90
	40 t/ha	25.27	22.67	76.93	47.60	90.00	119.00	108.00	133.30
	60 t/ha	21.60	20.20	59.53	42.42	69.70	106.00	83.60	118.80
150 Gy	0 t/ha	29.07	19.79	63.93	41.57	74.80	103.90	89.80	116.40
	20 t/ha	34.07	19.40	81.87	40.74	95.80	101.80	114.90	114.10
	40 t/ha	38.27	21.80	63.60	45.78	74.40	114.50	89.30	128.20
	60 t/ha	33.20	19.47	58.13	40.88	68.00	102.20	81.60	114.50
200 Gy	0 t/ha	35.00	17.27	55.07	36.26	64.40	90.60	77.30	101.50
	20 t/ha	26.73	18.47	49.67	38.78	58.10	96.90	69.70	108.60
	40 t/ha	43.16	17.93	80.00	37.66	93.60	94.10	112.30	105.40
	60 t/ha	30.60	19.73	63.00	41.44	73.70	103.60	88.50	116.00
250 Gy	0 t/ha	26.13	15.33	65.40	32.20	76.50	80.50	91.80	90.20
	20 t/ha	33.20	17.93	56.67	37.66	66.30	94.10	79.60	105.40
	40 t/ha	33.93	15.87	52.77	33.32	61.70	83.30	74.10	93.30
	60 t/ha	28.80	17.80	62.73	37.38	73.40	93.40	88.10	104.70
300 Gy	0 t/ha	31.53	18.87	57.87	39.62	67.70	99.00	81.20	110.90
	20 t/ha	19.13	19.73	39.73	41.44	46.50	103.60	55.80	116.00
	40 t/ha	42.00	20.07	64.80	42.14	75.80	105.30	91.00	118.00
	60 t/ha	25.53	18.07	58.07	37.94	67.90	94.80	81.50	106.20

LSD (0.05): Genotypes × mulching × planting date= 12.88, 17.45, 25.52,29.71 or 3,6,9, 12 weeks after planting

4.2.3 Chlorophyll content

The chlorophyll content of plants that were mulched differed significantly ($P < 0.05$). Plants from the 40 t/ha mulch recorded the highest chlorophyll content while the 60 t/ha level of mulch recorded the lowest chlorophyll content (Figure 14).

The single effects genotypes and planting date did not show significantly different ($P > 0.05$).

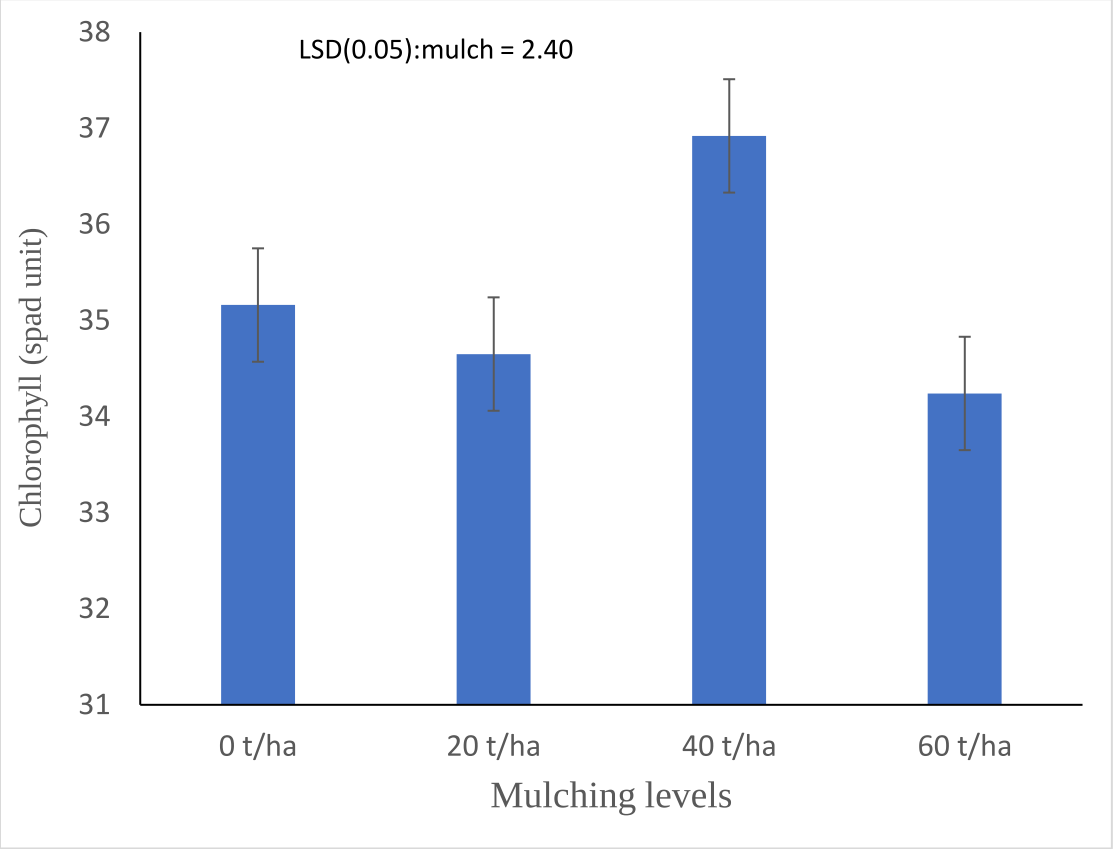

Figure 14: Chlorophyll content of soybean (*Glycine max L*. Merrill) during the rainy season of 2020.

The interaction between mulching and planting date for chlorophyll content also differed significantly ($P < 0.05$) . The plants from 40 t/ha mulch from the first planting recorded the highest content of chlorophyll whereas those from 20 t/ha much from the second planting recorded the lowest chlorophyll content (Figure 15)

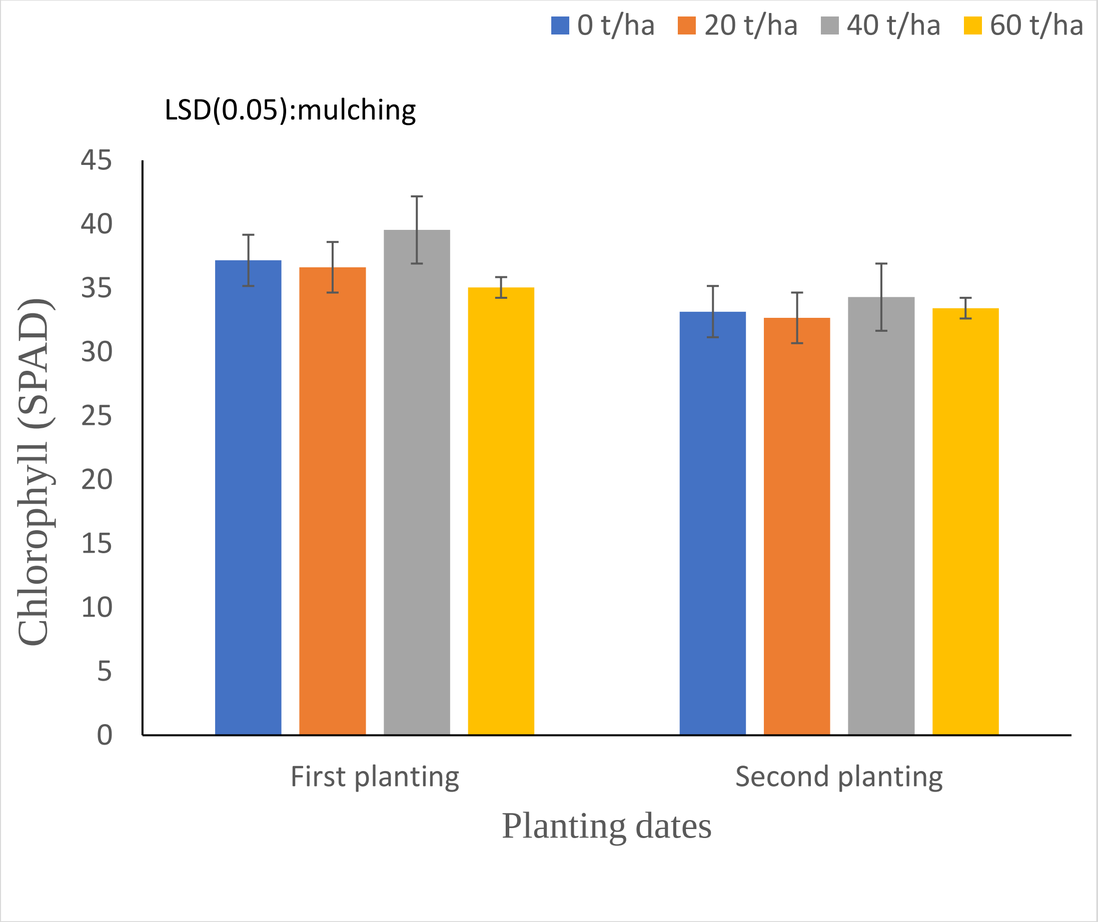

Figure 15: Interaction of mulching and planting date for chlorophyll content during the rainy season of 2020.

The interaction of soybean genotypes and mulch for chlorophyll content varied significantly ($P < 0.05$) . The 200 Gy from 40 t /ha rate of mulch recorded the highest chlorophyll content while the Jenguma with 60 t/ha rate of mulch recorded the lowest chlorophyll content (Table 14)

Table 14: Mulching ×planting date for chlorophyll content during the rainy season of 2020.

Genotypes	Mulching			
	0 t/ha	20 t/ha	40 t/ha	60 t/ha
Jenguma	37.17	35.37	37.51	30.88
150 Gy	32.08	37.11	36.78	35.52
200 GY	33.23	34.04	39.26	34.70
250 Gy	35.81	34.26	34.06	36.29
300 Gy	37.52	32.46	36.97	33.81

LSD (0.05): Genotype × planting date =5.367

There was a significant difference ($P < 0.05$) in the interaction of soybean genotypes and planting dates. The 200 Gy from the first planting recorded the highest chlorophyll content whereas the same soybean genotypes recorded the least chlorophyll content at the second planting (Table 15)

Table 15: Interaction of soybean genotypes and planting date for chlorophyll content during the rainy season of 2020

Genotypes	Planting Date	
	First planting date	Second planting date
Jenguma	36.17	34.30
150 Gy	36.47	34.28
200 Gy	38.04	32.57
250 Gy	37.15	33.06
300 Gy	37.66	32.72

LSD (0.05): Genotypes × planting dates = 3.795

The result from the table below shows a significant variation ($P < 0.05$) in the interaction among the soybean genotypes, mulching, and planting date. The 200 Gy with the mulching of 40 t/ha from first planting recorded the highest chlorophyll content followed by the 150 Gy with the same rate of mulch and planting date. However, the 300 Gy with a 20 t/ha mulching for second planting recorded the lowest chlorophyll content (Table 16).

Table 16: Interaction of genotypes, mulching, and planting date for chlorophyll content during the rainy season of the year 2020

		Planting Date	
Genotypes	Mulching(t/ha)	First planting	Second planting
Jenguma	0	38.03	36.30
	20	35.33	35.40
	40	40.77	34.26
	60	30.53	31.23
150 Gy	0	32.67	31.50
	20	41.40	32.82
	40	35.17	38.40
	60	36.63	34.41
200 Gy	0	36.33	30.12
	20	34.93	33.15
	40	43.90	34.62
	60	37.00	32.40
250 Gy	0	39.93	31.68
	20	35.20	33.33
	40	37.43	30.69
	60	36.03	36.54
300 Gy	0	38.87	36.18
	20	36.27	28.65
	40	40.47	33.48
	60	35.03	32.58

LSD (0.05): Genotype × mulching × planting date = 7.590

4.2.4 Days to 50% flowering

The interaction for genotypes, mulching, and planting date varied significantly ($P < 0.05$) for days to 50 % flowering of plants. The 200 Gy at 20 t/ha rate of mulch from the second planting took a few days to reach 50% flowering while the Jenguma at 60 t/ha rate of mulch from the first planting flowered late (Table 17).

Table 17: Genotypes × mulching × planting date for the number of days to reach 50% flowering during the rainy season of 2020.

