**UNIVERSITY FOR DEVELOPMENT STUDIES**

# ON-STATION EVALUATION OF SOYBEAN (*Glycine max* (L.) Merill) MUTANT GENOTYPES FOR IMPROVED AGRONOMIC TRAITS IN NORTHERN GHANA

**BY**

**YAKUBU ABDUL-KARIM**

**(UDS/MCS/0030/16)**

**THESIS SUBMITTED TO THE DEPARTMENT OF AGRONOMY, FACULTY OF AGRICULTURE, UNIVERSITY FOR DEVELOPMENT STUDIES, NYANKPALA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE**

**MARCH, 2020**

# DECLARATION

STUDENT:

I hereby declare that this thesis is the result of my original work and that no part of it has been presented for another degree in this University or elsewhere:

Yakubu Abdul-Karim ……………………….. …………………………

(Student) Signature Date

SUPERVISORS:

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

Dr. Isaac Kwahene Addai ……………………….. …………………………

(Principal Supervisor) Signature Date

Dr. Fredrick Kankam ……………………….. ..…………………………

(Co-Supervisor) Signature Date

## ABSTRACT

Soybean [*Glycine max* (L.) Merrill] is an important oilseed crop in the world. Despite the important role soybean plays in the achievement of nutritional security in low income families, its production is low due to relatively long maturity period, pod shattering, low yield, poor quality oil, low resistance to diseases and abiotic stresses. Previous studies in the Department of Agronomy of the University for Development Studies have resulted in the production of mutant genotypes with desirable agronomic traits. In the present study, these soybean mutant genotypes were evaluated in three agro-ecological zones – Transition, Guinea Savannah, and Sudan Savannah zones of northern Ghana. The soybean genotypes used for the study were 150 Gy, 200 Gy, 250 Gy, and 300 Gy mutants and the un-irradiated (0 Gy) which served as control. Fertilizer application rates of 0 kg/ha, 45 kg/ha, 60 kg/ha, and 75 kg/ha of Triple Super Phosphate (TSP) were applied three weeks after planting. The treatment combinations were replicated 3 times in each agro-ecological zone resulting in a 5 x 4 x 3 factorial experiment and laid out in Randomized Complete Block Design (RCBD). Data were taken on agronomic and yield parameters and analyzed. The results showed that with the exception of plant height, the 0 Gy and 300 Gy recorded the lowest values of traits measured. The 150 Gy, 200 Gy and 250 Gy mutants recorded significant improvement in terms of agronomic and yield traits. The 150 Gy, 200 Gy, and 250 Gy mutants recorded higher grain yields than the 0 Gy and the 300 Gy. The 200 Gy and the 250 Gy genotypes are therefore recommended for on-farm evaluation prior to their release for commercial production.

## DEDICATION

This work is dedicated to my family and friends for their sense of care and love.

## ACKNOWLEDGEMENTS

I am most grateful to the Almighty Allah for His protection, grace and mercies shown me throughout this time.

My sincere thanks go to the USAID - Feed the Future (FtF) Agricultural Technology Transfer (ATT) for providing funding to support the research.

I wish to express my profound gratitude to my supervisor, Dr. Isaac K. Addai, for his suggestions, direction, guidance and constructive criticisms to put this work to good shape. I equally acknowledge the immense contribution of my Co-supervisor, Dr. Fredrick Kankam towards the successful completion of this work.

I also acknowledge all the staff of the Agronomy Department of UDS for showing me a path to endless opportunities and I pray that they reap the fruits of their efforts especially Dr. Benjamin K. Badii, the immediate past Head of Agronomy Department for guiding me throughout the study and preparation of this thesis. To the ATT project coordinator Prof. Samuel Donkoh and his abled assistant Mr. Isaac Gershon, I am humbled by your guidance and positive criticisms to come out with this work.

My profound gratitude goes to my parents Abdul-Karim Mahame “Nyankpala Dungunaa” and Hajia Memunatu Wumbei as well as the rest of my family members for their prayers and financial support. There is a lot I could not have done without their support.

Lastly, I am also indebted to all those who supported directly or indirectly including the following people: Mr. Abdulai, Mohammed Awal, Adamu, Isaac Kenja, Seidu, and Thomas for your support throughout my field work and in the write-up of this thesis “Mpagya ya pam”.

## TABLE OF CONTENTS

Content Page

## LIST OF TABLES

Table Title Page

## LIST OF FIGURES

## LIST OF ACRONYMS

| Acronym | Meaning |
|---|---|
| CRI | Crops Research Institute |
| CV | Coefficient of Variation |
| d. f. | Degree of Freedom |
| F. pr. | Fisher's Probability |
| G x E | Genotype x Environment |
| Gy | Gamma Irradiation |
| IITA | International Institute for Tropical Agriculture |
| LSD | Least Significant Difference |
| NB | Number of Branches |
| NL | Number of Leaves |
| NP | Number of Pods |
| PH | Plant Height |
| RCBD | Randomized Complete Block Design |
| s. s | Sum of Squares |
| S.E D | Standard Error of Difference |
| SARI | Savanna Agricultural Research Institute |
| TSP | Triple Super Phosphate |
| UDS | University for Development Studies |
| WAP | Weeks after Planting |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background

Soybean [*Glycine max* (L.) Merrill] is an important oilseed legume crop in the world occupying third position next to cowpea and groundnuts (Ramesh *et al*., 2015). It is believed to have originated from China and was first introduced into the colony of Georgia, United States of America by Samuel Bowen in 1765 (Hymowitz and Shurtleff, 2005). Soybean was first introduced to Sub-Sahara Africa (SSA) by traders from China in the 19th century and was grown as an economic crop as early as 1903 in South Africa (Khojely *et al*., 2018). It was later introduced into Ghana in 1909 (Shurtleff and Aoyagi, 2014). Soybean is considered a triple beneficiary crop, for the fact that it contains 20 % oil and 38-42 % high quality proteins, and equally fixes atmospheric nitrogen in the soil at the level of 150-200 kg per hectare per season (Deshmukh and Deshmukh, 2013).

Soybean is a highly nutritious food item and it is known as the “golden bean”, “miracle bean” and or “the crop” of the planet because of the extraordinary benefits we derive from it (Arshad *et al*., 2006). A soybean on the average has 40% protein and 20% oil respectively and is thus considered as a highly nutritional value crop (Arefrad *et al*., 2012). Soybeans were cultivated for their seeds, which could be processed into wide varieties of food including soymilk, bean curd (tofu), sufu, soy sauce, and tempeh hence, soybean and its products were regarded essential to ordinary diets (Cai, 2012). Soybean seed is an essential source of minerals including those of potassium (K), Calcium (Ca), Zinc (Zn), Iron (Fe), Boron (B), and phosphorus (P). High oleic acid and low linolenic acid are desirable for the oil industry as a result of their contributions to oil steadiness and shelf life (Bellaloui *et al*., 2015).

Globally, soybean production has been increasing due to the high demand of soy products for food, feed and the developing market for biodiesel to replace the depleting fossil fuel resources. It is however projected that, it will account for almost 20% of total production by 2030 (Harvey and Pilgrim, 2011). The crop is categorized as an oilseed containing substantial amounts of all ten indispensable amino acids, minerals and vitamins for human nutrition (Sarwar *et al*., 2013). It has quite a number of benefits associated with its production and has the potential of making the fight against global hunger and malnutrition a reality. In terms of nutrition, soybean is believed to have twice the protein content of meat or poultry and contains all eight essential amino acids required for childhood development (Arshad *et al*., 2006). Soybean rightly claims the title "the meat that grows on plant" (Arshad *et al*., 2006). Soybean is the highest, cheapest and easiest source of best quality proteins and fats and also has a vast multiple uses as food and industrial products (Gopinath and Pavadai, 2015).

Soybean production over the last decade has more than doubled. The production currently reaches close to 6% of the global total cultivable land. The production is expanding considerably faster than other most important grains or oilseeds globally (Goldsmith, 2017). Soybeans progressively are being engaged as the contemporary input of choice for consumers. They are mainly used as intermediary food, feed and industrial inputs and not final consumer products, therefore remaining somewhat imperceptible in the economy. It is only 2% of soybean protein that is believed to have been and is eaten directly by humans in the form of soy food commodities such as tofu, soy hamburger, or soy milk analogs (Murphy *et al*., 1999). All but a fewer percentage of the other 98% is processed into soybean meal and given to livestock, such as poultry and pigs.

Soybean demand is thus fundamentally a resultant demand for meat. It has climbed to become a prominent crop since the income elasticity of meat is high. End users of soybean have shifted their eating from cereal grains, such as rice and wheat to meat and other animal products as individual incomes rise around the globe (Goldsmith, 2017).

The future looks bright for soybean producers as demand for soybean seed and soybean foodstuffs in the global market continue to increase. This is because there is a growing demand for soy products across the globe. For instance, Goldsmith (2017) reported that soybean demand in Europe is swelling for there is a high increase in demand for vegetarian animal feeds to substitute bone meal. According to Smith and Huyser (1987) soybean serves as a cheaper and a higher protein rich substitute to animal protein. This makes soybean an important crop in the world and has been the dominant oilseed since the 1960s. Also, fish feedstuff obtained from wild fish stocks is on the decline, creating a booming and new market in the high-growth aquaculture-producing regions of Asia and South America. It is worth noting that food manufacturers are gradually shifting far from animal by-products as a source of fat or oil, and in the 1970s concerns were raised about saturated fats from tropical oils. Consequently, it triggered a rise in demand as U.S. food producers switched from palm oil to less saturated oils, such as soybean. These events generated substantial prospects for soybean oil to become the favorite oil for food producers. Subsequent evidence links the presence of trans-fatty acids, found in refined soybean oil, with heart disease (Goldsmith, 2017).

Currently, exports of soybean seed and products account for more than 10% of world agricultural trade (Wilson, 2008). Production of soybeans in the United States of America in contemporary years shows an upsurge in average values of 76 million acres of soybean being harvested annually from 2009-2013 (Glauber and Effland, 2016). Correspondingly, average price per bushel of soybean (1 bushel = 27.2 kg) has also almost doubled, from $7.65/bu from 2004-2008 to $12.03 from 2009-2013 (Coe *et al.*, 2014 and Hill *et al.*, 2014).

Before 1976, very little soybean was grown in Argentina, Brazil, Paraguay, and Uruguay but between 1976 and 2010, soybean cultivation in the four countries increased from 1.58 million tons grown on 1.37 million hectares of land to well over 130 million tons on 45 million hectares (FAO, 2012). That is, there was an average increase of 1.09 million hectares planted and 3.22 million tons produced annually (Bonato *et al.*, 2006 ). Soybean is considered a non-native and non-staple crop in Sub-Saharan Africa (SSA) which potentially could become a commercial crop owing to its wide variety of uses as food, feed, and industrial raw material. Over the last four decades, soybean cultivation area and total production in SSA has increased tremendously from about 20,000 ha and 13,000 t in the early 1970s to 1,500,000 ha and 2,300,000 t in 2016 (Khojely *et al.*, 2018). Also the share of soybean production in the world's oilseed production has increased averaging 55%. Over the last ten years total production of the crop has expanded at a rate of over 5% per year on average (Thoenes, 2006).

The world's leading producers of soybean are the United States of America, Brazil, Argentina and China. These four countries together produce up to 90% of the global soybean with Africa and other countries in Asia apart from China accounting for only 5% of the total world production figures (Thoenes, 2006). According to Cai (2012), China in the past was the largest soybean producer and exporter in the world until the second half of the 20th century. However, in this day and age the main producers of soy are the United States, Brazil, Argentina and China. Brazil produced 95 million tons in almost 31-million-hectare area. It is considered the second largest producer and exporter of the crop in the world (Marchiori *et al*., 2015). According to Guilherme *et al* (2002) soybean is the fourth most widely cultivated crop in the world. Soybean is also a major source of protein rich feed component for livestock, poultry, pig and fish farms in Ghana (Dei, 2011 and Dogbe *et al*., 2013). Soybean meal which is a by-product of soybean oil processing can be utilized as a major source of protein feed for chicken, cattle, horse, sheep, and fish and many prepackaged meals as well (Hassan, 2013). This makes the crop an important cash and oil seed crop in the country. The crop is comparatively drought tolerant and needs lower production inputs and technical know-how yet produces good yield especially in good soils, it does not grow and develop well in water logged areas (Morgan, 2017).

Ghana has a total land area of 23,853,300 hectares of which the arable land area is 13, 600,000 hectares and only 6, 341, 930 is put under cultivation of crops (MoFA, 2017). The total land size put under crop production indicates that a greater proportion of it is allocated for the cultivation of crops like cassava, maize, yam, plantain, groundnut, rice, and cocoyam, etc to the detriment of crops like soybean (MoFA, 2017). In fact the report indicates that the total annual estimated land used for soybean production from 2007 to 2016 had never exceeded 92, 000 ha. The annual production from this same report indicates a steady increase in soybean being production since 2013 after it drastically reduced in 2012 from 165, 000 Mt to about 152, 000 Mt respectively.