Genotype s	Mulching(t/ha)	Planting Date	
		First planting date	Second planting date
Jenguma	0	42.00	37.00
	20	41.33	36.33
	40	41.33	36.33
	60	42.67	37.67
150 Gy	0	37.00	32.00
	20	36.00	31.00
	40	35.67	30.67
	60	37.67	32.67
200 Gy	0	37.33	32.33
	20	34.00	29.00
	40	34.33	29.33
	60	38.33	33.33
250 Gy	0	35.67	30.67
	20	35.33	30.33
	40	37.33	32.33
	60	36.67	31.67
300 Gy	0	35.67	30.67
	20	38.67	33.67
	40	37.00	32.00
	60	36.67	31.67

LSD (0.05): Genotype × mulching × planting date = 4.847

4.2.5 Shoot -root ratio

The interaction of genotypes and planting date for shoot-root ratio showed significant variation ($P < 0.05$) . The 250 Gy from second planting was observed to have the highest shoot-root ratio followed by the Jenguma of the same planting date while 150 Gy and 200 Gy from first planting recorded the lowest in terms of shoot-root ratio (Figure 16).

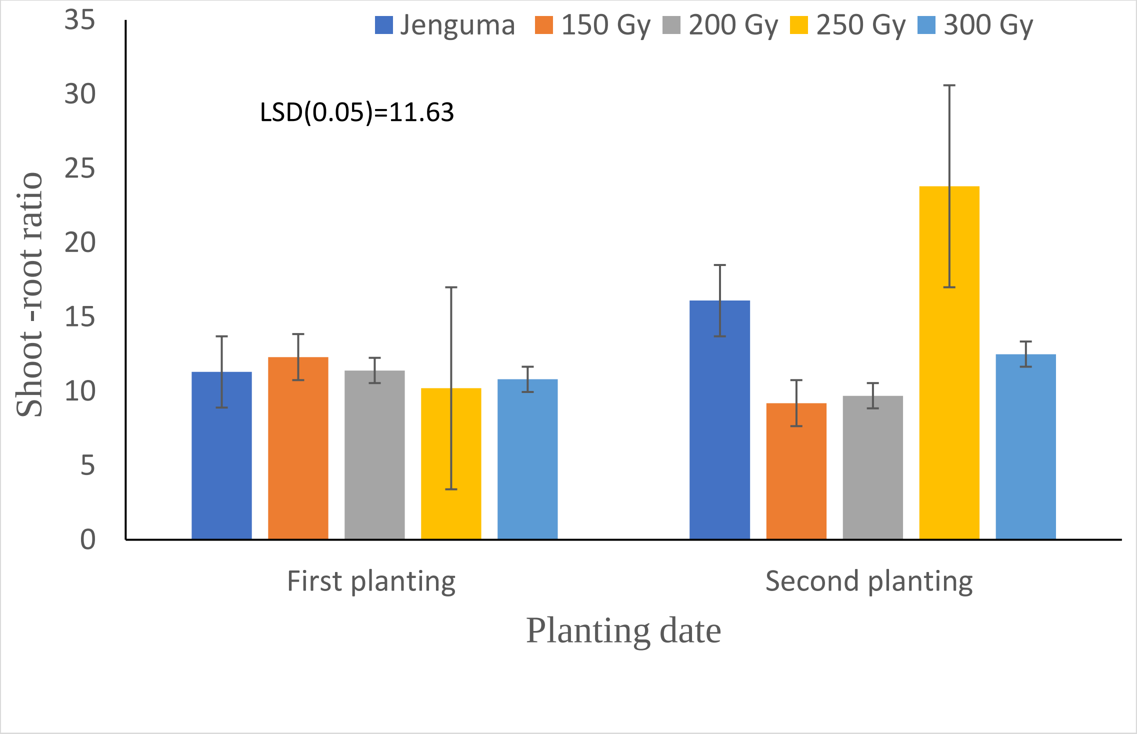

Figure 16: Interaction of soybean genotype and planting date for the shoot to root ratio in the rainy season of 2020.

There was significant ($P < 0.05$) variation observed in the interaction between mulching and planting date. The soybean genotypes with the mulching rate of 20 t/ha from second planting recorded the highest shoot-root ratio. However, plants from 40 t/ha and 60 t/ha also from the second planting recorded the lowest shoot-root ratio (Figure 17).

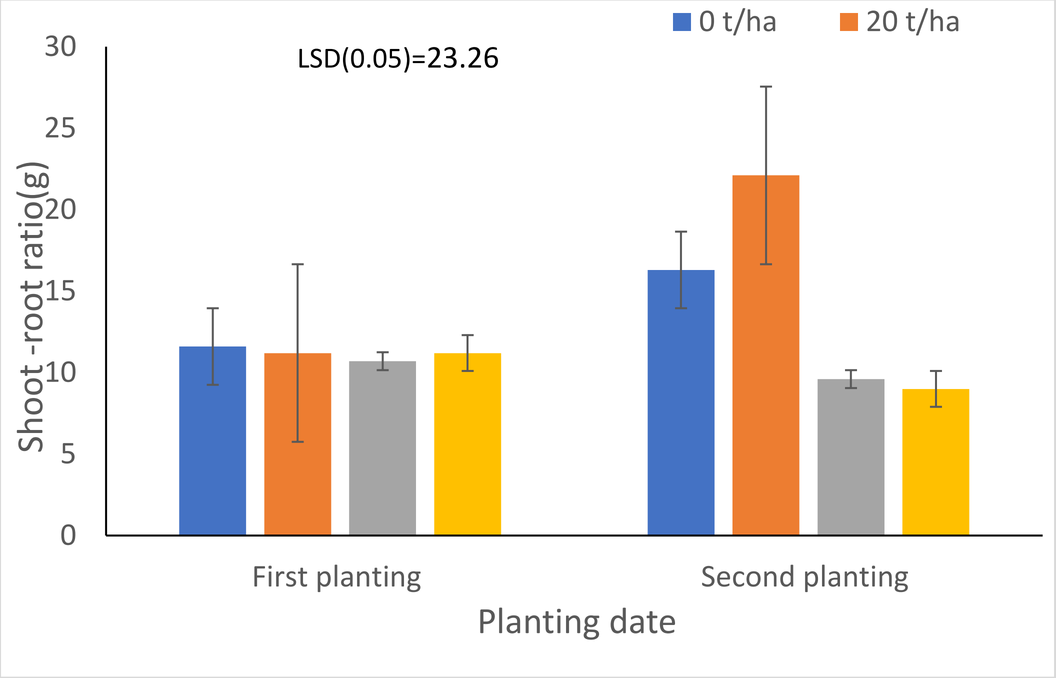

Figure 17: Interaction of mulching and planting date for shoot root ratio during the rainy season of 2020

The interaction of soybean genotypes and mulching also differed significantly ($P < 0.05$). The 250 Gy plants from the 20 t/ha rate of mulch recorded the highest fresh shoot-root ratio. Jenguma with the mulch level of 60 t/ha recorded the lowest shoot-root ratio (Table 18).

Table 18: Interaction of mulch and planting date for the shoot root ratio during the rainy season of 2020.

Genotypes	Mulching			
	0 t/ha	20 t/ha	40 t/ha	60 t/ha
Jenguma	13.5	22.0	9.8	9.5
150 Gy	10.2	11.1	12.3	9.5
200 GY	11.5	10.5	10.4	9.8
250 Gy	21.1	28.3	7.1	11.5
300 Gy	13.6	11.5	11.3	10.3

LSD (0.05): Genotypes × mulching = 16.45

4.2.6 Fresh root biomass

The interaction of mulching and genotypes for fresh roots showed significant variation ($P < 0.05$) . The 250 Gy at 40 t/ha rate of mulch produced the highest fresh root biomass. Jenguma at 40 t/ha of mulching recorded the lowest fresh root biomass (Table 19).

Table 19: Interaction of mulch and soybean genotypes for the fresh shoot during the rainy season of 2020

Genotypes	Mulching			
	0 t/ha	20 t/ha	40 t/ha	60 t/ha
Jenguma	13.50	12.80	9.80	19.10
150 Gy	10.60	13.30	13.50	11.00
200 GY	13.30	26.00	15.10	14.8
250 Gy	14.300	11.30	43.20	16.80
300 Gy	10.4	9.00	17.80	15.60

LSD (0.05): Genotypes × mulching = 21.61

4.2.7 Biomass accumulation

The interaction of planting date and genotypes for biomass accumulation showed significant variation ($P < 0.05$) . Generally, plants from the first planting produced the highest root biomass as compared to those from the second planting (Figure 18).

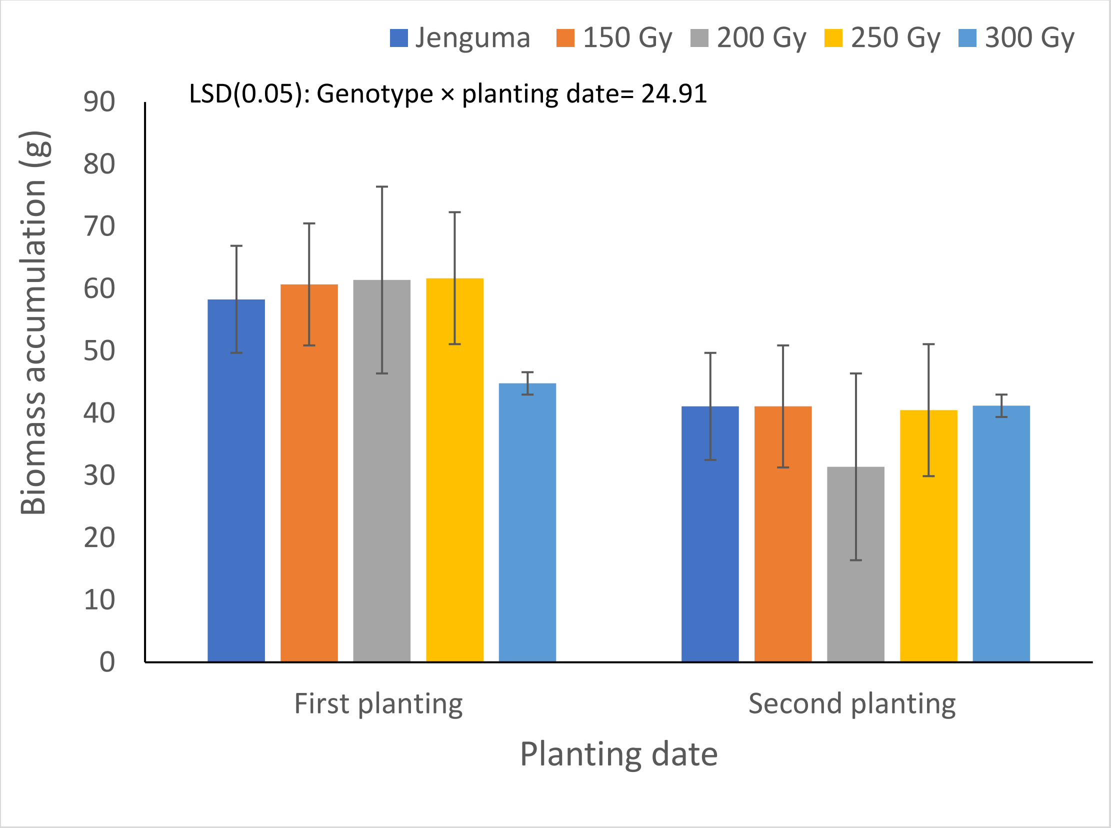

Figure 18: Interaction of soybean genotype and planting date for biomass accumulation during the rainy season of 2020.

A significant difference ($P < 0.05$) was observed in the interactions between mulching and planting date. The genotypes at 20 t/ha from the first planting had the highest biomass accumulation whilst the biomass accumulation recorded at 40 t/ha from the second planting was the least (Table 20).

Table 20: Interaction of mulching and planting date for biomass accumulation during the rainy season of 2020.

Mulching	Planting Date	
	First planting	Second planting
0 t/ha	51.50	42.70
20 t/ha	68.40	36.80
40 t/ha	54.70	33.20
60 t/ha	54.80	43.40
LSD (0.05): Mulching× planting date =22.28		

Genotypes × mulching × planting date for biomass accumulation differed significantly ($P < 0.05$). The 150 Gy at 20 t/ha from the first planting was observed to produce the highest biomass accumulation whereas the dry biomass accumulation recorded by the 250 Gy at 40 ton/ha from the second planting was the least (Table 21).

Table 21: Interaction of mulch and planting date for dry biomass accumulation during the rainy season of 2020

Genotypes	Mulching(t/ha)	Planting Date	
		First planting	Second planting
Jenguma	0	48.80	60.70
	20	73.500	25.10
	40	45.10	24.00
	60	65.70	54.70
150 Gy	0	67.30	27.80
	20	94.00	27.50
	40	39.60	47.200
	60	41.80	61.70
200 GY	0	44.00	31.20
	20	79.90	32.10
	40	76.30	36.01
	60	45.30	26.00
250 Gy	0	47.60	52.30
	20	49.60	46.70
	40	60.70	23.40
	60	88.70	39.50
300 Gy	0	50.00	41.70
	20	45.20	52.90
	40	51.60	35.50
	60	32.50	34.90
LSD (0.05): Genotype × mulching × planting date = 49.81			

4.2.8 Leaf area index

The interaction of planting date and mulching varied significantly ($P < 0.05$) for leaf area index at 3 weeks after planting. The genotypes mulched and also from the first planting recorded the highest leaf area index as compared to those genotypes from the second planting (Figure 19).