## 1.2 Problem Statement

The United Nations in its 2015 report projects the world's population to increase from the current 7.3 billion to 9.7 billion people by 2050; and that most of this increase is expected to be occurring in the developing world and thus suggests the necessity to increase food production (FAO, 2014). Considerable efforts are carried out to improve grain legume production levels. Unfortunately, soybean yields in many developing countries seem far lower when compared to those attained in the developed countries (FAO, 1983). For example, yields of soybean are said to be averaging 240, 368, 553, 714 and 1167 kg/ha for Tanzania, Nigeria, Cameroon, Rwanda and Uganda in that order. This is in sharp contrast to the recorded yields of soybean for United States of America (U.S.A.) and Brazil which record higher values, being in excess of 2400 kg/ha (Dunbar, 1975; Egli and Cornelius, 2009). According to the Agriculture in Ghana Facts and Figures report (2012), Ghana has achievable soybean yield potential of 2.3 Mt/ha but currently averaging at 1.9 Mt/ha. The higher yields recorded are partly attributed to the application of enhanced crop production methods including the utilization of biological nitrogen fixation (BNF) techniques (Nkwiine and Zake, 1990).

Farmers face challenges in the cultivation of soybeans; some of these include pod shattering, low yield, poor quality oil, low resistance to diseases, and susceptibility to drought. Poor seed quality of soybean affects its processing quality as (Mbanya, 2011) in Ghana. Pod shattering causes significant yield loss in most soybean genotypes, especially if found in cultivated farms. This results in the emergence of the crop as a weed in the following growing season as well as having a drastic effect on yield.

Low production of soybean in some African countries could also be attributed to the gender imbalance as it is male dominated (Agada, 2015). The nutrient content of soybeans and its products is affected by amount of anti-nutritional factors (ANFs), inefficiency of the oil-extraction process as well as the quantity of unwanted bodies available, the heat processing and many other reasons ( Rocha *et al*., 2008). According to Palacios et al., (2004), the anti-nutritional factors of soybean can result in retardation of growth, reduced feed efficiency, goitrogenic responses, pancreatic hypertrophy, hypoglycemia, as well as liver damage in monogastric animals depending on their species, age, size, and sex, condition of health and level of nutrition required.

According to Mohammed (2010), large scale production of soybean takes place in Ghana within the Transition and Guinea Savanna agro ecological zones. Crops mature at the end of October or early November, for most of the varieties that are cultivated in Ghana. Considering the growing population, researchers are interested in releasing crop varieties that are able to give relatively higher yields at lesser cost to feed the ever increasing population and efforts made at introducing genetically modified crops is not easy because of cultural, religious and ethical concerns (Glenn, 2013).

Production of soybeans in the world is projected to increase by 2.2% yearly to 371.3 million tons by 2030 (Masuda and Goldsmith, 2009). More efforts need to be put in place in the face of diminishing arable land to other developmental projects as there is a move towards an uncontrolled industrialization. Available arable land for soybean production will decrease as a result of increasing farmland loss due to urbanization, intensified sensitivities about agricultural utilization of land, and weak property rights in regions such as Africa that militates against the use of modern agricultural techniques (Goldsmith *et al.,* 2015)

Several steps could help remedy the situation in order to save the growing population of hunger and malnutrition. Some of these steps may include carrying out more research in the areas of breeding to produce high yielding crops such as soybean. Thus, the continuous breeding of new cultivars having high yield, stability and better adaptation to several growing regions is very important to maintaining competitiveness of soybean as well as increase its economic returns comparatively to other crops (Guilherme *et al.*, 2002).

Research for expanding soybean yields, resistance to disease, and overall cost-effectiveness could help soybeans compete favourably with other grains. The soybean industry may seek to give a boost to the corresponding relationship with corn through vigorously pursuing research that aims at reducing cost of pest management and control, and fertilizer costs, and that which enhances soil quality and environmental performance when soybeans are alternated with corn (Goldsmith, 2017). Mutagenesis has been employed to increase the yield and agronomic performance of most crops but more needs to be done especially in grain legumes. Conventional breeding takes a lot of time in producing new varieties with improved and/or desirable traits. Genetic engineering has also been employed in crop improvement but considering issues of religion, health, and ethics, not many people are interested in transgenic plants.

### 1.3 Justification

Increasing soybean production which invariably would result in an increase in the consumption of soybean and its products is of paramount significance for achieving the goals of self-sufficiency and food security in Ghana. Many small scale farmers mostly in the low rainfall areas are gradually digressing from producing traditional crops such as maize to soybean production that is believed to be fetching them more attractive prices on the market, despite its being money involving (Bindura and Bindura, 2014). An important distinguishing trait of soybean is its ability to grow in harsh ecological environments (Deshmukh and Deshmukh, 2013).

Consequently, for increasing supply of soybean to cater for the decline in land availability, it is important for policy makers and managers to see the crucial need for significant increases in investments in yield improvement research (Masuda and Goldsmith, 2009). Two scenarios are suggested to help increase soybean output to meet the demand of the commodity; increase planted hectares or increase yield (tons/ha). It is believed that, going forward, available farmland for soybean production could be limited as a result of decreasing quantities of land not already in production, increased farmland loss to urbanization, heightened sensitivities about agricultural uses of land, and weak property rights such as the land tenure systems in regions such as Africa that constrains the employment of modern and integrated agricultural methods. Development of new soybean genotypes with high grain yield potential would thus be important.

Different breeding approaches have been employed to bring about improvements in crops. CRI (2010) report has it that, soybean production went up from 1000 to 10,000 t between 1979 and 1992 due to the fact that farmers' adopted improved cultivars and production technologies, but imports of soybeans continued to increase (198,000 t imports, versus 96,050 t productions in 2009). Before we can increase production and export, it is important to develop high yielding soybean varieties and, or expand production technology with quality control. Even though soybean is an important oil crop and was introduced in the country in early 19th century it is not able to get popularized among many farmers and the main reason being that, there is lack of genetic variation and breeding work, and/or inadequate genotypes for different cropping systems (Arshad *et al*., 2006). According to them, basic understanding of some genetic factors is very essential for proper understanding and handling of any crop breeding programme. This is important because grain yield is the result of the manifestation and association of several plant growth components. Though correlation coefficients may be useful in determining the size and direction of character associations, it can be misleading if the high correlation between two traits is a result of the indirect effect of the traits (Arshad et al., 2006).

Mutation breeding (Mutagenesis) is one of the techniques that have been applied to improve the quality of some varieties of crops including soybean to meet specific needs. Mutation breeding has been employed in recent years as a valuable supplement to other methods of plant breeding in developing new variability and development of crop varieties with new architecture, greater biochemical composition and appropriate growth and developmental rhythms. The use of this method is obvious from the fact that in a number of crops induced mutants have been released as new varieties (Khan and Tyagi, 2013). Qing et al., (1996) has reported that after irradiation of soybean seeds for

3 days with 500 rad gamma rays, the number of mitochondria per cell decreased, while the number of vacuoles increased and cell structure changed dramatically with formation of organelles. It is in the light of this that work started in the Department of Agronomy of the Faculty of Agriculture of the University for Development Studies - Nyankpala Campus on mutagenesis in the year 2013 and has since produced mutant genotypes with improved agronomic traits. These soybean mutant genotypes are being evaluated in all the three agro-ecological zones of northern Ghana to evaluate the genotypes for their adaptability in the various ecological zones.

## 1.4 Objectives

The main objective of the research is to develop genotypes of soybean with improved agronomic traits and determine the effect of Triple Superphosphate on their yield performance in three different agro-ecological zones of northern Ghana.

## 1.5 Specific Objectives

1. To produce soybean genotypes with earliness to flowering
2. To produce soybean genotypes with high yielding ability.
3. To determine the effect of Triple Superphosphate on the mutant genotypes
4. To produce soybean genotypes that mature early.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Origin and Distribution of Soybean

Historical and geographical evidence has it that soybean (*Glycine max*) was domesticated in the 1l$^{th}$ century BC in northern China. Soybean is considered one of the ancient plants on earth, for the reason that its growing in the Far East dates back from written records, three thousand years BC (3,000 BC) and has since then represented the customary food of the Asian continent of the world (Vlahović, *et al*., 2013). Soybean is more popularly referred to as a Chinese herb, because it is believed to have originated from China. Its present-day history begins in the 19$^{th}$ century in America where it began spreading the world over and occupied an important place in contemporary agriculture.

According to Ho (1955) soybean spread from China to other parts of Asia by traders from China who took soybeans with them on sea expeditions but they were not known in the West until 1765 when it was first introduced to the United States as reported by Hymowitz and Harlan (1983). But it was not until the 1920s that American farmers started growing soybeans in commercial quantities, basically for animal feed. Conversely, by the Second World War, when edible oils and customary sources of protein were in limited supply, soybean began to make its valued contribution to the human diet, establishing it as one of the world's most important economic crop.

The similarities between *Glycine max* and *Glycine soja* was studied with a survey of landraces all over China. The two species were most related in seed protein content, frequency of “Ti” a (trypsin inhibitor) (Burton, 1997).Yellow River Valley, the native land of primordial Chinese civilization, was the likely place of Centre of origin because of the existence of great number of landraces with high genetic diversity. It then spread from there to southern and east China through Korea into Japan (Probst and Judd, 1973). The Yellow River basin is thus a major candidate for the Centre of origin of soybean domestication. Southern China, the Yangtze basin has also been suggested as the native land of soybean based on phylogenetic and clustering analyses by means of microsatellites and nucleotide diversity (Guo *et al*., 2010).

Piper and Morse (1923) reported that Eastern Asia is the native place of soybean and that *Glycine ussuriensis*, the progenitor of *G. max* was known in China, Manchuria and Korea. Fukuda (1933) argued that Manchuria was the birthplace of soybean. He centered his arguments on the following fact that *G. gracillis*, a closely related species is common in Manchuria, and numerous soybean varieties are grown in Manchuria and many of the cultivated varieties found in Manchuria and near region have primitive characteristics in their morphology.

According to Hymowitz and Shurtleff (2005) soybean is believed to have originated from China and was first introduced into the colony of Georgia, United States of America by Samuel Bowen in 1765. Through the activities of Chinese traders, soybean was introduced into Africa in the early 19th century. Soybean was first grown in Tanzania in 1907. But in Ghana, soybean was first cultivated in 1909 as was same in the case of Gambia and Kenya (Shurtleff and Aoyagi, 2014).

## 2.2 Production of Soybean

Soybean is currently cultivated over a large geographical area globally with United States of America, Brazil and Argentina being the most important producers of the commodity in the world. When matched with other major food crops, soybean has experienced the highest percentage of annual increases in production area over the last four decades, up from 29 million ha in 1968 to 97 million ha in 2008. This constitutes about 6% of the world's farmlands; but still follows wheat, rice, and maize in the world's total area under production (Hartman *et al*., 2011). Soybean production is mainly attributed to its many uses including feed, oil and other products. There has been an increase in the world's demand for eatable oil from soybean and whose trend will continue to surge in the future following the ever increasing world population and the improvement in the economies of the developing world as well as the alteration in the dietary choices of the affluent in the society (Dei, 2011).

Most of the supermarkets today are chock-full of treated foods sandwiched with vegetable oil on the ingredient list. Mostly, oil is added to food for sense of taste, additional nutrition, and to enhance its cooking abilities. The use of the soybean oil has therefore been on the increase over the last decade. Its utilization in Brazil and China has risen to about 15% and 40% per annum, respectively. Brazil is the highest consumer with an average consumption of 30 kilograms of soybean oil per capita, whereas China consumes just 4 kilograms per capita. The United States on the other hand consumes about 27 kilograms per capita, this is a decline in its consumption rate of edible soybean oil by 21% over the past decade (Goldsmith, 2017). In recent times though, the United States seem to have shifted their attention from the high human consumption to biodiesel production which has led to a new but important market for soybean oil, and currently accounts for 15% of U.S. soybean oil requirements (USDA, 2007).

Soybean production in Sub-Saharan Africa (SSA) has increased tremendously from about 20,000 ha and 13,000 t in the early 1970s to 1,500,000 ha and 2,300,000 t in 2016 (Khojely *et al.*, 2018). Production in this area could have been more if the approximately 600 million hectares of arable land were put to cultivation. Geographically, Sub-Saharan Africa is the area of the African continent situated south of the Sahara, roughly between 15° N and 35° S with a total area of 21.2 million square kilometers but, of which less than 10% is now cultivated. The leading soybean producers in SSA currently are  South Africa, Nigeria, Zambia, and Uganda (Khojely *et al.*, 2018).

### 2.3 Climatic and Edaphic Requirements of Soybean

Cultivation of grain crops comprises one of the most significant agricultural activities in Ghana. These crops are highly affected by climate and soil properties in which they grow. Soybean is a hot weather crop that is appropriate for whole year growth in many parts of the tropics. At least 15$^{o}$C of temperature is necessary for germination of the soybean seed and average temperatures ranging from 20-25$^{o}$C for its growth and development. Soybeans need at least reasonable soil moisture for it to germinate and for seedlings to become well established, but require dry weather for the production of dry seed. Waterlogged soils make soybeans suffer. Mostly, growing soybean plants can tolerate substantial drought. Seed yield potential per plant is believed to be closely associated with the variety's day length requirement and the planting season (Martin, 1988). It is thus suggested, therefore, that in the introductory phases of developing soybean as a crop in a new area, several varieties be tried as well as a number of planting dates, and that careful notes be taken including planting date, date of flowering, harvest date, and number of seeds per plant.

In Ghana, there are about six known agro ecological zones with varied characteristics explaining why particular food crops are grown in each area. Crop adaptation is determined primarily by genotype x environment interaction. The suitability of a crop to a particular region depends largely on the climatic features of the region in relation to the requirements for normal growth and development of the crop. Crop performance will reflect a combination of the quality of the agronomic management regime imposed, the seasonal conditions experienced, and the adaptation of the crop species and cultivar. Soybean is one of the legumes that are well adapted to a variety of soils and soil conditions. Nonetheless, it performs well on fertile but workable, porous, loamy soil, which when well aerated allows free flow of air in particular within the roots and nitrogen for effective nitrogen fixation in the soil. It has been reported by Njeze (1993) that soybean can equally do well in fertile sandy soils within the acceptable pH range of 5.5 and 7.0, and also that the soybean plant tolerates acidity better than other leguminous crops but performs poorly in terms of growth and development in waterlogged, saline and alkaline soil conditions.

According to Ferguson (2003) the most favorable soil pH range of 5.5 - 7.0 for soybean production augments nutrient availability, including but not limited to nitrogen and phosphorus break down of residues and associated nitrogen fixation by available soil microbes. It is also reported by Rienke and Joke (2005) that optimum yield in loamy textured soil is encouraged.

The determination to expand soybean production faces various soil teething troubles, especially those of soil acidity and Aluminium toxicity. Aluminium (Al) toxicity is considered one of the major constraints to increased crop production on acid soils. This is particularly so in the light of the fact that 40% of the world's arable land is acidic (Horst and Klotz, 2002). Soybean is arguably one of the most delicate crops to Al noxiousness. This is so because the complex inheritance of Al tolerance attribute has for some time now been undermined by breeding efforts to develop Al-tolerant soybeans. Al toxicity remains a major problem for increasing global food production more especially in developing tropical and subtropical regions, where the increase in food production is highly needed (Yuliasti and Sudarsono, 2011). Al toxicity serves as a major problem for increasing world food production especially in developing tropical and subtropical regions, where the increase in food production is much needed. Al reduces crop yield by inhibiting and hindering root growth thus affecting nutrient and water uptake of soybean plants (Yuliasti and Sudarsono, 2011). Al tolerance has been studied for many years in soybean.

Aluminium in the soil decreases crop yield through root growth inhibition and interference in both nutrient and water uptake (Ciamporová, 2002; Gopal and Iwama, 2007). Several researches have been done on Al tolerance for many years in soybean. For these years, researchers have evaluated genetic response in a number of test settings including greenhouse pots, sandy culture, nutrient solution and tissue culture (Horst and Klotz, 2002). Nowadays, however, only reasonable levels of Al tolerance have been discovered in soybean. All these factors may potentially be important in the breeding of Al tolerant soybean cultivars.

Climate is a source of variability and risk, that is, it can cause, in some situations, a negative impact on agricultural activities thus affecting the farmer's decision. Studies have indicated that there is a correlation between climate and vegetative growth rate of soybean. Seed germination, as one of the growth stages in soybean is sensitive to low temperatures (Penalba *et al*., 2007) and it is revealed that within the sowing to flowering stage, air temperature and photoperiod mostly influence soybean, and humidity also influences the flowering to maturity stage (Penalba *et al*., 2007). Irrigation may prevent such losses in drought years, but water availability and the expense of installing and maintaining irrigation equipment may be limiting. Flooding can also be problematic, as soybean cannot survive many days with fully submerged roots (Oosterhuis *et al*., 1990). Soybean is tolerant to a wide range of soil conditions but does best on warm, moist, and well drained fertile loamy soils, that supply sufficient nutrients and good contact between the seed and soil for quick germination and growth (Osman, 2011).

Sanchez et al. (2003) stated that, soybean does well in fertile sandy soils with pH of between 5.5 and 7.0, and that the crop can tolerate acidic soils than other legumes but does not grow well in waterlogged, alkaline and saline soils. Maintaining soil pH between 5.5 and 7.0 boosts the availability of nutrients including nitrogen and phosphorus, and facilitates microbial breakdown of crop residues and symbiotic nitrogen fixation (Toth *et al*., 2006).

Among all the factors essential in agricultural production, the climate is the most difficult to control and it exercises greater restrictive action in the full yield of crops. It worsens as a result of the difficult to predict occurrences of adverse weather, the main risk factors in the exploration of major crops. Abiotic stresses such as drought, extreme rain, extreme temperatures and low light can significantly reduce yields of crops and restrict the locations, times and soils where the species of the most important commercial ones can or cannot be cultivated (de Avila *et al.*, 2013). Summer high temperature and rainfall excesses during the period of maturity and harvest have the greatest negative impact on the crop, whilst higher minimum temperatures during the growing season favour high yields (Penalba *et al*., 2007). Soybeans require moderate soil moisture for germination of seedlings and to become established, but requires dry weather for the production of seeds. Soybean plants may suffer under waterlogged conditions, but when established, soybean plants are able to tolerate considerable drought (Martin, 1988).

Soybean is a day length sensitive crop. The physiological response of plants to the relative lengths of the diurnal cycles of light (daylength) and dark periods is called Photoperiodism. The most fundamental aspect of this response is the change from vegetative to reproductive phase in photoperiod sensitive plants such as soybeans, which includes most modern day crop species. Depending on their adaptation, photoperiod sensitive species are induced to progress from vegetative to reproductive phase when subjected to certain critical daylengths. Most species of tropical or subtropical adaptation are classed as Short Day (SD) plants – they grow vegetatively through the long days of late-spring/summer/early-autumn, and undergo floral initiation when autumn daylength declines to a certain critical value. In contrast, most species of temperate adaptation are described as Long Day (LD) plants.

Yield per plant is related to the photoperiod requirement of the variety of soybean and its planting season (Martin, 1988). Soybeans remain at the vegetative phase under long day conditions, and flowering is rapidly initiated under short day length. This causes low pod filling as much time is wasted at the vegetative growth phase at the expense of the flowering stage (Harper *et al.*, 1970). The final yield of dry matter from a plant depends on the solar radiation absorbed by the leaves and the efficiency with which this radiant energy is converted into chemical energy through the process of photosynthesis. Photoperiod length of soybean varies from one variety to the other until it reaches its critical point above which flowering is delayed. Although flowering may occur, it is more slowly and thus rapidly as the days become shorter ( de Avila *et al.*, 2013).

In soybean production, water availability is very important especially at the germination, emergence and or flowering to grain filling stages. This is due to the fact that, excess or lack of water is detrimental to the crop’s establishment and at the same time obtaining a good but uniform plant population. To ensure good germination soybean seeds need to absorb an amount of water equivalent to 50% of its weight (de Avila *et al.*, 2013). Soybean is a tropical crop requiring temperatures between 15-25 $^{o}$C for germination and growth. de Avila et al. (2013) reported that soybean grows well at temperatures between 20$^{o}$C and 30$^{o}$C. It also requires moderate soil moisture but not waterlogged conditions for seedling germination and establishment. It requires dry weather for dry seed production and is able to withstand considerable drought levels (Martin, 1988).

## 2.4 Economic Importance of Soybean

Any improvement in the production and productivity of soybean is likely to give a contribution to agribusiness development that will create more employment opportunities. Soybean production is increasing much faster than other major crops. Close to 6% of the world's arable land is now being used for soybean production. Soybean is a valuable and economically important agricultural commodity for several reasons: It has good agronomic traits including good adaptability to wide range of soils and climate, and ability to enhance soil fertility by fixing atmospheric nitrogen through the root nodules and also through leaf fall on the ground at maturity (Uwaoma, 2015). The overall economic value of soybean is multifaceted as it serves the need of both humans and animals in several ways.

### 2.4.1 Soybean as source of animal feed

Currently soybeans and soybean products are used widely as a main source of animal feed. It is therefore grown as a source of protein and oil for the human as well as the animal feed market. Rocha et al. (2008) reported that soybean meal is generally regarded as the best source of plant protein considering its nutritional value and that, it is complementarily related with cereal grains in meeting the amino acids requirements of farm animals. Soybean is used as fodder to feed animals. This forage can be made into hay or silage. Soybean cake is also an excellent nutritive food for livestock and poultry. Also, soybean still remains the best source of protein and of course cheaper than meat in some developing countries, especially in rural areas, for improving the nutritional value of traditional foods (Akpapunam *et al*., 1996; Seralathan et al. (1987). In 1917, it was discovered that heating soybean meal made it suitable as livestock feed, which led to the growth of the soybean processing industry and the dual-purpose protein and oil crop of today. After that time, the USA expanded its production and by the

1970s supplied two thirds of the world's soybean needs (Hartman *et al*., 2011). The increased cultivation is attributable to increased meat production worldwide especially that of pork and chicken, in that about 75% of soybean production is used for animal consumption. These producers prefer soybean flour as animal feed to others, because of the high protein content of the soy seed (Fehlenberg *et al*., 2017). Goldsmith (2017) reported that humans consume only 2% of soybean protein directly usually in the form of soy food products including tofu, soy hamburger, or soy milk analogs. He stated that a very small percentage of the other 98% is processed into soybean meal and fed to livestock, such as poultry and pigs. Thus soybean demand is basically a derived demand for meat and has risen to become a leading crop because it has a high income elasticity of meat. This forces consumers to shift their consumption from grains, such as rice and wheat, to meat and other animal products as personal incomes rise around the world. Soybeans are mostly used as intermediate food, feed, and industrial inputs.

### 2.4.2 Soybean as source of edible oil

Soybean oil is now being consumed and added for taste, nutrition, and cooking performance. Its consumption over the last decade has seen an increase considerably (Goldsmith, 2017). Agada (2015) also reports that soybean contains 85% unsaturated and cholesterol free oil when compared with other legumes as well as other animal sources. This is an indication that the crop has a great potential to improve the nutritional status and welfare of the families of resource poor farmers. She opined that soybean is also medicinal and is extremely useful for the prevention and treatment of malnutrition, particularly among children, and in fighting diseases such as heart disease, cancer, diabetes, high blood pressure, stroke, ulcer as well as the loss of body mass among people living with (HIV/AIDS).

Soybean contains a high proportion of unsaturated fatty acids such as linolenic and lineic acids hence; it is healthful oil (Raes *et al*., 2004). The oil is highest in terms of quality (Uwaoma, 2015). Soy protein contains all the important amino acids most of which are present in amounts that closely match those needed from humans or animals. Dashiell (2008) reported that for every 1 kg of soybean there is as much protein in it as, 2 kg of boneless meat or 45 cups of cow milk or 5 dozens of eggs.

There are numerous uses of soy protein in human food. It is used to supplement animal protein products at a lower cost per unit of protein. For example, isolated soy proteins can be used in combination with meat, fish or milk to produce processed products like sausages, and canned meat. Soybean is used to fortify cereal products such as bread, cookies sandwich spread (Naik and Gleason, 2010).

Soybean is used for making high protein food for children. It is also used to fortify local foods so as to increase the protein content/quality of such foods. This includes mixing soybean with maize flour, cassava flour and wheat flour to make fufu. There are drinks mixed with soybean to boast energy as well as supply protein. Soybean contains a good amount of minerals, salt and vitamins (Naik and Gleason, 2010).

### 2.4.3 Soybean as source of foreign exchange

Soybean represents an important source of foreign currency for countries such as Brazil and Argentina in Latin America. Conversely, countries with solid processing industries but low soybean production levels resort to soybean exports to keep the actual labor force and to remain in business to supply the feed requirements of the increasing meat production industry (Chete *et al*., 2014). As an emerging cash crop, soybean production is revolutionizing the rural economy as it raises the living standards of not only soybean farmers but also women and children. In some parts of Asia, the sale of soybean crop represents between 30 percent and 60 percent of the average cash income of the farmer, which is used mostly to buy material inputs for the next crop.

According to reports, Argentina and Brazil are today's leading exporters of soybean meal, and together capturing 64% of world exports; on the other hand France, The Netherlands, and Italy lead soybean meal imports with 23%.

Since the mid-1990s, China dedicated itself to increasing its processing capacity. They shifted domestic policy to favor soybean meal for livestock feed, and soybean oil for human consumption. This policy causes China to import large quantities of soybeans, mostly from Brazil and the United States, to fuel its growing processing industry. China's demand combined with Brazil's relatively small-animal industry resulted in Brazil exporting 73% of the soybeans it produces (production + a small amount of imports), 48% in the form of meal and 52% as raw soybeans (Goldsmith, 2017). Soybean meal is a highly demanded product globally, with continuous increase in the production, exports, imports and consumption of same being observed year after year. Equally the global production and consumption of soybean oil has had similar trend in the last years (Fehlenberg *et al*., 2017).

### 2.4.4 Soybean as a major raw material for industry

Soybeans are used as raw materials for industrial products such as oil, soap, cream, inks, crayons, plastics, textiles and bio-diesels. A large number of industries are therefore established mainly to process soybean grains into edible products for human consumption. This serves as a major source of employment to many people around the world and thus, leads to some form of reduction in the unemployment situation in the world. Also, some processing (i.e., sorting, cleaning, grading, and packaging) of good quality soybeans occur in the country. The United States still holds the most soybean-processing capacity, followed by China and Brazil. Most of the world’s soybeans are processed or crushed into soybean meal and oil (Ali and Singh, 2010). It is estimated that 2% of soybean production is consumed by humans directly as food (Goldsmith 2008), which amounts to an estimated 3 million metric tons of total food produced. The processing industry plays a major role in the provision of adequate nutrition for the teeming populace due to its unique position in meeting the daily food need of different cadres of people in the society living in urban, semi-urban areas and in villages (Ogunsumi *et al*., 2005).