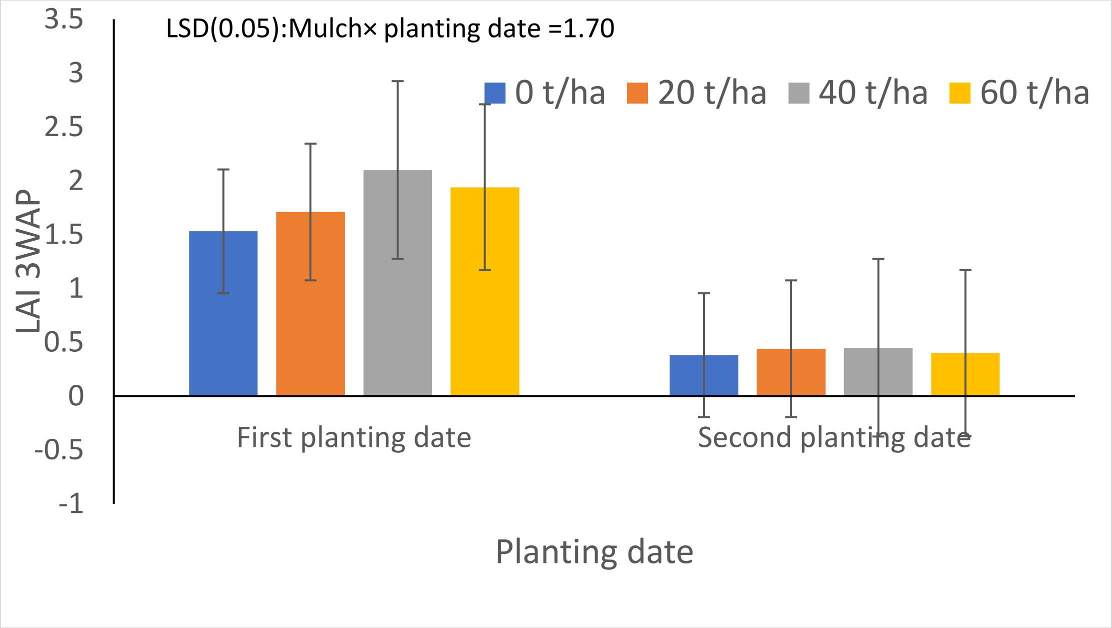

Figure 19: Interaction of mulching and planting date for leaf area during the wet season of the 2020 cropping season

The genotypes × planting date interaction was also a significant variation ($P < 0.05$) for leaf area index. The 150 Gy from the first planting recorded the highest leaf area index while 250 Gy from the second planting at week 3 after planting recorded the lowest leaf area index (Table 22).

Table 22: Genotypes × planting date for leaf area during the wet season of the 2020 cropping season

	Weeks after planting							
Genotypes	3		6		9		12	
	First planting	Second planting	First planting	Second planting	First planting	Second planting	First planting	Second planting
Jenguma	1.44	0.57	4.14	1.62	6.64	5.86	9.62	9.9
150 Gy	2.55	0.43	4.28	1.23	6.86	4.42	9.94	7.49
200 GY	1.94	0.40	3.01	1.15	4.83	4.12	7.00	6.99
250 Gy	1.61	0.33	3.41	0.95	5.46	3.40	7.91	5.77
300 Gy	1.56	0.36	3.39	1.03	5.44	3.71	7.88	6.28

LSD (0.05): Genotype × planting date =0.428, 1.12, 2.07, 6.35

The interaction between the planting date and the rate of mulch for leaf area index differed significantly ($P < 0.05$). At week 3 after planting, the 150 Gy with 60 t/ha of mulch recorded the highest leaf area index but the trend changed at 6, 9, and 12 weeks after planting whereas Jenguma with 40 t/ha of mulch recorded the highest leaf area index. 250 Gy from the second planting at week 3 after planting recorded the lowest leaf area index (Table 23).

Table 23: Genotypes × mulching for leaf area index during the rainy season of 2020

Weeks after planting	Genotypes	Mulching			
		0 t/ha	20 t/ha	40 t/ha	60 t/ha
3	Jenguma	0.81	1.38	1.16	0.67
	150 Gy	1.10	1.43	1.17	2.25
	200 GY	1.15	0.90	1.61	1.02
	250 Gy	0.69	1.03	1.09	1.07
	300 Gy	1.02	0.62	1.36	0.85
6	Jenguma	2.46	2.78	4.01	2.30
	150 Gy	2.85	3.75	2.46	1.97
	200 GY	1.52	1.43	3.13	2.26
	250 Gy	2.26	2.27	1.69	2.50
	300 Gy	2.75	1.72	2.49	1.89
9	Jenguma	5.55	5.78	8.65	5.02
	150 Gy	5.73	7.29	5.30	4.23
	200 GY	3.57	3.50	5.92	4.93
	250 Gy	4.16	4.76	3.54	5.27
	300 Gy	5.37	4.05	5.12	3.75
12	Jenguma	8.76	8.96	13.51	7.86
	150 Gy	8.83	11.12	8.29	6.61
	200 GY	5.67	5.61	8.98	7.72
	250 Gy	6.26	7.39	5.49	8.21
	300 Gy	8.20	6.45	7.92	5.74

LSD (0.05): Genotypes × mulching =0.855, 2.26, 4.15, 3.17

Table 24 indicates that genotypes × mulching × planting date interaction varied significantly ($P < 0.05$) for LAI. At 3 weeks after planting, the 200 Gy with 40 t/ha level of mulch from the first planting recorded the highest leaf area index. At week 6 after planting, plants with 20 t/ha also from the first planting, the 150 Gy recorded the highest leaf area index. However, at 12 weeks after planting, the Jenguma with a mulch rate of 40 tones/ha recorded the highest (Table 24).

Table 24: Interaction of genotypes, mulch, and planting date for leaf area index field during the wet season of the 2020 cropping season

		Weeks after planting							
Genotypes	Mulching(t/ha)	3		6		9		12	
		First planting	Second planting	First planting	Second planting	First planting	Second planting	First planting	Second planting
Jenguma	0	1.05	0.56	3.30	1.62	5.29	5.82	7.66	9.86
	20	2.31	0.46	4.23	1.33	6.77	4.78	9.81	8.10
	40	1.54	0.77	5.80	2.23	9.28	8.01	13.45	13.58
	60	0.87	0.47	3.25	1.34	5.21	4.82	7.55	8.17
150 Gy	0	1.78	0.41	4.52	1.18	7.23	4.24	10.48	7.18
	20	2.41	0.45	6.202	1.29	9.94	4.63	14.4	7.85
	40	1.87	0.48	3.55	1.37	5.68	4.93	8.23	8.35
	60	4.13	0.38	2.86	1.08	4.58	3.88	6.64	6.58
200 Gy	0	1.90	0.40	1.90	1.14	3.05	4.09	4.42	6.93
	20	1.38	0.42	1.64	1.22	2.62	4.38	3.79	7.43
	40	2.91	0.32	5.34	0.91	8.55	3.29	12.39	5.57
	60	1.58	0.46	3.19	1.32	5.12	4.74	7.41	8.02
250 Gy	0	1.19	0.18	4.00	0.53	6.40	1.91	9.28	3.24
	20	1.66	0.40	3.39	1.14	5.42	4.09	7.86	6.93
	40	1.88	0.29	2.54	0.84	4.07	3.01	5.89	5.09
	60	1.70	0.45	3.71	1.28	5.94	4.61	8.61	7.81
300 Gy	0	1.70	0.34	4.53	0.96	7.25	3.49	10.5	5.91
	20	0.79	0.45	2.14	1.30	3.43	4.67	4.98	7.91
	40	2.32	0.39	3.81	1.14	6.16	4.09	8.93	6.92
	60	1.44	0.25	3.06	0.72	4.9	2.59	7.10	4.39

LSD (0.05): Genotypes × mulch× planting date = 0.855, 2.26, 4.15, 3.17

4.2.9 Nodule weight

There was a significant difference ($P < 0.05$) in the interaction of soybean genotypes and planting dates for nodule weight. The 250 Gy from the second planting recorded the highest nodule weight while Jenguma with the same planting date recorded the lowest nodule weight (Figure 20).

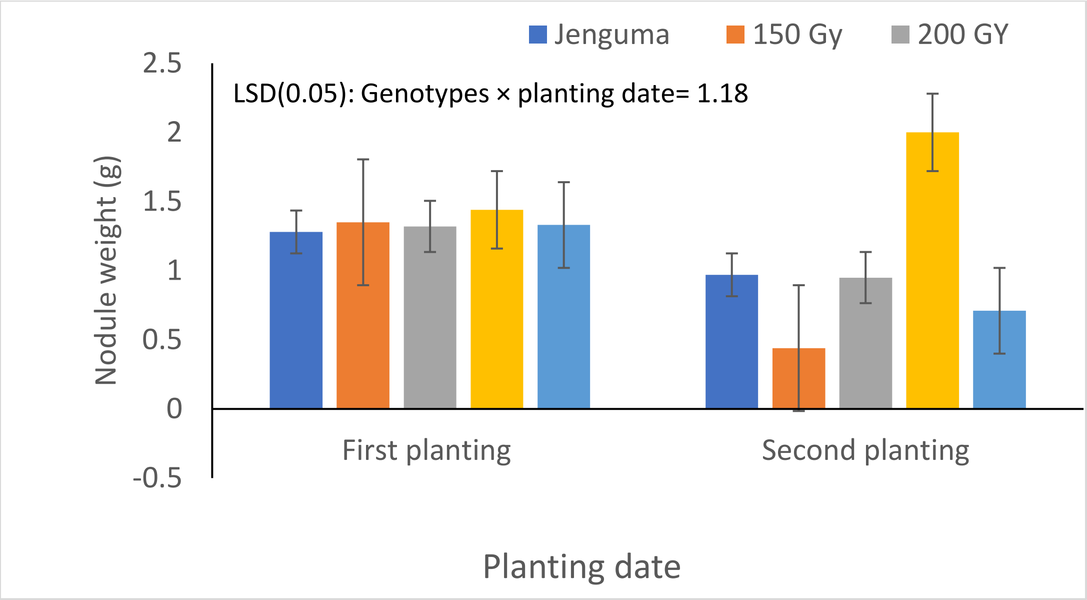

Figure 20: Interaction of soybean genotype and planting date for nodule weight during the rainy season of 2020

The interaction among the soybean genotypes, planting date, and mulch for nodule weight differed significantly ($P < 0.05$). The 300 Gy at no mulch planted first recorded the highest nodules weight followed by the 150 Gy at 20 t/ha of the same planting date. Meanwhile, the 250 Gy with no mulch planted late recorded the lowest nodules weight (Table 25)

Table 25: Genotypes × mulching for nodule weight during the rainy season of 2020.