## 2.5 Constraints to soybean production

Notwithstanding the increasing productivity in many parts of the world, the average crop yields in sub-Saharan Africa (SSA) have stagnated at less than 30% of the provincial potential Ariga et al. (2006). The low yields across this region is attributable to many reasons including the poor soils heightened by low fertilizer use, poorly developed agricultural advisory facilities or services, and farmers inability to access favorable input and outputs markets. Soybean production comes with a great potential for improving livelihoods of these resource constrained farmers as it can grow well with limited fertilizers, fix N that can increase production of associated cereals and its market value and demands are high (Mutegi and Zingore, 2014).

Despite the numerous advances countries are making in increasing the production of soybean, there are a lot of drawbacks in its production globally. Some of these challenges are broadly categorized into biotic and abiotic factors and are briefly discussed below.

### 2.5.1 Biotic factors affecting production

The biotic factors that militate against increased production of soybean in the world is attributable to the lack of suitable varieties, the large volumes of pest, viruses and fungi largely in the soil, inadequate number of bacteria for nitrogen fixation and other important microorganisms in the soil (Igiehon and Babalola, 2018). Their presence in either the seed or the soil affects its growth and development to a large extent and thus hinders the yield and quality of the crop. Biotic constraints tend to be geographically and environmentally restricted (Hartman *et al*., 2011). Some diseases like soybean rust may be explosive by producing copious amounts of air-borne spores.

#### 2.5.1.1 Lack of suitable varieties

In the production of soybean, the selection of suitable variety is an important and most difficult management decision a producer must make. In fact careful identification of the problems and needs of the production system is important for good returns. The selection of a suitable variety must take into consideration the maturity period, germination vigor, resistance to disease, and weed-control program, desired growth height, amount of sunlight among others relative to the climatic and edaphic factors in the production area. Multi-locational and multiple yield data are required for selecting the best variety for production in a given area. Consistently high yielding varieties, irrespective of climatic and edaphic factors should be considered (Lee *et al*., 2014). Seed yield and days to maturity are two major factors growers use to select cultivars that will best suit their best interest. Other factors such as plant height and lodging are also factors that can influence seed yield potential or performance. All of these factors combined in any cultivar of soybean, are lacking and choosing which cultivars to plant each year is a daunting task to the farmer (Richardson, 2016).

Soybean varieties with early maturity traits have some advantages as it allows for the farmer to harvest early, avoiding possible drought conditions which is likely to affect production. It also allows the farmer to harvest early to meet high commodity prices in the season (Lee *et al*., 2014). Diversifying plant genetics through planting of multiple soybean varieties may be a good strategy in lowering risks of yield loss due to stress factors (De Bruin and Pedersen, 2008). Equally important to consider when choosing a soybean variety is resistance to diseases. Nematode infection of soybean can reduce yield and varieties developed to resist nematodes must be selected for cultivation rather than non-resistant varieties. Other diseases such as Phytophthora root and stem rot, sudden death syndrome, soybean mosaic virus and stem canker reduces yield substantially and varieties with resistance to those diseases would be a perfect choice.

#### 2.5.1.2 Poor seed production and distribution

The low soybean yield in SSA can be attributed to the use of poor performing varieties and to the limited application of fertilizers and rhizobial inoculants in soils with no history of soybean production.

The use of uncertified seeds by farmers for production seriously affects production output of farmers. It is important to note that soybean seeds are extremely sensitive to many storage factors including temperature, humidity, aeration, pest and pathogens, and physical handling. Therefore, the seeds incline to lose viability in a short time even though they may be certified seeds. Which many a time the farmers are not cognizant of and do not recompense for, the low viability when planting seeds. This most often leads to the need for refilling due to poor germination as a direct result of using low quality seeds from the local market *(*Alhassan *et al*., 2016).

According to Khojely et al. (2018) varieties of soybean introduced from high latitudes in temperate regions and cultivated under short-day conditions at low latitudes in tropical and sub-tropical regions often flower too early, this results in poor seed yield because of insufficient vegetative growth before the reproductive phase of the crop. Hence, soybean varieties that are relatively insensitive to photoperiod are required in SSA regions for better yields.

#### 2.5.1.3 Poor control of insect pests and diseases

Soybeans, like most other crops require a minimum care once planted for proper establishment, growth and development. Weeds will often be a problem and are best controlled by adequate soil preparation and keeping fields free of weeds for 4-6 weeks before planting. Specific herbicide for control of grasses may be used. Broad-leafed weeds must be controlled mechanically. After germination of weeds, mechanical cultivation with a tractor-drawn cultivator or hoe can be done with much care to avoid damage to the plants (Wilcut *et al*., 1995). Diseases of soybean are best avoided by using disease resistant varieties when available, or by improved field practices such as elimination of plant residues and rotation of fields (Krupinsky *et al*., 2002). In general these techniques are useful for insect control as well. Viruses for which there are no curative measures sometimes infect soybeans. Leguminous crops and weeds should be kept away from soybean. If possible, control the disease vectors (insects that carry the virus, such as aphids and white flies). Fungal diseases are most common under wet conditions. Use clean seed, a chemical treatment, and resistant varieties. Insect pests are highly location-specific. Some possible pests and their control are mentioned below:

Aphids could be controlled using biological or chemical control measures. Beetles which are highly varied, some of which may be difficult to control, preventive measures such as weed control and destruction of alternate host plants could be helpful. Others such as flies and moths are likely to be few when soybeans are grown the first time. They are however, likely to increase, as soybeans are grown continuously, or over a wider area. The insect and disease problems that occur are best dealt with individually when encountered.

### 2.5.2 Abiotic factors affecting soybean production

These are those factors that affect the production of soybean but characterized by the absence of life or associated with nonliving or inanimate beings. There are a number of important abiotic and biotic constraints that threaten soybean production by directly reducing seed yields and/or seed quality. Abiotic constraints include extremes in nutrients, temperatures and moisture. These may reduce production directly, but also indirectly through increases in pathogens and pests. Abiotic constraints affecting soybean production are those caused by the physical environment. This includes weather related phenomena, soil nutrient availability, salinity, and response to photoperiod. Farming practices may control some of these abiotic constraints, but many, such as drought, flooding, and frost, have few if any remedies (Hartman *et al.*, 2011).

#### 2.5.2.1 Poor agronomic practices

Several agronomic practices such as variety selection, planting date, planting population, row spacing, and weeding or weed control regimes have effects on the yield potential of soybean. Using inappropriate agronomic practices, such as ploughing, planting (inter and intra planting distances), fertilizer application and weed control methods on soybean farms coupled with low farmer knowledge further results in low output levels of farmers. Generally, these farmers, according to Alhassan et al. (2016) use more labor intensive technologies in land preparation, planting, weeding, harvesting, shelling and bagging of soybean. One of the many constrains to increased soybean production of soybeans in some parts of West Africa is the wide variation in the germination and emergence of soybean seeds in the field from year to year such that plant population densities cannot be met (Adeniyah and Ayoola, 2007). The causes of these challenges include the use of poor quality seeds under bad storage conditions, increased incidence of seed-borne fungal infection (Sinclair *et al*., 2014) and sowing and harvesting when environmental conditions are unfavorable (Martin *et al*., 1988). Planting date affects the yield of soybean and can lead to yield reduction when delayed only a week after the first planting week of the production area (De Bruin and Pedersen, 2011). Early planting of soybean can help increase the yield potential through increases in the crop canopy throughout the season. It is believed that good crop canopy increases light interception and can influence yield potential of crops. Also, early canopy establishment help conserve enough soil moisture that is critical for soybean plant especially at the reproductive stage. Weed control is very critical in improving the yield potential of soybean. The critical period of weed control must be known because that is the period in the crop life-cycle where weed competition causes loss of crop yield. Soybean seedling establishment, weed density, weed species, crop row spacing, and tillage system are some of the factors affecting weed management decisions and the critical period of weed control.

#### 2.5.2.2 Poor Storability

Soybean seeds have a relatively short storage life (Groot *et al*., 2012). In order to obtain a maximum life, soybeans for seed should be grown under exceptional conditions and should mature during dry weather. Pods should be permitted to dry to safe moisture content as much as possible in the field before harvest. Once these pods are dry, they should be harvested by hand or machine. But further drying of the plants in the sun can be done to facilitate threshing. Threshing of soybean is done by hand by flailing (beating) or by machine (Hanna and Quick, 2007). Even after threshing, final drying may be necessary to actually attain safe moisture. This is usually done on a floor (concrete slab) or tarpaulin where the beans are turned regularly. Farmers who have produced coffee should know the details. Once the seeds are dry and before their storage, much trash and dust can be removed by sieving over hardware cloth.

Dry soybeans are best stored at a cool temperature in sealed containers. They can also be stored in a household refrigerator to keep them viable till next growing season (Bewley and Black, 2012). Most soybeans for field planting are not stored for more than one year by which time most of them would lost their viability. In hot, humid climates with poor storage facilities, the viability of the soybeans may fall considerably before the next planting season (Probert, 2003). The viability of the soybean seed can drop to even 50% in just three months if proper storage conditions are not met (Vertucci and Roos, 1990). These are but important factors that must inform the choice of a cultivar in breeding and to ensure the farmer gets value for his investment but, most farmers fail to adhere to these factors in their production in most of the situations. To achieve this, the breeder would want to examine the length of time these seeds could be stored and would still have the ability to remain viable for a long time. There are similar reports that suggest that smaller seeds tend to have a longer storage life under poor storage conditions, including moisture content of the seed grains at harvest and the surrounding temperature/humidity, so you might want to consider storability when making your final variety selections (Romero *et al*., 2005). A proper storage condition for soybean seed may also maintain quality for foods made from soybeans.

### 2.5.2.3 Marketing Problems

Marketing in soybean is a major challenge to increased soybean production and productivity. The fact that most of the producers of the commodity are resource- poor farmers, most of their produce are lost even on the field due to their inability to use mechanized technologies to harvest, clean, dry, and even transport the produce to the marketing centers where they would get good prices for their soybean produce. Agada (2015) reported that because of insufficient capital, a lot of small-scale farmers may perhaps not be able to expand their scale of production and/or take full advantage of gainful packages of machinery to boost productivity. Also, most farmers are not aware of the best post-harvest handling methods of this produce to reduce post-harvest losses as there is inadequate number of extension agents to educate them on these issues. Most soybean farmers do not have information on the market trends when selling their produce and as such unscrupulous traders capitalizes on their ignorance to cheat them. Most farmers are said to be in a total dark as far as this information of marketing of soybean and its products is concerned (Udimal, 2015). They do not have information on the existing prices of the products but rely on price information provided by colleagues and deceitful traders who are in to take advantage over the ignorant producers.

The marketing of agricultural produce in Ghana is an age-long problem. The absence or poor nature of access roads to enhance the evacuation of farm produce from the producing centers to the markets are biggest challenge the farmers face daily. This is further aggravated by the inadequate storage facilities and insufficient agro-processing plants at the production centres and even at the bigger cities in the country. This obstructs agricultural production. During the harvesting period, farmers are at the mercy of middlemen who purchase farm produce cheaply in the areas of production, all in the name of high transportation cost. The seeming lack of good markets for the produce deters farmers from increasing production McGrath et al. (1993).

### 2.5.2.4 Linkage Problems

There is a gap between producers and the consumers, especially such users as government, industry, and research institutions. The government can link up farmers to credit facilities under special policies and programs aimed at fighting malnutrition and hunger for the latter to increase their production. These measures may be in place already but the seeming lack of information may result in farmers not being privy to such interventions. Thus agriculture departments and extension agencies at the local, regional and national levels should link farmers to sources of credit for improved soybean production and productivity. This could be achieved by engaging more extension officers.

The challenge is the lack of adequate extension service staff who have the requisite skills in training and in the spread of agricultural information (Agada, 2015). Also, research institutions should engage the farmers as well in the development of new varieties.

## 2.6 Concepts of Adaptability and Stability

Breeding aims at improving both qualitative and quantitative traits of seeds, which are usually achieved, to a larger extent by plant breeders. It is obvious that the genotype x environment interaction (G x E) is an important factor to consider when selecting and/or when recommending a cultivar to a farmer, and is one of the greatest complications the plant breeder faces (Silva *et al*., 2016).

The challenge however, is how those bred lines are able to adapt to different environments or conditions and maintain their performance. It is therefore imperative to measure the adaptability and stability of genotypes newly developed to further give credence to it being better than the parent cultivar. Also, due to the differences in the edaphic and climatic conditions of different regions, and for that matter agro ecological zones, the need for any new cultivar to be adapted to those environments and also planting dates, investigations are required on the performance of these soybean genotypes for the selected agro ecologies in order to measure the effects of the Genotype x Environment interactions on the desirable traits in the development of soybean lines and cultivars (Batista *et al*., 2015). There are a number of loci involved in phenotypic expression and the influence of environmental factors on the desired traits making gains in the plant-breeding process more difficult. This therefore, makes the use of cultivars that have wide adaptability and good stability a better alternative in reducing the effect of their interaction (Silva *et al*., 2016). Different methodologies have been used to evaluate genotype adaptability and stability in a set of environments, and each methodology adopting different criteria to, as it were, clearly define and estimate these parameters.