Genotypes	Mulching	Planting Date	
		First planting	Second planting
0 Gy	0	8.59	8.49
	20	8.25	8.27
	40	9.40	9.22
	60	7.95	7.92
150 Gy	0	9.48	7.61
	20	9.78	7.72
	40	8.52	7.42
	60	7.85	7.14
200 Gy	0	6.36	7.94
	20	6.47	7.68
	40	8.85	6.79
	60	8.09	7.84
250 Gy	0	8.85	5.71
	20	8.09	7.18
	40	7.61	6.61
	60	7.56	8.10
300 Gy	0	10.30	7.59
	20	8.38	7.56
	40	8.98	7.22
	60	7.17	6.22

LSD (0.05): Genotypes × mulching × planting date = 2.55

4.2.10 Nodule number

The interaction of the soybean genotypes and planting date showed significant variation ($P < 0.05$). Generally, the soybean genotypes from the second planting recorded the highest nodules number as compared to the genotypes planted first

Figure 21Figure 21)

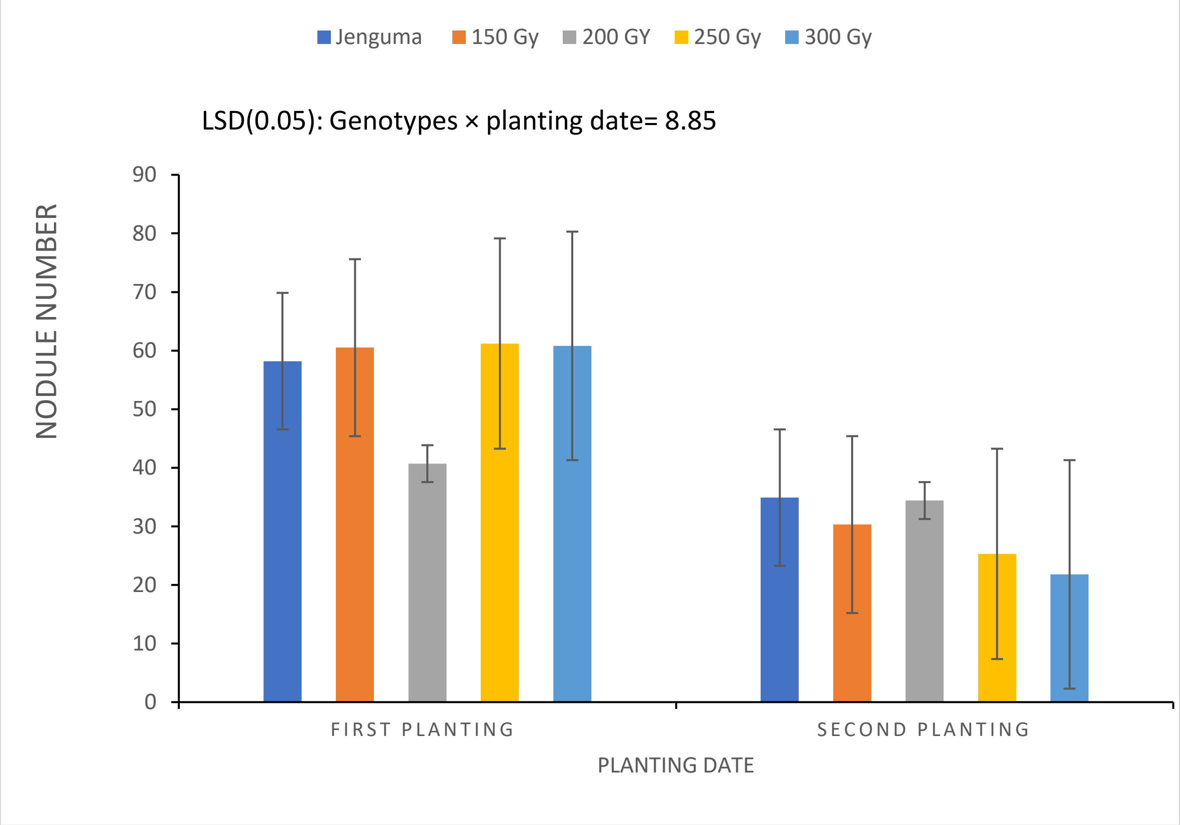

Figure 21: Interaction of genotype and planting date for the number of nodules during the rainy season of 2020.

Figure 22 showed significant variation in the interaction between the date of planting and the rate of mulching (*P* < 0.05). Plants with no mulch planted first were observed to have recorded the highest number of nodules whiles the 20 t/ha rate of mulch recorded the lowest number of nodules.

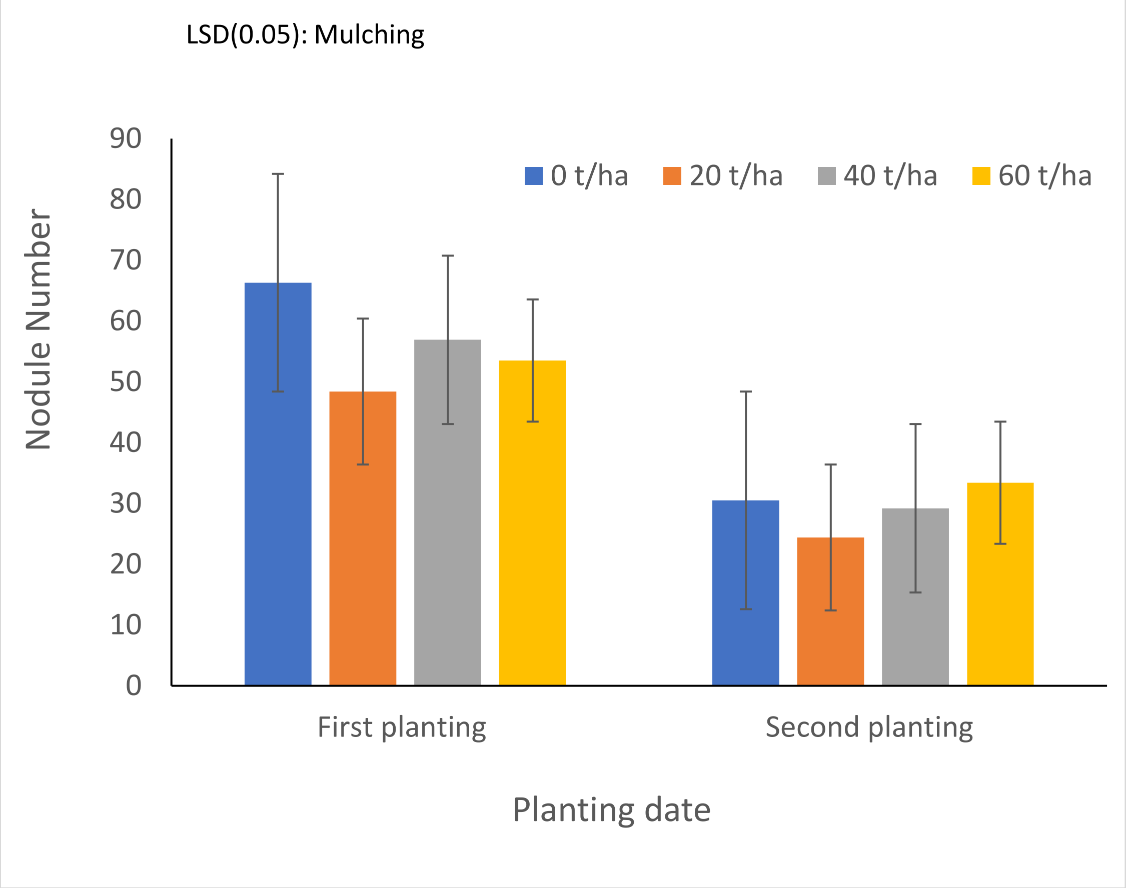

Figure 22: Interaction of mulching and planting date for the number of nodules during the rainy season of 2020.

The interaction among the soybean genotypes, planting date and the rate of mulch for nodule number differed significantly (*P* < 0.05). The 250 Gy at no mulch planted early counted the highest number of nodules followed by the 300 Gy at 20 ton/ha of the same planting date. Meanwhile, the 300 Gy with a 20 t/ha rate of mulch planted late recorded the lowest number of nodules (Table 26).

Table 26: Genotypes mulching for nodule number during the rainy season of 2020

Genotypes	Mulching(t/ha)	Planting Date	
		First planting	Second planting
0 Gy	0	66.30	50.30
	20	55.70	20.70
	40	61.00	27.70
	60	50.00	41.00
150 Gy	0	70.00	29.70
	20	71.70	27.30
	40	63.00	42.00
	60	37.30	22.30
200 Gy	0	46.00	30.30
	20	26.70	34.30
	40	46.00	25.30
	60	44.00	47.70
250 Gy	0	78.30	21.70
	20	47.70	21.70
	40	57.00	28.40
	60	62.00	29.70
300 Gy	0	71.00	20.30
	20	40.30	18.00
	40	57.70	22.70
	60	74.30	26.30

LSD (0.05): Genotypes × mulching × planting date = 35.26

4.2.11 Hundred seed weight

Both the single effects and all the interactions of the soybean for hundred seeds weight showed significant ($P < 0.05$) variation. Genotypes from 200 Gy and 250 Gy recorded the highest seed weight whilst 150 Gy mutants recorded the lowest (Figure 23)

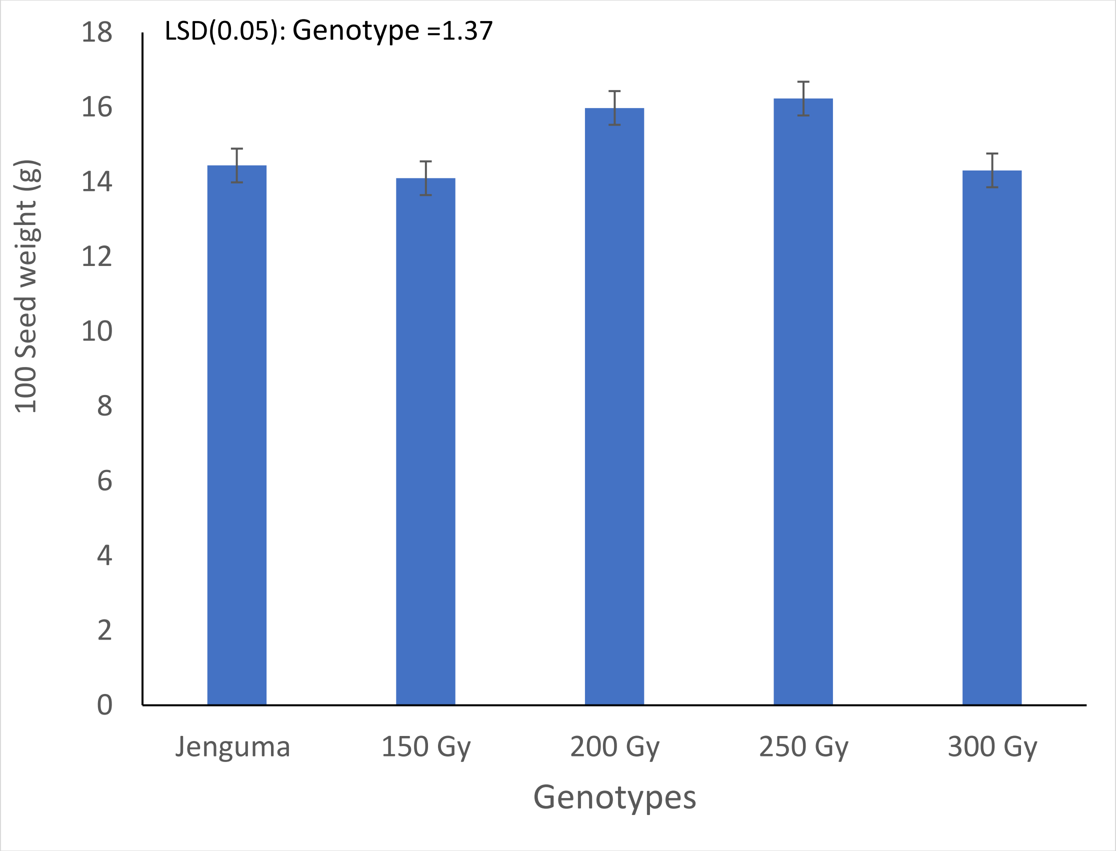

Figure 23: Hundred seed weight of soybean (*Glycine max* L. Merrill) during the rainy season of 2020.

The planting date for a hundred seeds' weight varied significantly ($P < 0.05$). Generally, the genotypes from the first planting recorded the highest hundred seed weight as compared to the genotypes from the second planting (Figure 24).