Adaptation of a variety/genotype is defined as the ability of the genotype to take advantage of differences in the environment where it is grown. It is thus, a correlation in a way useful to the organism, between structure, function and environment while stability is a reflection of the predictability of behavior of a genotype under varying environmental conditions in which it is grown (Batista *et al*., 2015). Thus the stability of a given genotype is the ability of the genotype to resist displacement or its ability to recover an original position after displacement. That is stability of a genotype is described by its ability, to as it were resist effective changes or to return to its original condition of equilibrium after a short change.

Ramalho et al. (2012) found out in their study that genotype x environment (G x E) interaction hinders their selection on the bases of quantitative traits that have low heritability and therefore require evaluation in different environments. Several studies have also reported that G x E interactions can be reduced using either specific cultivars in particular environments or cultivars with wide adaptability and stability.

### 2.6.1 Adaptability Analysis

According to Silva et al. (2016), production of grain and its adaptation represents the most complex genetic control character, and the effect of environmental factors on such trait is widespread. It is worth noting that in plant breeding, adaptability is usually referred in an agronomic sense and determined in terms of yield potential. Consequently, there is always that conflict between the goals which nature and plant breeders are striving to achieve. Soybean's expansion has been boosted in new agricultural farm lands as a result of the large adaptability of the crop to different environmental conditions (Marchiori *et al*., 2015).

It is imperative to note that, understanding and evaluating the elements that compose Genotype x Environment interaction are very important for genetic breeding programs to allow for further identification of genotypic responsiveness and its predictability due to environmental differences. The adaptability of a particular cultivar is related to its capacity of taking advantageous use of environmental conditions that instigate a response; in other words stability is the ability of the genotype to show a trait that is highly predictable as a matter of environmental modification. Freiria et al. (2016) cited in Cruz et al. (2004) reported in their work that the choice of method for assessing adaptability and stability is linked to the number of available environments as well as to the type of information and the level of experimental precision required. It is therefore important to know and evaluate the elements that comprise the interaction which is very important for genetic breeding programs because they allow for further identification of genotypic responsiveness and predictability as a result of environmental variations.

### 2.6.2 Stability Analysis

Most breeders aim is to improve on the yield of an existing cultivar; as such successful new varieties developed must exhibit high performance for yield and other important agronomic traits. Also, the superiority of this new cultivar, should be reliable across a wide range of environmental conditions (Leon and Becker, 1988) to proof its stability for possible consideration at the expense of the parent cultivar. The reaction of genotypes to such environmental stresses as drought, photoperiodism, and high humidity among others can explain the effects of the G x E interactions and these must be established before one could even think of releasing same for adoption by farmers. One major obstacle in the selection of superior soybean genotypes worthy of promoting is the G x E interactions. It is however, also important as it gives an opportunity for the breeder to select positive interactions that can be associated with the cultivar for production in a wide range of predictable environmental conditions.

### 2.7 Fertilizer Requirements of Soybean

The upsurge in the level of nutrient depletion and soil dilapidation in many smallholder farming systems, in addition to the high cost of fertilizers that limit farmers' ability to replenish soil fertility require alternate nutrient management systems for the restoration and reverse of soil degradation. Soybean plants can utilize nitrogen released by mineralization, residual soil nitrogen, fertilizer nitrogen or atmospheric nitrogen, which is transformed into a usable form in root nodules through a symbiotic relationship between (*Brady rhizobium japonicum*) bacteria and the soybean plant. According to Rao and Reddy (2010), while the soil is the most important source of nitrogen for many crops, soybean obtains 65 % – 85 % of its needs through the symbiotic nitrogen fixation method.

According to the AQUASTAT (2005) soils develop from highly weathered parent materials, alluvial and eroded surface soils are common to all the agro - ecological zones, most of which are characteristically infertile, or the infertility as a result of human activities (MoFA, 1998). Research has shown that the northern half of Ghana is dominated by Luvisols which are designated as having a diversified mineralogy, high nutrient content and decent drainage (Bridges and Van Barren, 1997). According to the AQUASTAT (2005), percentage organic matter and nitrogen are particularly low in the Savannah and Transition agro-ecological zones. It is generally documented that most soils in Ghana have low fertility with the following range of nutrients: pH (4.5 – 6.7), organic matter (0.6 – 2.0), total nitrogen (0.02 – 0.05), available P (2.5 – 10.0 mg $kg^{-1}$ soil) and available Ca (mg $kg^{-1}$ soil) (AQUASTAT, 2005), which are responsible for low food production. In order to maintain soil and crop productivity, it is very important as it were to discover alternate soil fertility replacing strategies different from what small-scale farmers are used to, which will be effective and inexpensive to support value-added livelihoods.

Soybean is famous for its rich source of protein in human diet and animal ration; this is so because it contains substantial quantities of all the essential amino acids, oil, minerals and vitamins (Tefera, 2010). It is therefore economically important leguminous crop in Ghana which is widely cultivated across different agro - ecologies, but its production as per its consumption each year still lags far behind (Plahar, 2006). This according to Byerlee et al. (2007) and Shiferaw (2004), is as a result of low fertility status of most of the cultivated tropical soils which is the major factor leading to the low crop yield. This is further worsened by unsuitable cropping systems including continuous cropping with little or no external inputs as is normally witnessed among smallholder farmers predominantly in northern Ghana (Shiferaw, 2004). Fundamentally, nutrient deficient soils are characterized by low soil organic matter, available phosphorus and total nitrogen, especially in the savannah and transition zones (AQUASTAT, 2005) of Ghana. Consequently, agricultural practices that supplement or conserve these nutrient stocks are for that reason needed for sustainable soybean production.

Soybean, like all other leguminous crops, holds high levels of nitrogen fixation potentials. Solomon et al. (2012) observed that legumes, for that matter soybean can attain between 50 and 80% of their nitrogen concentration requirements through Biological Nitrogen Fixation (BNF). On the other hand, Sanginga et al. (2002), however, believes that the contemporary promiscuous soybean genotypes require external nutrient supply as all their demand for growth and seed development cannot be met only by $N_2$ fixation.

Inoculation of soybean seeds before planting is another important way of instigating or enhancing sufficient nutrient supply to soybean and this is highly encouraged. However, the success of inoculation does not only depend on high quality of the inoculant and good inoculation practices but also on the setting up of effective and efficient BNF through optimization of the factors that have impact on its performance; including legume genotype, climatic, edaphic as well as management factors (Sanginga *et al.*, 1995; Giller and Wilson , 2011). Improved crop yield is now interconnected to Integrated Soil Fertility Management (ISFM) (Sanginga *et al.*, 2009; Vanlauwe *et al.*, 2010; FAO, 2011). Integrated soil fertility management has greater prospects in improving soil fertility status and achieving high crop yield because of the combination of mineral fertilizers, organic input and inoculants; which could synergistically improve the physical, chemical and microbiological properties.

### 2.7.1 Response to Phosphorus Fertilizer

Phosphorus is one of the major nutrients required by plants especially legumes for growth and development. It is known to play important roles in many life processes of legumes such as energy transfer, nodulation, atmospheric nitrogen fixation, flower initiation, fruit development, and seed formation (Ahiakpa *et al*., 2018). Soybean as a leguminous crop thus requires more phosphorus for growth than its requirement of nitrogen which is being fixed through the root nodules. Phosphorus is critical to legume yield because it stimulates growth, initiates nodule formation and enhances the efficiency of the rhizobium-legume symbiosis (Hayat *et al*., 2010). The application of phosphorus fertilizer coupled with the right environmental conditions may contribute to increased yield in grain legumes on farms. Yields are generally higher in the Northern region partly due to better soils and better rainfall distribution. The response to phosphorus application, although varying from region to region, shows an average positive effect of 390 kg ha$^{-1}$ for soybean grains ( Ahiakpa *et al*., 2018).

According to Li et al (1998) phosphorus (P) is an important nutrient used in inorganic fertilizer due to its important role in transfer of energy, photosynthesis and growth in plants. Phosphorus is needed by plants generally and in soybean for nodule growth and development and functioning (Sa and Israel, 1991). There are a wide variety of influences in the soil that affect P availability. Phosphorus availability in the soil can vary greatly with multiple and coexisting causes. For instance, the P source and soil properties such as pH or drainage can impact soil phosphorus availability to plants (Helget, 2016).

Phosphorus is cycled in soils through a complex phenomenon and largely depends on such factors as environment, soil moisture and temperature. The amount of available phosphorus accessible to plants in solution is limited and is affected by soil, plants and microorganisms. To ensure the availability of phosphorus in solution form to plants at every growth stage, available phosphorus has to be constantly replenished to replace plant needs over the course of a plant’s life. Contribution and bioavailability of organic phosphorus in soil solution is not completely understood (Helget, 2016).

### 2.7.2 Response to Nitrogen Fertilizer

Unlike cereals, soybean as a legume crop rather fixes atmospheric nitrogen into the soil through the activities of certain bacteria. Soybean forms root nodules that contain bacteria called rhizobia. The bacteria is capable of fixing nitrogen from the air into a form that soybean can use for growth in a process called biological nitrogen fixation (BNF). The nitrogen requirement of soybean can be supplied through biological nitrogen fixation and by the inoculation of soybean seeds with selected *Brady rhizobium japonicum*/*B. elkanii* strains (Mahmood and Javaid, 2010). It is reported by Nicolás et al. (2006) that biological nitrogen fixation can reduce the need for nitrogen fertilizers, leading to an economy estimated in US$ 3 billion per crop season. The soybean residues (falling leaves/stover) and roots contain lots of nitrogen and when incorporated through cultivation into the soil its fertility and organic matter are both enhanced. For soybean, the amount of free nitrogen brought into the soil is the equivalent of over a 100 kg (2 bags) of urea (MoFA, 2017). This explains the importance of growing soybean in rotation with other crops.

In addition, soybean has the potential to control the parasitic weed, *Striga hermonthica.* Therefore, farm lands that are avoided as a result of Striga infestation are put back into cultivation of maize and other cereals which are seriously affected by Striga.

### 2.7.3 Response to Potassium Fertilizer

Potassium (K) is the third most important plant nutrient after nitrogen (N) and phosphorus (P). Its plays an important role in the growth, metabolism, and development of plants. Inadequate supply of potassium may cause poor root development, slow growth, production of small seeds and even lower yields (McAfee, 2008, White *et al*., 1993) and the increased susceptibility to diseases (Amtmann *et al*., 2008, Yadav and Sidhu, 2016) and pest (Amtmann *et al*., 2006, Troufflard *et al*., 2010). Sometimes K requirement increases in the plant where agricultural soils lack sufficient phyto-available K for crop production (Rengel and Damon 2008). It is generally supplied as K-fertilizers in both intensive and extensive agricultural systems (Pettigrew, 2008, Dasan, 2012, Phua *et al*., 2012, Youssef *et al*., 2010, Zhang *et al*., 2013). Large areas of the agricultural land of the world are however deficient in potassium.

## 2.8 Breeding

Soybean breeding and selection is a continual process by means of which yield levels are increased and resistance to biotic and abiotic stresses stands the chance of being improved (Fasoula and Fasoula, 2002). By way of its self-pollinating reproductive behavior, conventional plant-breeding procedures such as mass selection, pure line selection, backcrossing, single pod descent, pedigree breeding and bulk population breeding are some of the more common procedures used in order to develop improved varieties of soybean (Acquaah, 2015). Various studies have shown that genetic improvement for yield potential of soybean has been achieved through increased lodging resistance, increased stability across a wide range of environments, increased tolerance to water stress, adaptation of improved cultivars and production methods, increase in atmospheric $CO_2$ concentration, greater nitrogen fixation, supplying more assimilates during seed filling period, better tolerance to stress of high plant populations, and increased resistance to major pathogens (Pathan and Sleper, 2008), or even adjusted planting date (Rowntree *et al.,* 2013). Breeding of a crop like soybean could be for drought tolerance which is probably one of the most challenging goals in soybean breeding. One of the oldest breeding strategies for drought tolerance is drought index. Breeding goal is to minimize yield differences between stress and non-stressed environments.

There are a large number of accessions of soybean germplasm in the National Gene Bank, some are improved varieties, some are native varieties and majority of which are also wild soybeans awaiting development and final release to farmers. About 2500 accessions of introduced varieties are also stored all providing basis for soybean breeding. The knowledge of certain genetic parameters is important for proper understanding and their manipulation in any crop improvement programme. Grain yield is the result of the expression and association of several plant growth components. Arshad et al. (2006) have established that correlation coefficients, could be useful in quantifying the size and direction of trait associations, but they can also be misleading if the high correlation between two traits is the result of the indirect effect of the traits.

Although there is an annual growth of about 54% in soybean production globally, it is by far not enough when compared to the demand of the crop as a commodity in the whole world (Alhassan et al., 2016). In order to meet the rising demand trend of the crop for food, feed, oil and or fuel needs, various players in the soybean industry in the world are calling for the adoption of pragmatic and more efficient measures to increase production of soybean, hence the need to breed high yielding varieties of soybean using various breeding methods. One of the most important traits to consider in breeding soybean is the length of growing season because it is affected by photoperiod (Dlamini, 2015). Thus varieties differ based on their responses to day length. While some varieties flower under relatively longer nights (shorter days), others flower under shorter nights (longer days), thus affecting their maturity periods.