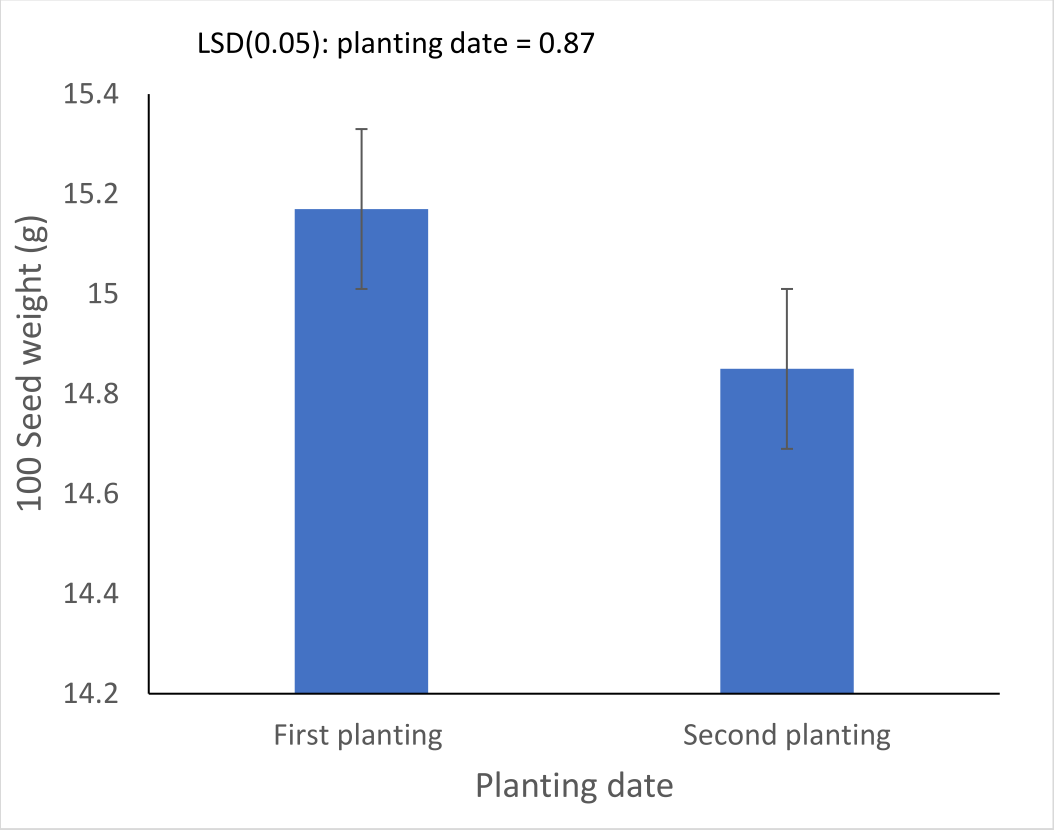

Figure 24: Hundred seed weight of soybean (*Glycine max* L. Merrill) for planting date the rainy season of 2020.

There was a significant difference in the interaction of soybean genotypes and the rate of mulching ($P < 0.05$). The 200 Gy with a mulch rate of 60 t/ha recorded a hundred seeds while the 150 Gy and the 300 Gy with mulch rate of 0 t/ha and 60 t/ha recorded the lowest respectively (Table 27).

Table 27: Genotypes × mulching for hundred seed weight during the rainy season of the 2020 cropping season

Genotypes	Mulching			
	0 t/ha	20 t/ha	40 t/ha	60 t/ha
0 Gy	14.67	15.25	13.50	14.33
150 Gy	12.92	14.58	13.92	15.00
200 Gy	15.58	15.33	15.92	17.08
250 Gy	16.58	16.33	16.50	15.50
300 Gy	14.50	15.08	14.75	12.92

LSD (0.05): Genotypes × mulching =1.38

The Genotypes× mulching× planting date interaction differed significantly ($P < 0.05$) for hundred seed weight. Plants from 200 Gy applied with 60 t/ha mulch also from the second planting recorded the highest hundred whereas plants from 300 Gy with mulching of 60 t/ha recorded the lowest (Table 28).

Table 28: Genotypes × mulching × planting date for hundred seed weight during the rainy season of 2020

Genotypes		Planting date	
	Mulching	First planting	Second planting
0 Gy	0	15.17	14.17
	20	15.83	14.67
	40	14.83	12.17
	60	14.67	14.00
150 Gy	0	13.33	12.50
	20	15.33	13.83
	40	14.33	13.50
	60	14.67	15.33
200 Gy	0	16.00	15.17
	20	14.33	16.33
	40	15.50	16.33
	60	16.50	17.67
250 Gy	0	16.83	16.33
	20	15.17	17.50
	40	16.17	16.83
	60	15.17	15.83
300 Gy	0	14.33	14.67
	20	15.67	14.50
	40	14.50	15.00
	60	15.15	10.70

LSD (0.05): Genotypes × mulching × planting date = 3.88

4.2.12 Total grain yield

Only the interaction between genotypes and planting dates for total grain yield varied significantly ($P < 0.05$) . The 250 [Gy from the first planting recorded the highest total grain yield whereas the Jenguma from the second planting recorded the lowest in terms of total grain yield (Figure 25).

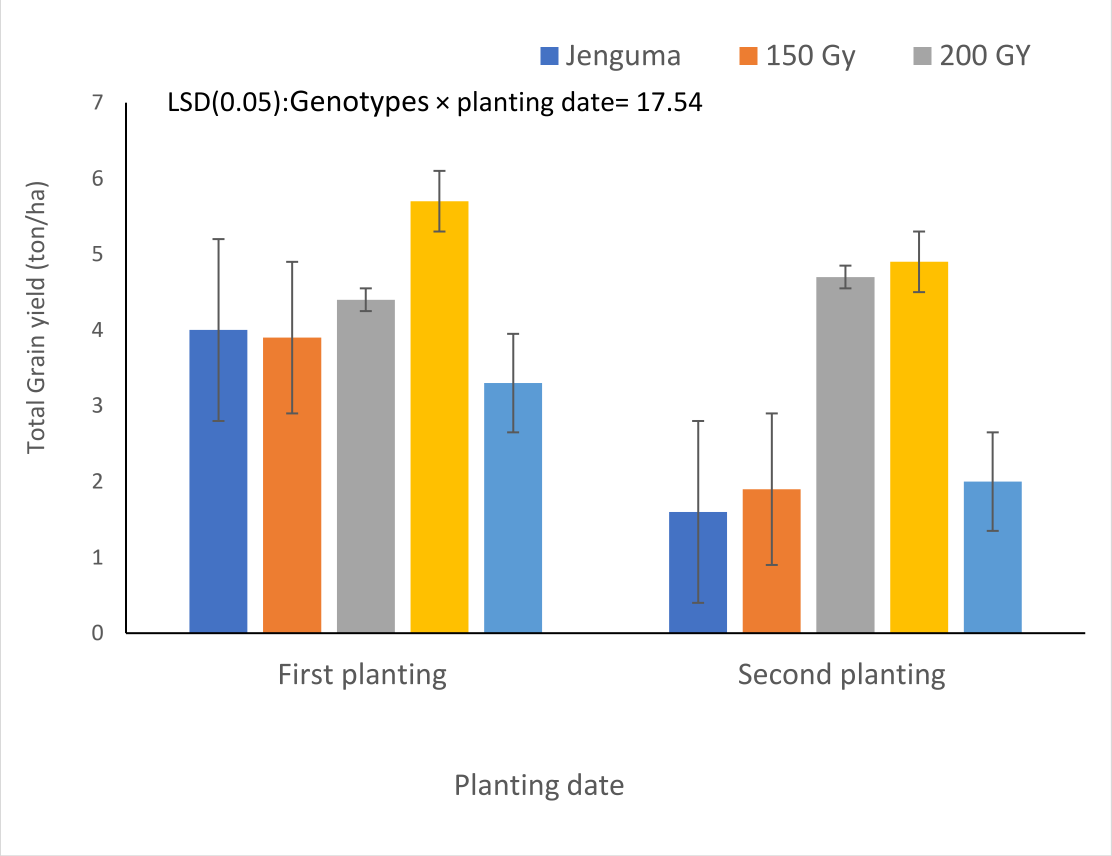

Figure 25: Total grain yield of soybean (*Glycine max* L. Merrill) genotypes during the rainy season of 2020.

CHAPTER FIVE

DISCUSSION

5.1.1 Plant growth and development

In summary, the study's findings revealed that plant growth and yield differed significantly. The mutagenesis used had a substantial impact on agronomic parameters. This agrees with the findings made by Mudibu, (2012) who reported that a considerable increase in grain yield and yield components was seen when 200 to 400 Gy were applied to soybean plants. This finding was also confirmed by Tshilenge-Lukanda *et al*. (2013) when using 100 Gy on peanut seeds (*Arachis hypogaea*) and by Fontes *et al*. (2013) when using 50 Gy on cowpea seeds (*Vigna unguiculata*)

There was a substantial difference in plant height among the genotypes. Plant heights for the Jenguma and 150 Gy increased consistently up to 12 weeks after planting but decreased for mutants derived from higher gamma irradiation doses. According to Asare *et al*. (2017), mutagenic therapy may have harmed the mechanism of cell division and cell elongation, resulting in a reduction in plant height which confirmed the finding of this study. Plants irradiated with 250 Gy at weeks 3 and 6 after planting was leading in the plant height but a different result was observed at weeks 9 and 12 where the Jenguma which is the control took the lead as 250 Gy declined. The 200 Gy plants mulched with 40 t/ha mulch, as well as the Jenguma treatments mulched at 40 t/ha mulch, outperformed the others in terms of plant height. The 200 Gy plants mulched with 40 t/ha mulch, as well as the Jenguma treatments mulched at 40 t/ha mulch, outperformed the others in terms of plant height. The difference in plant height may not only be due to the treatment but also the genotypic difference. Underwater stress, Khan *et al.* (2014) observed a drop in plant height in soybean, which they attributed to the establishment of shorter internodes.

The study revealed that in terms of the number of leaves, the 200 Gy and 250 Gy mutants outperformed the Jenguma and 300 Gy mutants but the 150 Gy mutant recorded the highest followed by the 200 Gy. Variations in leaf numbers identified in the study could be attributable to their reaction to drought or water stress. In general, plant growth is stimulated by low doses of gamma irradiation according to Mouss (2011), which was in confirmation with the results of this finding. The study revealed that mutants derived from higher gamma irradiation dosages. These findings from the present study are in line with Ochatt *et al.* (2001) who made similar observations in grass pea (*Lathyrus sativus* (L) in their flow cytometry studies.

Plants from the first planting recorded the highest number of leaves up to 6 weeks after planting, but the contrary was found after 9 weeks of growth, according to the study, this could be due to the plants' decreased ability to withstand water stress. The maximum number of leaves were found in 200 Gy mutants treated with 100 percent WUE without mulch, followed by 250 Gy mutants treated with 100 % WUE and 60 ton/ha mulching. Jenguma, which had not been mulched and was treated with 40% WUE, had the lowest yield. According to a study conducted by Khan *et al.* (2014), drought stress affects cell elongation, expansion, and leaf development during vegetative growth phases. Sacita *et al*. (2018) validated the study's findings, stating that the number of leaves reduced as water stress levels increased. The loss of leaves during stress is caused by disturbances in plant growth and adaptation mechanisms, such as defoliation to reduce transpiration rates. More leaves were found in the 300 Gy mutant with 40 tons/ha of mulch. The Jenguma that received the same quantity of mulch produced the most leaves, particularly in the sixth week following planting. Similarly, the 150 Gy mutant from the second planting at week 12 after planting with plus 40 ton/ha mulch produced the highest number of leaves. The information deduced from this observation could imply that high-temperature stress disrupts the growth and production of crops and greatly decreases their physiological growth attributes. According to EL Sabagh *et al*. (2021), temperature and photoperiod, among other environmental variables, have a substantial impact on soybean plant vegetative growth and productivity. Soybean cultivars' height and the number of nodes increased when temperatures were raised from 15.6 °C to 32.2 °C over a 14-hour photoperiod according to Allen *et al*. (2018) which agreed with the finding of this study.

According to the study, there was substantial variation in soybean nodule weight and count when genotypes and planting interactions were considered. Therefore, the 250 Gy from the second planting recorded the highest nodule weight as compared to the Jenguma with the same planting date which recorded the lowest in terms of nodule weight. In general genotypes from the first planting produced the most nodules as compared to genotypes which could be a result of water stress during the second planting. The highest number of nodules were found in soybean genotypes that were planted without mulch, while the lowest number of nodules were found in genotypes that were mulched at 20 tones/ha from the second planting. According to Fernández-Luqueño *et al.* (2008), only when soybean plants are exposed to extreme drought conditions do nodule numbers decrease which is confirmed by the finding of this study. A similar observation was also made by Franco *et al*. (2011) who reported that as root mass develops, drought changes root architecture as well as the partitioning of root to shoot biomass.

5.2 Chlorophyll development, leaf area, and photosynthetic rate

There is a strong correlation between soybean chlorophyll content and mutagenesis in this study. Low-dose gamma-irradiated mutants exhibited enhanced chlorophyll content. The results confirm that gamma irradiation enhanced chlorophyll levels in Paulownia tomentosa plants, as reported by Abu *et al.* (2005). Additionally, gamma-ray treatment of dried Lupin seeds improved total chlorophyll content and photosynthetic activity, according to Khodary and Moussa, (2003) findings. The 150 Gy mutant applied with 60 % WUE without mulch recorded a high chlorophyll content. The same genotype applied with 40% WUE with 60 t/ha of mulch also performed well.

Moreover, the 200 Gy mutant with mulching of 40 t/ha from first planting also recorded high chlorophyll content. The 150 Gy mutant of the same mulching rate and planting date also records high chlorophyll content. In general, drought inhibits energy transmission from PSII to PSI, which has a considerable impact on photosynthesis according to Siddique *et al*. (2016) who agreed with the finding of the study. There is also less palisade of spongy tissues and ultimate leaf thickness, resulting in a decrease in chlorophyll fluorescence according to Wang *et al.* (2018). Measurements of chlorophyll fluorescence are used to determine how photosynthesis responds to drought (Kalaji *et al.*, 2018). The plants from 200 Gy with mulching of 40 t/ha from the first planting date recorded high chlorophyll content followed by the 150 Gy of the same mulching and planting dates. Chlorophyll decreased under soil moisture stress conditions. Oxidative stress generated by chlorophyll degradation and pigment photo-oxidation is attributed to soil moisture stress, as described by Wijewardana *et al*. (2019) in their study. Reduced moisture leads to photosynthesis and low dry matter production, according to the current study. These results are in confirmation by Gunes *et al.* (2008) and Masoumi *et al.* (2010) who reported that the reduction in chlorophyll content is attributed as a typical symptom of oxidative stress.

The genotypes with 40 t/ha mulch from the first planting had the highest chlorophyll content as compared to the genotypes that applied the same mulch from the second planting. This could be a result of water stress during the second planting phase. There was less chlorophyll and photostatic rate per unit of the ground area because of the smaller canopy, which is a valuable indicator for measuring how much radiation can be converted to plants. It appears that drought and high temperatures, as Hussain *et al.* (2018) found, produced a large drop in pigment concentration. Drought-stressed soybean plants had a 31 % lower chlorophyll content than control plants, according to Majdi *et al*. (2020). Atti *et al*. (2004) came to similar conclusions. Drought stress causes pigments and related protein complexes to be photo-inhibited and destroyed, as well as the photosynthetic membrane to be disrupted. The current study's decline in chlorophyll content could be due to a decrease in the activity of several enzymes involved in chlorophyll synthesis and an increase in the activity of enzymes that degrade chlorophyll content (Dias and Brüggemann, 2010). According to Guo *et al.* (2006), heat stress may have lowered chlorophyll levels by damaging thylakoid membranes which agreed with the finding of this study. As a result of heat stress, Chlorophyll a and Chlorophyll b, as well as carotenoid and chlorophyll fluorescence levels, decreased in the plants, according to Moussa, (2011). Heat stress could lead to the development of hazardous redox oxygen species (Camejo *et al*., 2006; Guo *et al*., 2007). Temperature increases chlorophyllase activity in plants, which inhibits photosynthetic and respiratory activity, according to research (Todorov *et al*., 2003; Sharkey and Zhang, 2010)

The results from this study also showed that mutagenesis and disrupted as well as negatively affected the leaf area index of soybean. Mutants derived from the low dosage of irradiation had an improved leaf area index. In general, Jenguma at week 12 after planting recorded a higher leaf area index than the improved genotypes followed by 150 Gy mutant which also recorded the second-highest leaf index. A similar finding was observed by Stoeva, (2000) who reported that irradiating dry bean seeds of cultivar Plovdiv10 with 150 and 200 Gy inhibits the development of young bean plants by 23 and 50 % respectively. Plants applied with 60 t/ha mulching recorded the highest leaf area index followed by the 40 t/ha whereas the crops without mulch recorded the least leaf index. This means the availability of adequate soil moisture and optimum soil temperature improves the leaf area index. According to Pagter *et al*. (2005), the lower LAI under drought stress circumstances is due to fewer newly produced leaves with smaller sizes and a higher rate of dropping which is in line with the finding of this study.

5.3 Biomass Accumulation

The highest fresh shoot-root ratio was found with 250 Gy mutant from the second planting, followed by Jenguma planted at the same time, while the lowest fresh shoot-root ratio was found with 150 Gy and 200 Gy mutant from the second planting. Also mulching rate of 20 tons/ha of plants planted late recorded the high fresh shoot-root ratio whilst plants from the 40 t/ha and 60 t/ha from the second planting recorded the lowest fresh shoot-root ratio. Soybean genotypes showed similar results in terms of fresh root weight. According to Fenta *et al*. (2014), drought stress affects soybean root architecture, including branching density, root angle, depth, and biomass levels in the soil. Many soybean accessions have exhibited reduced root lengths and biomass accumulation during drought circumstances according to Thu *et al*. (2014). According to Franco *et al*. (2011) and Fenta *et al.* (2014), drought changes root architecture as well as the breakdown of root-to-shoot biomass.

The 150 Gy mutant 20 t/ha mulching planted early produced the highest biomass accumulation. This study also found that Jenguma mutant plants had higher biomass and seed output than the 150 Gy mutant plants. There were increases in leaf area, grain yield, and other yield-related indicators in plants treated with these qualities. A study by Yang *et al.* (2019) confirm that biomass and root-shoot ratio are critical markers of plant vigor in an ecosystem where interplant rivalry is present. A similar finding was observed by Craine and Dybzinski, (2013), in terms of nutrients and moisture, plants with a higher biomass accumulation and comparative root mass are more competitive. Drought stress reduced biomass accumulation by 63% and total biomass by 61% when considering the influence of water stress on biomass accumulation. Soybean biomass accumulates as a result of a reduction in plant leaf number and leaf size caused by dryness. This finding agrees with Marron *et al*. (2003) who said continuous drought decreases the number of leaves and leaf area expansion rates. In addition, they continued to argue that shorter cotyledonary branches and the main axis in water-stressed groundnut plants are observed following drought. The finding agrees with Candido *et al.* (2000) who concluded that the availability of water influences stem elongation which results in a decrease in dry matter accumulation. High-temperature stress occurs when the temperature rises above 35°C. Heat stress slowed plant growth and reduced the number of grains in pods, resulting in lower biomass accumulation.

5.4 Component of the yield and earliness to flower

All of the mutants flowered early, even though they were genetically altered. According to Zaka *et al.* (2004), mutagenesis lowered the number of days to 50 % flowering and days to maturity, suggesting that there is a link between the two factors. When irradiated at high levels, however, days to flowering decrease. This observation is also in line with Kushan and Mandal (2003). As gamma irradiation dosages were increased, seed germination and plant growth may have been delayed, contributing to the late flowering responses. Gamma irradiation may have delayed seed germination and plant growth, which may have contributed to the late-blooming responses.

In comparison to the mutant, Jenguma had a noticeable and significant delay in flowering. The interaction between genotype, mulch, and planting dates was also significant, according to the findings of this study. The 200 Gy mutant at a 20 ton/ha mulching from second planting took fewer days to reach 50 % flowering as compared to Jenguma and mutant genotypes. Early flowering of plants from the second planting date may be a result of a mechanism to tolerate and escape water stress. Plants from 250 Gy mutants applied with 100% WUE and mulched 20 t/ha grasses took a smaller number of days to reach 50% flowering. Plant development, as well as the number of flowers and seeds per pod, is delayed by the high temperatures of the plants that were not mulched. This backs up the conclusion of Canci and Toker (2009). Also, heat stress influences the reproductive stage by decreasing the number and size of flowers, deforming floral organs, and resulting in the loss of flowers and young pods, and hence a reduction in seed yield (Morrison and Stewart, 2002). High temperatures exhibited a significant unfavorable impact on reproductive processes in the current research. According to Jumrani *et al.* (2018), the period of flowering was greatly prolonged while the number of flowers and pods generated was drastically reduced. Stress during the vegetative process might have reduced photosynthetic rate, leaf area, and biomass accumulation with the plant recovering to some degree once the stress was removed. stress during the reproductive stage affected reproductive processes such as flower abortion, reproductive efficiency, seed growth, and young pod development. Stress during the reproductive process also had little chance of recovery, resulting in a significant loss of soybean productivity as reported by Jumrani *et al.* (2017).

Also, the highest seed weight was found in genotypes 200 Gy and 250 Gy. The weight of the soybean hundred seeds differed significantly depending on the planting date. In general, genotypes from the first planting had the highest hundred seed weight relative to genotypes from the second planting. The highest hundred seed weight was recorded by the 200 Gy at 60 tones/ha mulched planted second, while the lowest hundred seed weight was recorded by the 300 Gy at 60 tones/ha mulched planted first. According to Udensi *et al.* (2011) the number of pods per plant, pod length, number of seeds per pod, 100 seed weight, and seed yield are all related. mutagenesis may have increased flower set and, as a result, pod production which was evident with the 250 Gy mutant. Temperature variations during seed filling affect legume yield, according to Rainey and Griffiths (2005). In the current study, heat stress throughout the pod and seed filling stages led to a considerable drop in grain yield. High temperatures have been linked to a decrease in seed weight and number in a variety of crops (Devasirvatham *et al*., 2010)

5.4.1 Total yield

The total grain yield of the 250 Gy from the first planting was the highest, while the total grain yield of Jenguma from the second planting was the lowest. The study's findings revealed that mutagenesis improved grain yield. Addai and Safo-Kantanka (2006) found a similar increase in yield after exposing three soybean genotypes to gamma radiation at varied dosages. Plant number, dry matter production, seed number, and seed size are the main factors that influence soybean yield. Plants from the first planting produced the highest grain yield which could be attributed to the fact that they were not exposed to any water stress. According to Jumrani and Bhatia (2018), water stress led to poorer soybean yields in terms of seed weight, total biomass, pods per plant, seeds per plant, seeds per pod, and grain weight per 100 grains. In the reproductive stage of soybeans, water constraints can alter plant metabolism, resulting in smaller pods and seeds, reduced seed weight, leaf senescence, as well as a shorter plant life cycle, all of which can affect productivity as reported by Farooq *et al*. (2017).

Heat stress also interferes with the seed filling process, which hurts seed production. They finally reduce assimilate production and mobilization to develop seeds in numerous crops (Zare *et al.*, 2012).

But different crop species have varied heat sensitivity (Sung *et al.*, 2003); an increase of one degree Celsius reduces plant output by at least 10%. Seed filling is expedited at high temperatures to minimize the duration of this stage to limit the yield potential (Boote *et al.*, 2005).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Four mutant soybean genotypes plus one standard check (Jenguma) were planted and subjected to five levels of water application and four levels of mulching in both pot and field studies. The observed variations in the growth and yield of these genotypes revealed that mutagenesis had a significant effect on these mutant genotypes. The 200 Gy and 250 Gy as the best performing genotype. In general, drought stress had adverse effects on the growth and yield of the genotypes. However, 150 Gy, 200 Gy, and 250 Gy mutants were found to be tolerant

In general, genotypes from the first planting date with mulching of 20 t/ha and 40 t/ha were also observed to be tolerance to heat stress.

6.2 Recommendations

Genotypes 200 Gy and 250 Gy are recommended to be released as varieties to farmers in the Guinea Savanna agroecological zone. Further studies should be carried out in different agroecological zone to evaluate the response of the mutant soybean genotype to drought and high soil temperature.