Also, other characteristics, such as yield, yield stability, maturity, lodging, and disease resistance must be considered when breeding varieties for production in a given area. In any breeding program, the genetic diversity of the selected parent has a direct bearing on the amount of genetic improvement to make on the developing cultivar (Sudarić *et al*., 2006).

### 2.8.1 Mutation Breeding

Mutation breeding refers to the process of developing new varieties by generating and utilizing genetic variability through chemical and physical mutagenesis (Lundqvist *et al*., 2012). Mutation breeding has been used in recent years as a cherished supplement to other approaches of plant breeding in generating new variability and improvement of crop varieties with new architecture, superior biochemical constitution and suitable growth and developmental measures. It is now one of the three mainstays of contemporary plant breeding with the other two being recombinant and transgenic breeding methods. Mutation breeding procedures are an unconventional breeding method opposed to genetically modified organism (GMOs) practices and conventional breeding methods as it is safe and easily affordable (Jain, 2010)

While mutation breeding charts the same rules of qualities being under genetic control, it differs from other breeding procedures in that it creates new genetic variation (Zamir, 2001). Another way it differs is the way of screening and selection of the desirable breeding lines, and in the possibility to improve a new variety, by speeding up the development of desired phenotypes. As in other contemporary breeding arrangements, mutation breeding activities advances in genomics in choosing desired lines by genotyping somewhat than phenotyping, under what is dubbed “molecular mutation breeding”. Mutation breeding in crop plants is an active method in the improvement of crops having slim genetic base such as in soybean. It is an important supplementary way of crop improvement. Mutations by definition are changes in the genetic make-up of an organism that usually occurs in a sudden, random, but fundamental to the source of variation in the organism that are heritable. Mutation sometimes occur spontaneously but chances of its occurrence is very minimal (Palmer *et al.*, 2008).

Genetic variation of soybean genotypes can be examined using the plant’s morphological traits, agronomic as well as molecular characteristics (Mudibu *et al.*, 2012). Genetic diversity of crop plants happens to be the basis for the sustainable development of new and improved varieties of crops to meet not only present but future challenges to crop production in the world. When conventional breeding methods fail due to lack of appropriate genetic variation, induced mutation is the best alternative that offers numerous benefits to crop improvement (Raina *et al.*, 2016).

Mutagenesis is the process whereby sudden heritable changes occur in the genetic information of an organism not caused by genetic segregation or genetic recombination, but induced by chemical, physical or biological agents.

Induced mutagenesis is where mutations occur as a result of irradiation (gamma rays, X-rays and ion beam). Treatment with chemical mutagens also known as site-directed mutagenesis is the process of creating a mutation at a defined site in a DNA molecule, and insertion mutagenesis, which is due to DNA insertions, either through genetic transformation and insertion of T-DNA or activation of transposable elements. The main aim of plant breeding is to induce genetic variation of useful traits for crop improvements. However, multiple mutant alleles are the sources of genetic diversity for crop breeding as well as functional analysis of the targeted gene in many cases.

The key point in mutation breeding is the process of identifying individuals with a target mutation. Mutant screening is a process involving selection of individuals from a large mutated population that meet specific selection criteria, for instance early flowering, and disease resistance as compared to the parent. This selection is repeated over a number of seasons till consistency in specific desired traits is achieved by the breeder.

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Description of the study area

The research comprised on-station multi-locational trials conducted in the following three agro-ecological zones of northern Ghana: the transitional zone, the Guinea Savannah and the Sudan Savannah agro-ecologies during the 2017 cropping season.

Nyankpala is located in the Tolon District located in the Guinea Savannah agro-ecological zone of Ghana. The study site lies between latitudes 09° 15′` and 10° 0 02` N and Longitudes 0° 53′and 1° 25′ W. It shares boundaries to the north with Kumbungu, North Gonja to the west, Central Gonja to the south, and Sagnarigu districts to the east (Ghana Statistical Service, 2014). The experimental site is located on longitude $0^{o}$ 58' W and latitude $9^{o}$ 25' N with an altitude of 183 m above sea level. The area experiences a unimodal rainfall, ranging from 1000 mm to 1200 mm. Rainfall starts in April-May and gets to its maximum between July and September but there is a sharp decline from October and absolutely no rain in November (Lawson *et al*., 2013). The temperature and relative humidity lies between $23.4^{o}$C - $34.5^{o}$C and 46% - 76.8 % respectively (Kombiok *et al*., 2012). Physical properties of soils at the site are loamy sand textural class derived from voltaian sandstone and classified as Nyankpala series (Kombiok *et al*., 2012).

Manga is within the Bawku municipality which is located in the Sudan Savannah agro ecological zone of Ghana with a total land area of 247.23720 sq.km and it is located approximately between latitudes $11^{o}$ 11″ and $10^{0}$ 40″ N and longitude $0^{o}$ 18″ W and $0^{o}$ 6″ E in the north eastern corner of the region. It shares boundaries with Pusiga district to the north, Binduri district to the south, Garu-Tempane district to the east and Bawku West district to the west (Ghana Statistical Service, 2014).

Gulumpe is located in the Kintampo Municipality, of the Transitional agro ecological zone of Ghana, and located approximately between latitudes 8°45’N and 7°45’N and Longitudes 1°20’W and 2°1’E. It shares boundaries with five other municipals namely; Central Gonja Municipal to the north; Bole Municipal to the west; East Gonja Municipal to the north-east, Kintampo South Municipal to the south; and Pru Municipal to the south- east. The Municipal Capital, Kintampo, is about 130 km away by road from the regional capital and lies east of the Brong Ahafo Regional Capital, Sunyani. The municipal has a surface area of about 5,108 km². In terms of location, the municipal is strategically located at the centre of Ghana and serves as a transit point between the northern and southern sectors of the country (Ghana Statistical Service, 2014).

### 3.2 Seed irradiation

The present study was a continuation of a study which started in 2013 in the Department of Agronomy of UDS, Nyankpala campus. The $M_1$ seeds were produced during the 2013 cropping season by irradiating and planting some seeds of soybean (Jenguma variety) collected from farmers’ field in Nyankpala. These seeds were subjected to 150 Gy, 200 Gy, 250 Gy, and 300 Gy doses of gamma rays from Cobalt - 60 sources and planted with some unirradiated seeds serving as control. All $M_1$ seeds were harvested and replanted in the cropping season of 2014 in order to raise the $M_2$ seeds. Selected $M_2$ plants with improved agronomic traits were advanced to $M_3$ in 2015. During the cropping season of 2016, the soybean genotypes of $M_3$ with improved agronomic traits were advanced to $M_4$ generation evaluated in on-station multi-locational trials in Techiman, Nyankpala and Bawku located in the Transitional zone, Guinea Savannah zone and Sudan Savannah zones respectively.

The present study was the second evaluation on-station study of the desirable mutant seeds selected from the previous studies for improved agronomic traits. Results from this on-station study would determine the next line of action as it would be compared with the previous results to see if there is consistency in the agronomic traits so far observed in both on-station trials at the various ecological zones under consideration.

### 3.3 Experimental Design

The set up was a 5 x 4 x 3 factorial experiment which gave a total of 60 treatment combinations for the experiment. Soybean genotypes (seeds selected from previous studies) for the experiment included 150 Gy, 200 Gy, 250 Gy, and 300 Gy mutant genotypes and some unirradiated seed (0 Gy – Jenguma standard check) were planted. Fertilizer rates: 0 kg/ha, 45 kg/ha, 60 kg/ha, and 75 kg/ha of TSP were applied at three weeks after planting (3 WAP). The treatment combinations were replicated 3 times in Randomized Complete Block Design (RCBD) at each agro-ecological zone. Planting distance was 75 cm x 10 cm. Plot size of 9 $m^2$, and 2 m alleys between replications, and only 1 m between experimental units were employed.

### 3.4 Land preparation

All sites were ploughed and manually leveled with hoe to give a fine tilth. Small ditches were also covered to control water flow through the fields as heavy runoff was capable of damaging plants on plots. Exposed and larger weeds were removed, gathered and burnt to prevent obstructions during the planting and subsequent farming operations. Layout of the field was done with the support of the field technicians in the Agronomy Department using garden line, pegs, and tape measure. The sites were planted and sprayed with a pre-emergence herbicide at all locations to suppress weed growth.

### 3.5 Cultural practices

The cultural practices including refilling and weeding were carried out at all the three locations. Leveling in particular was done to provide fine tilth for the planting of the seeds and to ensure that no obstructions occur during farming activities. This was followed by lay out of the field during which various plots were demarcated and walk ways were left out for easy movement on the field. Planting was done on the same day at the same location, but on different days at different locations to allow the researcher time to be able to visit and carry out all activities on the fields without neglect considering how far apart the agro ecological zones are to each other. Refilling was done a week after germination at all locations to boost the emergence population of plants per mutant genotype. This further improved the emergence count of soybean plants established on the fields at each location of the experiment.

Weeding on the field was done three weeks after planting at all locations and subsequent weeding were done as and when the need arose. The weeding was done by use of hoe; this to a very large extent helped the plants as aeration was enhanced.

## 3.6 Data Collection

Data on plant height, number of leaves, number of branches, number of days to 50% flowering, number of days to maturity, number of seeds per pod, number of pods per plant, 100-seed weight and total grain yield were recorded. These are briefly described below.

### 3.6.1 Plant height

Data on plant height were taken at all the experimental sites at two-week intervals starting from the fourth week after planting (4WAP) through to the eighth week after planting (8WAP). The plant height was measured from the ground level to the highest tip of the stem for all ten tagged plants on each plot.

The height was taken by measuring an average looking individual plant with a meter rule to the nearest centimeters and recorded. Averages for all ten selected plants from each plot in the three replications was taken as the average plant height of the said plot and or mutant genotype compared with others from the three replicates and three locations.

### 3.6.2 Number of leaves

The number of leaves for each of the ten tagged plants from each plot were counted and recorded over a period of six weeks starting from the second week through to the eighth week as was done in the case of the plant height. Counting was manually carried out by close observation.

### 3.6.3 Number of branches

Unlike the number of leaves and plant height, counting of the number of branches was done from the sixth week and was repeated on the eighth week after planting. Excessive branching in most crops, especially in soybean results in higher yields. The branches counted in this study were, however that of the primary and secondary branches, leaving out the tertiary branches as part of the secondary branch as well as the primary branches. Counting of the branches was however discontinued after the eighth week as more distraction of the plant was affecting data taking.

### 3.6.4 Number of days to 50% flowering

Through careful observation, the number of plants that flowered on the field was estimated for half of the plants on each plot. When the soybean plants started flowering, a daily walk through of the field counting the number of plants that had flowered was done for all plots and soybean genotypes across all the three locations.

### 3.6.5 Number of days to maturity

Through field monitoring and observation, number of days taken by plants to mature fully for harvesting was counted. When plots started to show signs of senescence, all of the plots were walked through every 2-3 days to record maturity periods. When a plot was 95% mature, based on the color of pod and stem, the date was recorded. This date showed how many days it took from planting an individual plot to reach full maturity. Full maturity marked readiness for harvest of the mutant genotype. The various maturity dates were therefore recorded for each of the soybean genotypes at the various locations.

### 3.6.6 Number of pods per plant

An average number of pods borne by three plants on each plot were taken through manual counting of pods of the selected plants. Average values were taken and recorded as representative sample for the entire plot for all the three locations and various soybean genotypes at harvest. Counting of the pods was done by observing pods from each plant and counting and recording them separately.

### 3.6.7 Number of seeds per pod

An average number of seeds per pod were taken by sampling three plants from each mutant line and recording the number of seeds found in each pod for the various soybean genotypes. Averages for each mutant line was recorded as the representative sample of the particular mutant line at the specific location it was planted. Care was taken to prevent shattering of pods as pods were fully dried and thus exposed to high risk of shattering when disturbed. It was replicated across all the three locations.

### 3.6.8 100-seed weight

According to research the weight of a seed determines the size and vigor with which the seed germinates and these have direct bearing on the survivorship of the seedling it bears. It is known that smaller seeds are faster to germinate than larger seeds. But larger seeds have higher rate of survivability when planted. Selected seeds numbering 100 were counted from each plot after drying to safe moisture levels and these were then tied in a light polythene bag and weighed using a digital weighing scale in grams for all the plots across all the locations.

### 3.6.9 Total grain yield

The yield for the soybean genotypes are very important in determining those that are performing well and consistent with the results obtained over the previous trials. The total grain yield for each of the soybean genotypes from each plot were determined using the net plot seeds harvested. The seeds were put in light polythene bags and weighed using a digital weighing scale in kilograms on a per plot basis and extrapolated to a per hectare basis. This was done for the three different locations and recorded for analysis.

## 3.7 Data analysis

The data for all the above parameters considered for the study were subjected to analysis of variance (ANOVA) using Genstat Statiscal Package (12th edition). Means were separated using Least Significant Difference (LSD) at 5%.