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APPENDICES

Appendix 1: Analysis of Variance of chlorophyll of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	757.7	378.9	1.73	
REP.*Units* stratum					
Genotype	4	1214.9	303.7	1.39	0.240
irrigation_rate	4	350.2	87.5	0.40	0.809
mulching	3	1676.2	558.7	2.55	0.057
Genotype.irrigation_rate	16	2814.3	175.9	0.80	0.682
Genotype.mulching	12	2569.2	214.1	0.98	0.473
irrigation_rate. mulching	12	2454.7	204.6	0.93	0.515
Genotype. Irrigation_rate. mulching	48	9941.9	207.1	0.94	0.049
Residual	198	43405.8	219.2		
Total	299	65184.9			

Appendix 2: Analysis of Variance of leaf area index of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.76822	0.38411	15.25	
REP.*Units* stratum					
Genotype	4	0.06017	0.01504	0.60	0.665
irrigation_rate	4	0.16675	0.04169	1.65	0.162
mulching	3	0.20363	0.06788	2.69	0.047
Genotype.irrigation_rate	16	0.43714	0.02732	1.08	0.372
Genotype.mulching	12	0.26377	0.02198	0.87	0.576
irrigation_rate. mulching	12	0.19050	0.01588	0.63	0.815
Genotype. Irrigation_rate. mulching	48	1.37086	0.02856	1.13	0.023
Residual	198	4.98754	0.02519		
Total	299	8.44859			

Appendix 3: Analysis of Variance of leaf area index of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.1964	0.0982	0.16	
REP.*Units* stratum					
Genotype	4	0.5790	0.1448	0.24	0.916
irrigation_rate	4	3.2752	0.8188	1.35	0.252
mulching	3	0.5809	0.1936	0.32	0.811
Genotype.irrigation_rate	16	4.9577	0.3099	0.51	0.940
Genotype.mulching	12	6.9505	0.5792	0.96	0.493
irrigation_rate. mulching	12	4.3310	0.3609	0.60	0.844
Genotype.irrigation_rate. mulching	48	28.3862	0.5914	0.98	0.024
Residual	198	119.9938	0.6060		
Total		299	169.2508		

Appendix 4: analysis of variance of leaf area index of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	8.795	4.397	1.36	
REP.*Units* stratum					
Genotype	4	20.504	5.126	1.58	0.050
irrigation_rate	4	10.203	2.551	0.79	0.534
mulching	3	10.541	3.514	1.09	0.356
Genotype.irrigation_rate	16	17.567	1.098	0.34	0.992
Genotype.mulching	12	24.018	2.002	0.62	0.025
irrigation_rate. mulching	12	30.206	2.517	0.78	0.673
Genotype.irrigation_rate. mulching	48	147.952	3.082	0.95	0.036
Residual	198	640.678	3.236		
Total	299	910.464			

Appendix 5: Analysis of Variance of PH12WAP of soybean mutant lines

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		67.0	33.5	0.11	
REP.*Units* stratum						
Genotype	4		757.3	189.3	0.60	0.665
irrigation_rate	4		1407.8	352.0	1.11	0.353
mulching	3		1236.9	412.3	1.30	0.276
Genotype.irrigation_rate	16		2407.5	150.5	0.47	0.957
Genotype.mulching	12		2215.0	184.6	0.58	0.855
irrigation_rate. mulching	12		2294.7	191.2	0.60	0.838
Genotype.irrigation_rate. mulching	48		20529.7	427.7	1.35	0.082
Residual	196	(2)	62174.2	317.2		
Total	297	(2)	92974.3			

Appendix 6: Analysis of Variance of PH3WAP of soybean mutant lines

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		117.63	58.82	2.20	
REP.*Units* stratum						
Genotype	4		230.87	57.72	2.16	0.035
irrigation_rate	4		159.02	39.76	1.49	0.207
mulching	3		66.67	22.22	0.83	0.477
Genotype.irrigation_rate	16		274.98	17.19	0.64	0.845
Genotype.mulching	12		125.84	10.49	0.39	0.965
irrigation_rate. mulching	12		611.64	50.97	1.91	0.035
Genotype.irrigation_rate. mulching	48		2101.33	43.78	1.64	0.010
Residual	194	(4)	5176.92	26.69		

Total	295	(4)	8806.70

Appendix 7: Analysis of Variance of PH6WAP of soybean mutant lines

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		662.97	331.48	4.73	
REP.*Units* stratum						
Genotype	4		1075.86	268.96	3.84	0.005
irrigation_rate	4		249.64	62.41	0.89	0.470
mulching	3		400.96	133.65	1.91	0.130
Genotype.irrigation_rate	16		540.58	33.79	0.48	0.954
Genotype.mulching	12		728.45	60.70	0.87	0.582
irrigation_rate. mulching	12		1111.56	92.63	1.32	0.208
Genotype.irrigation_rate. mulching	48		5258.09	109.54	1.56	0.018
Residual	195	(3)	13657.42	70.04		
Total	296	(3)	23360.90			

Appendix 8: Analysis of Variance of PH9WA of soybean mutant lines

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		52.4	26.2	0.10	
REP.*Units* stratum						
Genotype	4		1276.5	319.1	1.26	0.287
irrigation_rate	4		1528.1	382.0	1.51	0.201
mulching	3		2174.4	724.8	2.86	0.038
Genotype.irrigation_rate	16		2642.4	165.2	0.65	0.838
Genotype.mulching	12		1822.8	151.9	0.60	0.841
irrigation_rate. mulching	12		1641.5	136.8	0.54	0.887
Genotype.irrigation_rate. mulching	48		16971.0	353.6	1.40	0.060

Residual	195	(3)	49378.7	253.2		
Total	296	(3)	772			

Appendix 9: Analysis of Variance of LN12WAP of soybean mutant lines

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		48.	24.	0.02	
REP.*Units* stratum						
Genotype	4		5574.	1393.	1.19	0.019
irrigation_rate	4		3049.	762.	0.65	0.629
mulching	3		3525.	1175.	1.00	0.394
Genotype.irrigation_rate	16		6643.	415.	0.35	0.990
Genotype.mulching	12		5303.	442.	0.38	0.971
irrigation_rate. mulching	12		10787.	899.	0.76	0.686
Genotype.irrigation_rate. mulching	48		56557.	1178.	1.00	0.478
Residual	190	(8)	223333.	1175.		
Total	291	(8)	308176.			

Appendix 10: Analysis of Variance of LN3WAPof soybean mutant lines

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		146.07	73.03	3.88	
REP.*Units* stratum						
Genotype	4		267.49	66.87	3.55	0.008
irrigation_rate	4		113.36	28.34	1.50	0.202
mulching	3		52.94	17.65	0.94	0.424
Genotype.irrigation_rate	16		223.99	14.00	0.74	0.747
Genotype.mulching	12		324.18	27.02	1.43	0.153
irrigation_rate. mulching	12		170.13	14.18	0.75	0.698
Genotype.irrigation_rate. mulching	48		1083.53	22.57	0.020	0.197
Residual	195	(3)	3672.28	18.83		
Total	296	(3)	6010.73			

Appendix 11: Analysis of Variance of LN6WAP of soybean mutant lines

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		627.97	313.98	5.59	
REP.*Units* stratum						
Genotype	4		310.81	77.70	1.38	0.041
irrigation_rate	4		267.25	66.81	1.19	0.317
mulching	3		359.64	119.88	2.13	0.097
Genotype.irrigation_rate	16		844.79	52.80	0.94	0.524
Genotype.mulching	12		802.36	66.86	1.19	0.292
irrigation_rate. mulching	12		414.90	34.58	0.62	0.828
Genotype.irrigation_rate. mulching	48		4025.71	83.87	1.49	0.031
Residual	197	(1)	11063.75	56.16		
Total	298	(1)	18717.11			

Appendix 12: Analysis of Variance of LN9WAPof soybean mutant lines

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		20.6	10.3	0.03	
REP.*Units* stratum						
Genotype	4		542.7	135.7	0.43	0.085
irrigation_rate	4		1680.5	420.1	1.34	0.257
mulching	3		913.0	304.3	0.97	0.408
Genotype.irrigation_rate	16		2998.4	187.4	0.60	0.884
Genotype.mulching	12		3954.7	329.6	1.05	0.406
irrigation_rate. mulching	12		1329.5	110.8	0.35	0.978
Genotype.irrigation_rate. mulching	48		17594.0	366.5	1.17	0.232
Residual	196	(2)	61558.8	314.1		
Total	297	(2)	90421.3			

Appendix 13: Analysis of Variance of Day to the flowering of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	6569.3	3284.7	8.49	
REP.*Units* stratum					
Genotype	4	807.5	201.9	0.52	0.720
irrigation_rate	4	4194.6	1048.6	2.71	0.031
mulching	3	2452.1	817.4	2.11	0.100
Genotype.irrigation_rate	16	2400.3	150.0	0.39	0.984
Genotype.mulching	12	4778.6	398.2	1.03	0.423
irrigation_rate. mulching	12	9776.3	814.7	2.11	0.018
Genotype.irrigation_rate. mulching	48	25323.4	527.6	1.36	0.024
Residual	198	76596.3	386.9		
Total	299	132898.3			

Appendix 14: Analysis of Variance of vigor soybean mutant lines

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		0.12178	0.06089	0.70	
REP.*Units* stratum						
Genotype	4		0.15497	0.03874	0.44	0.777
irrigation_rate	4		0.36388	0.09097	1.04	0.388
mulching	3		0.54202	0.18067	2.07	0.106
Genotype.irrigation_rate	16		0.46048	0.02878	0.33	0.994
Genotype.mulching	12		0.50906	0.04242	0.49	0.922
irrigation_rate. mulching	12		0.76259	0.06355	0.73	0.724
Genotype.irrigation_rate. mulching	48		5.34396	0.11133	1.27	0.030
Residual	196	(2)	17.14156	0.08746		
Total	297	(2)	25.39477			

Appendix 15: Analysis of Variance of total Hundred seeds weight mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	36.149	18.075	3.17	
Rep.*Units* stratum					
Genotypes	4	97.380	24.345	4.26	0.004
mulching	3	3.902	1.301	0.23	0.877
Planting_Date	1	3.120	3.120	0.55	0.042
Genotypes. Mulching	12	52.282	4.357	0.76	0.036
Genotypes.Planting_Date	4	26.668	6.667	1.17	0.332
mulching. Planting_Date	3	2.092	0.697	0.12	0.947
Genotypes. mulching. Planting_Date	12	41.406	3.451	0.60	0.032
Residual	78	445.343	5.710		
Total	119	708.342			

Appendix 16: Analysis of Variance of Biomass Accumulation of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	30799.	15400.	1.17	
Rep.*Units* stratum					
Genotypes	4	31815.	7954.	0.60	0.662
mulching	3	1194.	398.	0.03	0.993
Planting_Date	1	13127.	13127.	0.99	0.322
Genotypes.mulching	12	139391.	11616.	0.88	0.571
Genotypes.Planting_Date	4	14356.	3589.	0.27	0.895
mulching. Planting_Date	3	5663.	1888.	0.14	0.934
Genotypes. mulching. Planting_Date	12	156351.	13029.	0.99	0.019
Residual	78	1030441.	13211.		
Total	119	1423137.			

Appendix 17: Analysis of Variance of Chlorophyll content yield of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Rep stratum	2	83.68	41.84	1.92	
Rep.*Units* stratum					
Genotypes	4	1.04	0.26	0.01	1.000
mulching	3	125.23	41.74	1.91	0.134
Planting_Date	1	412.85	412.85	18.94	<.001
Genotypes.mulching	12	398.86	33.24	1.52	0.023
Genotypes.Planting_Date	4	62.75	15.69	0.72	0.041
mulching. Planting_Date	3	52.00	17.33	0.80	0.030
Genotypes. mulching. Planting_Date	12	256.41	21.37	0.98	0.025
Residual	78	1700.59	21.80		
Total	119	3093.42			

Appendix 18: Analysis of Variance of Dry Biomass Accumulation of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3835.8	1917.9	2.04	
Rep.*Units* stratum					
Genotypes	4	1145.3	286.3	0.30	0.874
mulching	3	1190.9	397.0	0.42	0.737
Planting_Date	1	10060.2	10060.2	10.71	0.002
Genotypes.mulching	12	6624.5	552.0	0.59	0.846
Genotypes.Planting_Date	4	2185.7	546.4	0.58	0.677
mulching. Planting_Date	3	2424.2	808.1	0.86	0.465
Genotypes. mulching. Planting_Date	12	12552.8	1046.1	1.11	0.361
Residual	78	73248.2	939.1		
Total	119		113267.7		

Appendix 19: Analysis of Variance of dry shoot root ratio of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	117.14	58.57	2.07	
Rep.*Units* stratum					
Genotypes	4	25.70	6.42	0.23	0.923
mulching	3	51.82	17.27	0.61	0.610
Planting_Date	1	50.94	50.94	1.80	0.184
Genotypes.mulching	12	423.29	35.27	1.25	0.268
Genotypes.Planting_Date	4	145.60	36.40	1.29	0.283
mulching. Planting_Date	3	46.73	15.58	0.55	0.649
Genotypes. mulching. Planting_Date		12	312.72	26.06	0.032
0.531					
Residual	78	2208.27	28.31		
Total	119	3382.22			

Appendix 20: Analysis of Variance of Dry-shoot of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3361.6	1680.8	1.92	
Rep.*Units* stratum					
Genotypes	4	1154.9	288.7	0.33	0.857
mulching	3	1270.9	423.6	0.48	0.694
Planting_Date	1	8187.3	8187.3	9.35	0.003
Genotypes.mulching	12	6083.0	506.9	0.58	0.853
Genotypes.Planting_Date	4	2215.1	553.8	0.63	0.641
mulching. Planting_Date	3	2371.5	790.5	0.90	0.444
Genotypes. mulching. Planting_Date		12	11348.6	945.7	1.08
0.388					
Residual	78	68265.9	875.2		
Total	119	104258.7			

Appendix 21: Analysis of Variance of the dry root of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Rep stratum	2	17.33	8.67	0.82	
Rep.*Units* stratum					
Genotypes	4	13.52	3.38	0.32	0.865
mulching	3	1.48	0.49	0.05	0.987
Planting_Date	1	96.37	96.37	9.09	0.003
Genotypes.mulching	12	148.59	12.38	1.17	0.120
Genotypes.Planting_Date	4	42.07	10.52	0.99	0.017
mulching. Planting_Date	3	18.07	6.02	0.57	0.037
Genotypes. mulching. Planting_Date	12	162.76	13.56	1.28	0.047
Residual	78	826.52	10.60		
Total	119	1326.72			