## CHAPTER FOUR

## RESULTS

### 4.1 Plant height

The main effect of mutant genotypes for plant height at 4, 6 and 8 weeks after planting varied significantly ($P < 0.05$). The 0 Gy at week 8 after planting recorded the highest height. This was followed by the 300 Gy in the same week. The 200 Gy mutant genotype at week 4 recorded the lowest plant height but performed better than the 250 Gy mutant genotype at week 6 and performing just a little below the 250 Gy again at week 8 (Figure 1).

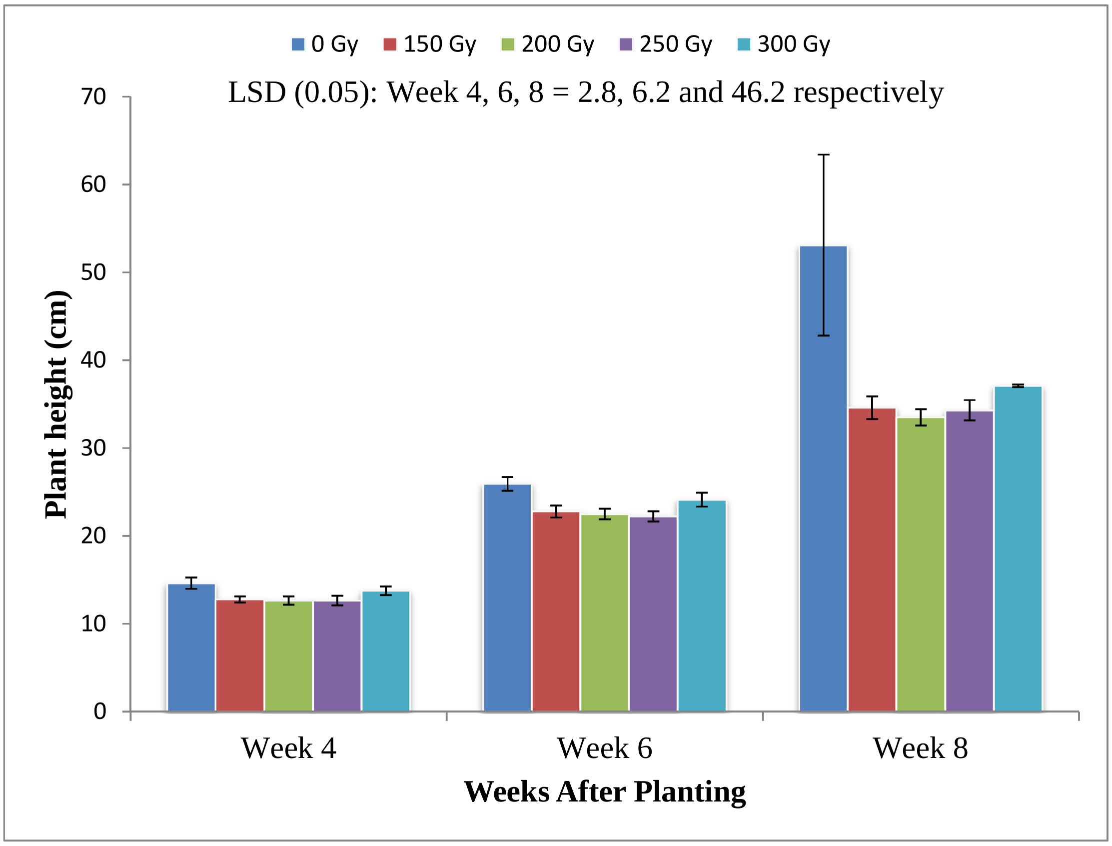

Figure 1: Variation in plant height of soybean genotypes for 4, 6, and 8 WAP

The main effect of location for plant height was significant ($P < 0.05$) at 4 weeks after planting. The average plant height recorded for all the mutant genotypes at Gulumpe was better than those at both Manga and Nyankpala. The average performance of the mutant genotypes at Nyankpala was however not significantly ($P > 0.05$) different from that of Manga (Figure 2).

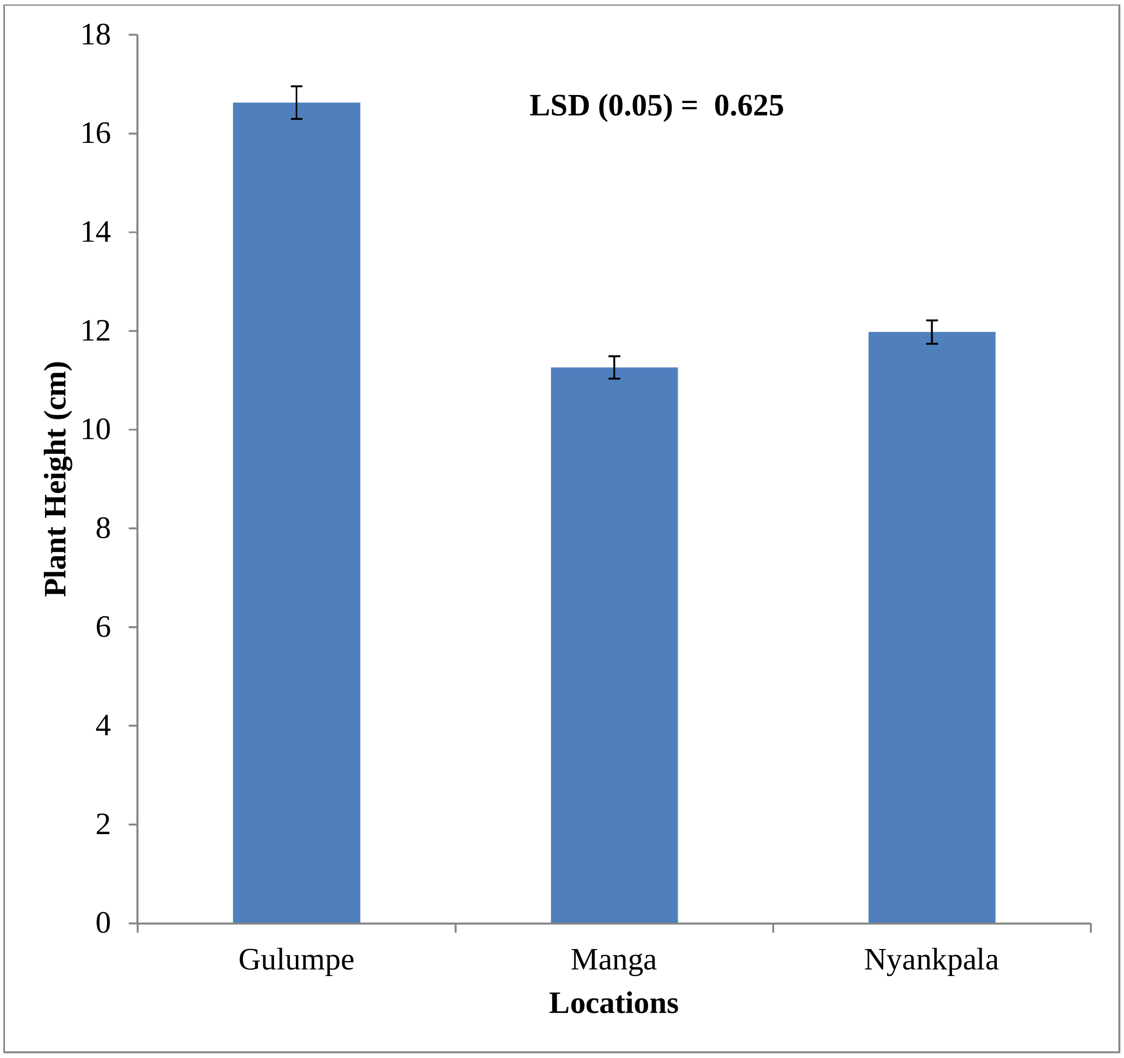

Figure 2: Variation in plant height across the 3 locations 4 WAP

The interaction effects of mutant genotypes and location at week 4 was significant ($P < 0.05$). The 0 Gy at Gulumpe recorded the highest height of 19.24 cm at week 4 followed by the 300 Gy (17.17) at the same location. The lowest height was recorded at Nyankpala for the 250 Gy (10.61) but that was not significantly ($P < 0.05$) different from those of the 200 Gy (10.83 cm) and 250 Gy (10.83 cm) at Manga (Table 1).

Table 1: Interaction effect of soybean genotypes and locations for PH at 4 WAP.

| **Soybean Genotypes** | **Location** | | |
|---|---|---|---|
| | Gulumpe | Manga | Nyankpala |
| **0 Gy** | 19.24 | 11.14 | 13.52 |
| **150 Gy** | 14.65 | 11.8 | 11.86 |
| **200 Gy** | 15.58 | 10.83 | 11.47 |
| **250 Gy** | 16.5 | 10.83 | 10.61 |
| **300 Gy** | 17.17 | 11.69 | 12.47 |

LSD (0.05): Soybean genotype x Location = 1.397; 0 Gy = Jenguma (unirradiated)

The interaction effect for fertilizer application rate, locations and soybean genotypes at week 4 and 6 was also significant ($P < 0.05$). At week 4, the 0 Gy at 0 kg/ha of TSP fertilizer at Gulumpe recorded the highest height, whilst 250 Gy at 75 kg/ha of fertilizer from Manga recorded the lowest value of plant height (Table 2).

Table 2: Interaction effect of TSP application, genotypes and locations for PH at 4 WAP

| Location | Soybean Genotypes | TSP Fertilizer Application Rate (kg/ha) | | | |
|---|---|---|---|---|---|
| | | 0 | 45 | 60 | 75 |
| Gulumpe | 0 Gy | 20.07 | 19.43 | 18.12 | 19.35 |
| | 150 Gy | 14.38 | 16.48 | 14.29 | 13.46 |
| | 200 Gy | 14.95 | 14.47 | 14.07 | 18.83 |
| | 250 Gy | 16.35 | 15.19 | 19.63 | 14.85 |
| | 300 Gy | 16.99 | 17.20 | 16.89 | 17.58 |
| Manga | 0 Gy | 10.79 | 11.13 | 10.97 | 11.67 |
| | 150 Gy | 12.20 | 10.61 | 13.35 | 11.04 |
| | 200 Gy | 11.96 | 10.11 | 11.41 | 9.84 |
| | 250 Gy | 12.07 | 10.96 | 11.31 | 8.93 |
| | 300 Gy | 10.33 | 12.50 | 12.73 | 11.19 |
| Nyankpala | 0 Gy | 12.75 | 13.14 | 14.72 | 13.46 |
| | 150 Gy | 11.68 | 11.32 | 13.08 | 11.36 |
| | 200 Gy | 11.25 | 11.89 | 12.49 | 10.26 |
| | 250 Gy | 10.33 | 10.54 | 9.37 | 12.21 |
| | 300 Gy | 13.24 | 12.36 | 12.45 | 11.81 |

LSD (0.05): Location x genotype x TSP Fertilizer Application = 2.79; 0 Gy = Jenguma (unirradiated) and 0 kg/ha = No application of TSP Fertilizer (control)

There was significant ($P < 0.05$) difference on plant height for the various TSP fertilizer application rates. The 60 kg/ha recorded the highest plant height of 24.93 cm and the 45 kg/ha application rate showing the lowest height of 23.02 cm which was not significantly different from the 0 kg/ha (23.03 cm) and the 75 kg/ha (23.07 cm) (

Figure 3).

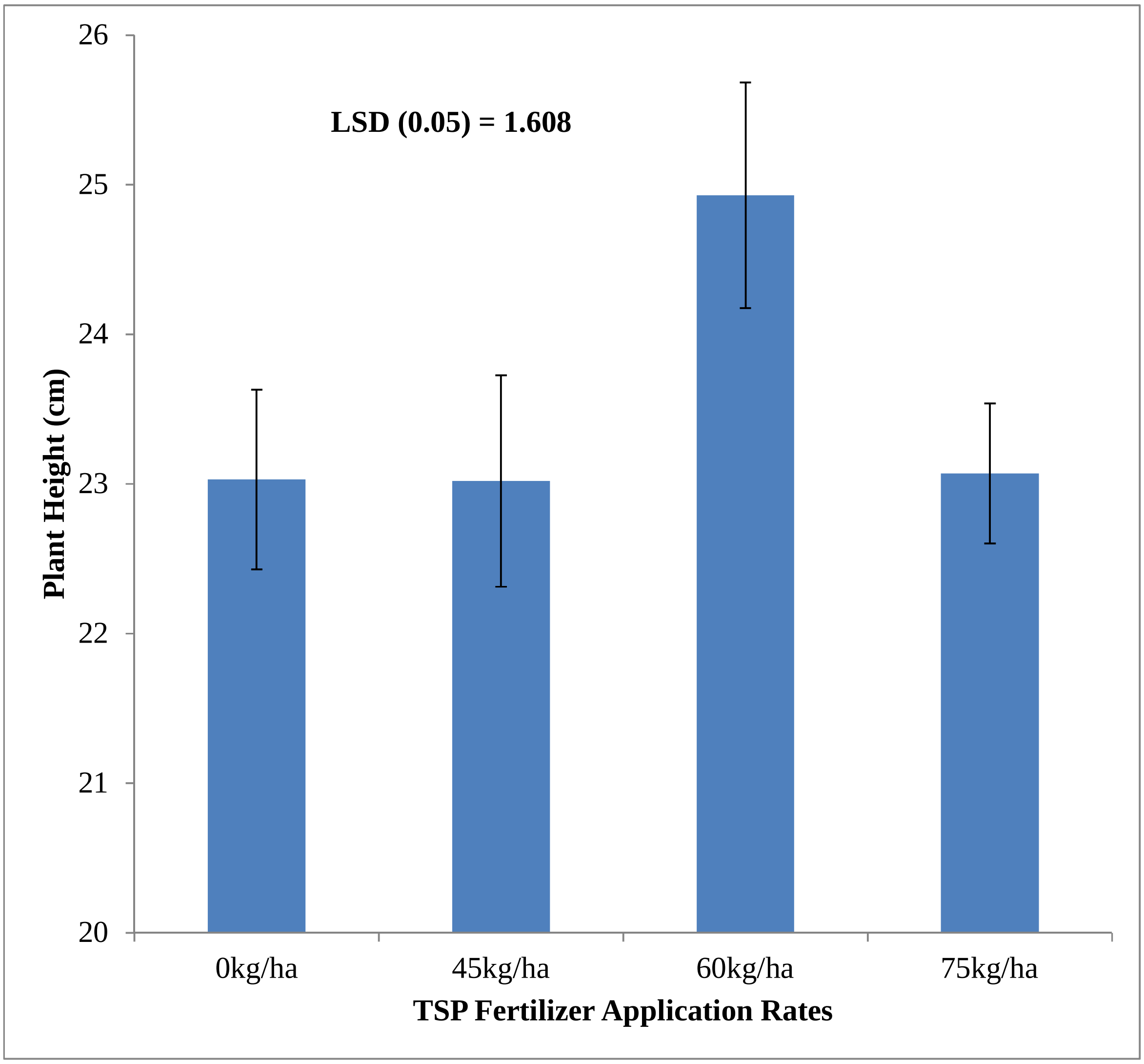

Figure 3: Variation in PH based on TSP Application rates of soybean genotypes 6 WAP