Appendix 22: Analysis of Variance of Days to 50% Flowering of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3226.467	1613.233	181.44	
Rep.*Units* stratum					
Genotypes	4	568.200	142.050	15.98	<.001
mulching	3	33.867	11.289	1.27	0.291
Planting_Date	1	750.000	750.000	84.35	<.001
Genotypes.mulching	12	115.800	9.650	1.09	0.024
Genotypes.Planting_Date	4	0.000	0.000	0.00	0.030
mulching. Planting_Date	3	0.000	0.000	0.00	0.012
Genotypes. mulching. Planting_Date		12	0.000	0.000	0.00
0.050					
Residual	78	693.533	8.891		
Total	119	5387.867			

Appendix 23: Analysis of Variance of fresh root wight of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	650.0	325.0	0.92	
Rep.*Units* stratum					
Genotypes	4	1393.4	348.4	0.99	0.420
mulching	3	889.7	296.6	0.84	0.476
Planting_Date	1	871.0	871.0	2.46	0.120
Genotypes.mulching	12	4233.8	352.8	1.00	0.038
Genotypes.Planting_Date	4	755.6	188.9	0.53	0.711
mulching. Planting_Date	3	791.5	263.8	0.75	0.528
Genotypes. mulching. Planting_Date		12	5759.9	480.0	1.36
0.204					
Residual	78	27563.2	353.4		
Total	119	42908.1			

Appendix 24: Analysis of Variance of fresh shoot root ratio of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	787.0	393.5	1.92	
Rep.*Units* stratum					
Genotypes	4	691.3	172.8	0.84	0.501
mulching	3	911.8	303.9	1.48	0.225
Planting_Date	1	283.0	283.0	1.38	0.243
Genotypes.mulching	12	1404.0	117.0	0.57	0.049
Genotypes.Planting_Date	4	1067.5	266.9	1.30	0.036
mulching. Planting_Date	3	825.9	275.3	1.34	0.026
Genotypes. mulching. Planting_Date	12	1806.6	150.5	0.74	0.713
Residual	78	15968.8	204.7		
Total	119	23745.9			

Appendix 25: analysis of variance of fresh shoot weight of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	31543.	15772.	1.34	
Rep.*Units* stratum					
Genotypes	4	24623.	6156.	0.52	0.720
mulching	3	3527.	1176.	0.10	0.960
Planting_Date	1	7235.	7235.	0.61	0.436
Genotypes.mulching	12	129647.	10804.	0.92	0.535
Genotypes.Planting_Date	4	14591.	3648.	0.31	0.871
Mulching. Planting_Date	3	6270.	2090.	0.18	0.911
Genotypes. mulching. Planting_Date	12	127096.	10591.	0.90	0.552
Residual	78	919304.	11786.		
Total	119	1263836.			

Appendix 26: Analysis of Variance of leaf area index 6WAP of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	26.272	13.136	6.81	
Rep.*Units* stratum					
Genotypes	4	13.099	3.275	1.70	0.159
mulching	3	5.185	1.728	0.90	0.447
Planting_Date	1	180.636	180.636	93.61	<.001
Genotypes.mulching	12	33.408	2.784	1.44	0.045
Genotypes.Planting_Date	4	4.257	1.064	0.55	0.028
mulching. Planting_Date	3	3.074	1.025	0.53	0.662
Genotypes. mulching. Planting_Date	12	32.319	2.693	1.40	0.016
Residual	78	150.520	1.930		
Total	119	448.769			

Appendix 27: Analysis of Variance of leaf area index 6WAPof of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.125	1.562	1.42	
Rep.*Units* stratum					
Genotypes	4	4.773	1.193	1.09	0.369
mulching	3	1.741	0.580	0.53	0.664
Planting_Date	1	59.222	59.222	53.96	<.001
Genotypes.mulching	12	9.325	0.777	0.71	0.039
Genotypes.Planting_Date	4	5.194	1.299	1.18	0.025
mulching. Planting_Date	3	1.235	0.412	0.38	0.021
Genotypes. mulching. Planting_Date			12	11.026	0.919
0.84	0.012				
Residual	78	85.614	1.098		
Total		119	181.256		

Variate: Appendix 28: Analysis of Variance of leaf area index 9WAP of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	77.952	38.976	5.97	
Rep.*Units* stratum					
Genotypes	4	65.220	16.305	2.50	0.050
mulching	3	18.846	6.282	0.96	0.415
Planting_Date	1	71.251	71.251	10.91	0.001
Genotypes.mulching	12	103.727	8.644	1.32	0.223
Genotypes.Planting_Date	4	14.240	3.560	0.54	0.703
mulching. Planting_Date	3	6.677	2.226	0.34	0.796
Genotypes. mulching. Planting_Date					
	12	97.446	8.120	1.24	0.270
Residual	78	509.605	6.533		
Total	119	964.964			

Appendix 29: Analysis of Variance of leaf area index 12WAP of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	171.50	85.75	5.62	
Rep.*Units* stratum					
Genotypes	4	162.76	40.69	2.67	0.038
mulching	3	43.81	14.60	0.96	0.418
Planting_Date	1	41.68	41.68	2.73	0.103
Genotypes.mulching	12	234.54	19.54	1.28	0.047
Genotypes.Planting_Date	4	37.62	9.41	0.62	0.042
mulching. Planting_Date	3	13.94	4.65	0.30	0.122
Genotypes. mulching. Planting_Date		12	219.12	18.26	1.20
0.001					
Residual	78	1190.85	15.27		
Total 119 2115.81					

Appendix 30: Analysis of Variance of leaves number 3WAP of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	178.16	89.08	1.42	
Rep.*Units* stratum					
Genotypes	4	240.41	60.10	0.96	0.436
mulching	3	432.15	144.05	2.29	0.084
Planting_Date	1	4164.23	4164.23	66.33	<.001
Genotypes.mulching	12	538.45	44.87	0.71	0.033
Genotypes.Planting_Date	4	360.42	90.10	1.44	0.030
mulching. Planting_Date	3	273.86	91.29	1.45	0.034
Genotypes. mulching. Planting_Date			12	697.03	58.09
0.93	0.026				
Residual	78	4897.17	62.78		
Total 119 11781.88					

Appendix 31: analysis of variance of leaves number 6WAP of soybean mutant lines

Variate: LN6WAP					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	753.4	376.7	3.27	
Rep.*Units* stratum					
Genotypes	4	1133.1	283.3	2.46	0.052
mulching	3	566.5	188.8	1.64	0.187
Planting_Date	1	14406.7	14406.7	124.93	<.001
Genotypes.mulching	12	1981.5	165.1	1.43	0.040
Genotypes.Planting_Date	4	393.3	98.3	0.85	0.496
mulching. Planting_Date	3	206.8	68.9	0.60	0.618
Genotypes. mulching. Planting_Date		12	2196.8	183.1	1.59
0.113					
Residual	78	8994.8	115.3		
Total		119	30633.1		

Appendix 32: analysis of variance leaves number 9wap of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	865.8	432.9	1.76	
Rep.*Units* stratum					
Genotypes	4	3261.7	815.4	3.31	0.015
mulching	3	1225.6	408.5	1.66	0.183
Planting_Date	1	22367.9	22367.9	90.78	<.001
Genotypes.mulching	12	3107.2	258.9	1.05	0.413
Genotypes.Planting_Date	4	1097.7	274.4	1.11	0.356
mulching. Planting_Date	3	173.4	57.8	0.23	0.872
Genotypes. mulching. Planting_Date		12	3736.8	311.4	1.26
0.257					
Residual	78	19218.0	246.4		
Total		119	55054.2		

Appendix 33: analysis of variance leaves number of 12wap of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1264.7	632.4	1.89	
Rep.*Units* stratum					
Genotypes	4	4323.3	1080.8	3.24	0.016
mulching	3	1673.9	558.0	1.67	0.180
Planting_Date	1	18458.8	18458.8	55.26	<.001
Genotypes.mulching	12	4371.0	364.2	1.09	0.380
Genotypes.Planting_Date	4	1414.9	353.7	1.06	0.383
mulching. Planting_Date	3	259.8	86.6	0.26	0.855
Genotypes. mulching. Planting_Date		12	5217.2	434.8	1.30
0.235					
Residual	78	26054.3	334.0		
Total		119	63037.8		

Appendix 34: analysis of variance of nodule weight of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.567	0.783	0.37	
Rep.*Units* stratum					
Genotypes	4	9.724	2.431	1.14	0.343
mulching	3	7.027	2.342	1.10	0.354
Planting_Date	1	3.254	3.254	1.53	0.220
Genotypes.mulching	12	30.463	2.539	1.19	0.303
Genotypes.Planting_Date	4	7.310	1.828	0.86	0.492
mulching. Planting_Date	3	5.266	1.755	0.83	0.484
Genotypes.mulching. Planting_Date		12 27.199	2.267	1.07	0.400
Residual	78	165.902	2.127		
Total		119	257.711		

Appendix 35: Analysis of Variance of Number of nodules of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	10658.4	5329.2	11.33	
Rep.*Units* stratum					
Genotypes	4	1228.8	307.2	0.65	0.626
mulching	3	2185.0	728.3	1.55	0.209
Planting_Date	1	21759.4	21759.4	46.25	<.001
Genotypes.mulching	12	4066.8	338.9	0.72	0.727
Genotypes.Planting_Date	4	4064.2	1016.1	2.16	0.081
mulching. Planting_Date	3	1014.6	338.2	0.72	0.544
Genotypes. mulching. Planting_Date		12	3196.9	266.4	0.57
0.013					
Residual	78	36696.0	470.5		
Total		119	84870.1		

Appendix 36: Analysis of Variance of plant Height of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	71.30	35.65	0.97	
Rep.*Units* stratum					
Genotypes	4	160.48	40.12	1.09	0.365
mulching	3	192.72	64.24	1.75	0.163
Planting_Date	1	2315.29	2315.29	63.15	<.001
Genotypes.mulching	12	263.79	21.98	0.60	0.036
Genotypes.Planting_Date	4	265.76	66.44	1.81	0.035
mulching. Planting_Date	3	7.33	2.44	0.07	0.977
Genotypes. mulching. Planting_Date		12	697.75	58.15	1.59
0.013					
Residual	78	2859.94	36.67		
Total		119	6834.36		

Appendix 37: Analysis of Variance of Plant Height 6WAP of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	339.4	169.7	1.22	
Rep.*Units* stratum					
Genotypes	4	865.8	216.4	1.56	0.193
mulching	3	502.5	167.5	1.21	0.312
Planting_Date	1	10.5	10.5	0.08	0.784
Genotypes.mulching	12	1848.0	154.0	1.11	0.363
Genotypes.Planting_Date	4	330.3	82.6	0.60	0.667
mulching. Planting_Date	3	105.8	35.3	0.25	0.858
Genotypes. mulching. Planting_Date		12	903.3	75.3	0.54
0.880					
Residual	78	10807.7	138.6		
Total		119	15713.3		

Appendix 38: Analysis of Variance of Plant Height 9WAP of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1496.2	748.1	3.10	
Rep.*Units* stratum					
Genotypes	4	1318.1	329.5	1.37	0.254
mulching	3	172.2	57.4	0.24	0.870
Planting_Date	1	21792.0	21792.0	90.30	<.001
Genotypes.mulching	12	4500.2	375.0	1.55	0.123
Genotypes.Planting_Date	4	1587.6	396.9	1.64	0.171
mulching. Planting_Date	3	280.1	93.4	0.39	0.763
Genotypes. mulching. Planting_Date		12	2852.0	237.7	0.98
0.021					
Residual	78	18823.5	241.3		
Total		119	52821.9		

Appendix 39: Analysis of Variance of Plant Height 12WAP of soybean mutant lines

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2958.1	1479.0	3.06	
Rep.*Units* stratum					
Genotypes	4	2008.8	502.2	1.04	0.393
mulching	3	298.5	99.5	0.21	0.892
Planting_Date	1	8188.2	8188.2	16.92	<.001
Genotypes.mulching	12	8718.1	726.5	1.50	0.142
Genotypes.Planting_Date	4	2493.8	623.4	1.29	0.282
mulching. Planting_Date	3	492.8	164.3	0.34	0.797
Genotypes. mulching. Planting_Date		12	5751.3	479.3	0.99
0.466					
Residual	78	37747.2	483.9		
Total		119	68656.6		