0 kg/ha = No application of TSP Fertilizer (control)

On the basis of mutant genotypes, there were similar performances among the 150 Gy, 200 Gy, 250 Gy, and 300 Gy in terms of plant height at week 6. The 0 Gy (standard check) recorded the highest plant height 25.93 cm which was followed by the 300 Gy of 24.13 cm (Figure 4).

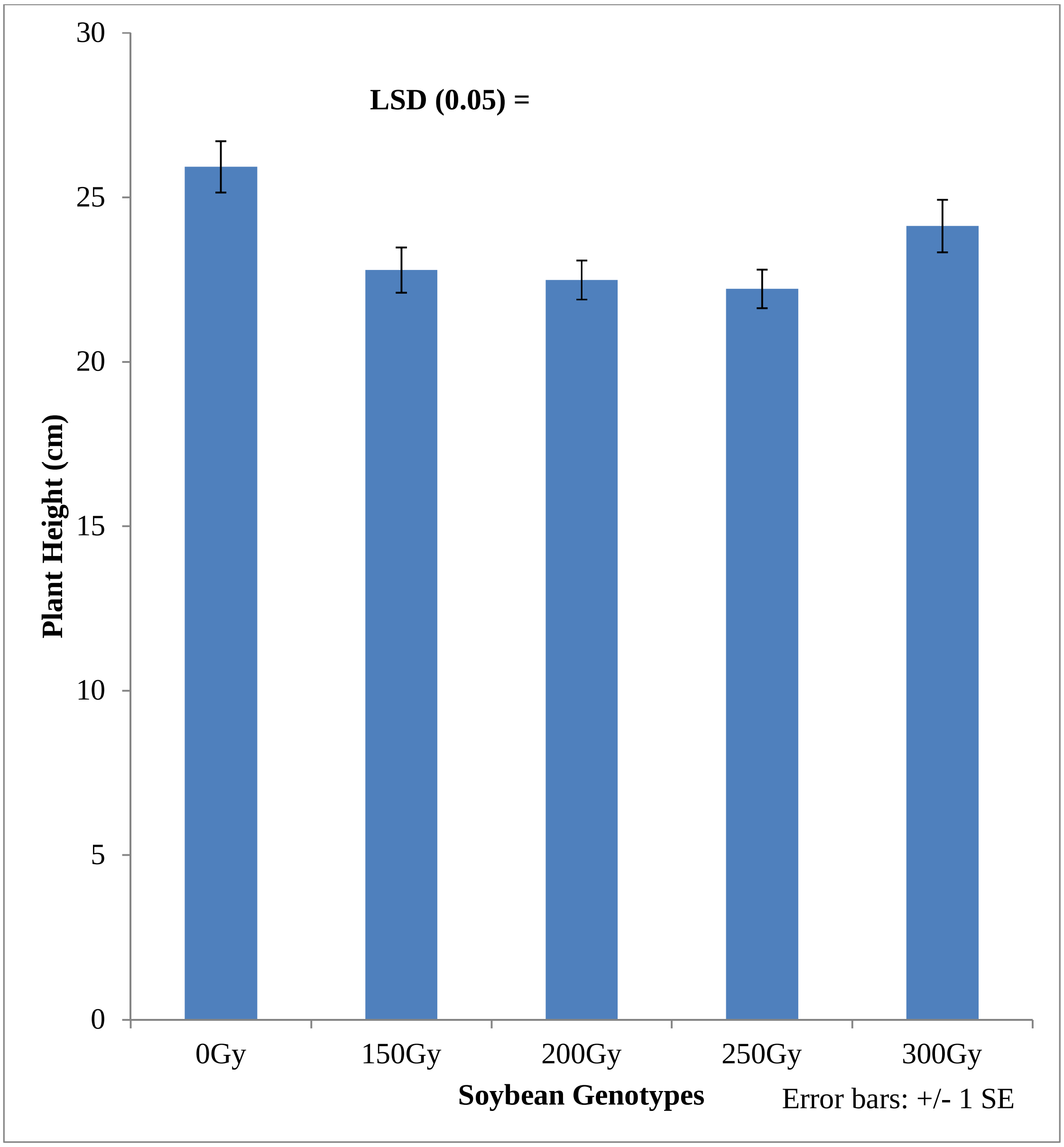

Figure 4: Variation in PH of soybean genotypes 6 WAP

0 Gy = Jenguma (unirradiated)

The plant height for the various locations at week 6 showed significant ($P < 0.05$) difference being recorded between Gulumpe on one hand, and Manga and Nyankpala on the other hand (Figure 5).

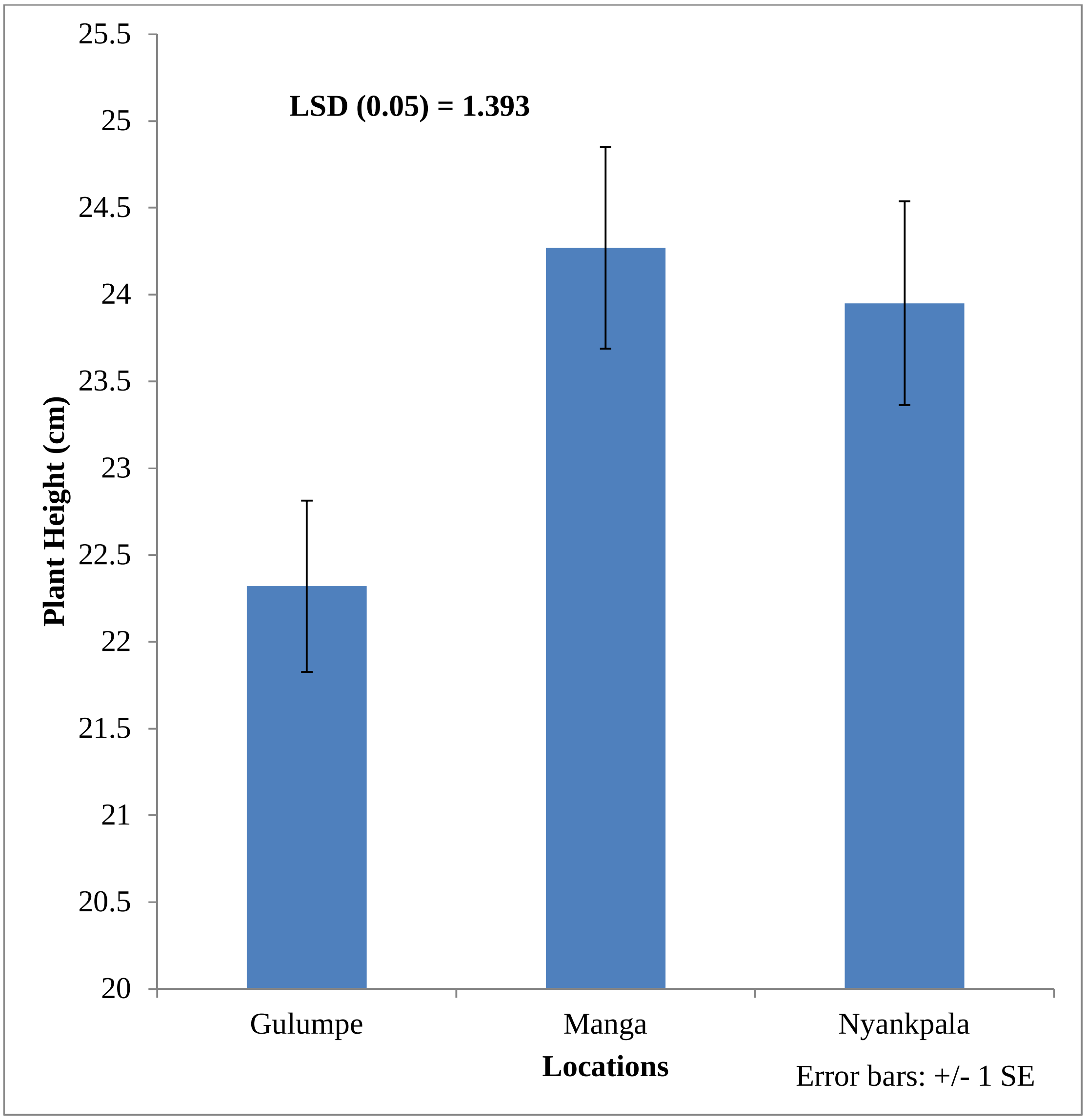

Figure 5: Variation in PH of soybean genotypes at various locations 6 WAP

There were interaction effects on TSP fertilizer application rates and that of the locations. Plant height for the TSP fertilizer application rate of 60 kg/ha was the highest among the various application rates and across all the three locations. But for the 75 kg/ha at Gulumpe, the second highest plant height recorded at both Manga and Nyankpala was the 0 kg/ha. The least plant height however, was recorded at Gulumpe with the TSP fertilizer application rate of 0 kg/ha (Table 3).

Table 3: Interaction effect of TSP application rate and locations for PH at 6 WAP

| **TSP Fertilizer Application Rate (kg/ha)** | **Location** | | |
|---|---|---|---|
| | Gulumpe | Manga | Nyankpala |
| **0** | 21.04 | 24.17 | 23.87 |
| **45** | 21.83 | 23.92 | 23.32 |
| **60** | 23.44 | 25.33 | 26.01 |
| **75** | 22.95 | 23.66 | 22.60 |

LSD (0.05): TSP Fertilizer Application Rate x Location = 2.785; 0 kg/ha = No application of TSP Fertilizer (control).

At 6 weeks after planting, the 0 Gy at 60 kg/ha of TSP fertilizer from Nyankpala recorded the highest height whilst the 250 Gy mutant at 60 kg/ha of TSP recorded the lowest plant height for Nyankpala. The 150 Gy mutant at 75 kg/ha of TSP fertilizer from Gulumpe recorded the lowest plant height at 6 weeks after planting (Table 4).

Table 4: Interaction of TSP application, genotypes and locations for PH 6 WAP

| Location | Soybean Genotypes | TSP Fertilizer Application Rate (kg/ha) 0 | 45 | 60 | 75 |
|---|---|---|---|---|---|
| Gulumpe | 0 Gy | 23.39 | 25.39 | 26.18 | 25.86 |
| | 150 Gy | 19.40 | 22.40 | 20.09 | 17.67 |
| | 200 Gy | 19.48 | 18.97 | 20.94 | 25.87 |
| | 250 Gy | 21.70 | 19.96 | 25.99 | 20.59 |
| | 300 Gy | 21.26 | 22.43 | 23.99 | 24.77 |
| Manga | 0 Gy | 25.61 | 23.13 | 21.36 | 26.09 |
| | 150 Gy | 25.30 | 22.78 | 27.67 | 24.77 |
| | 200 Gy | 23.12 | 22.82 | 24.68 | 21.43 |
| | 250 Gy | 25.75 | 23.46 | 23.59 | 21.05 |
| | 300 Gy | 21.09 | 27.42 | 29.35 | 24.94 |
| Nyankpala | 0 Gy | 24.74 | 29.08 | 35.49 | 24.82 |
| | 150 Gy | 22.98 | 22.06 | 26.94 | 21.35 |
| | 200 Gy | 23.47 | 21.59 | 27.18 | 20.33 |
| | 250 Gy | 21.85 | 21.21 | 18.11 | 23.43 |
| | 300 Gy | 26.29 | 22.65 | 22.32 | 23.04 |

LSD (0.05): Location x genotype x TSP application = 6.23; 0 Gy = Jenguma (unirradiated)

At week 8, the average highest plant height was recorded at the Nyankpala location which was followed by the Manga and Gulumpe respectively (Figure 6).

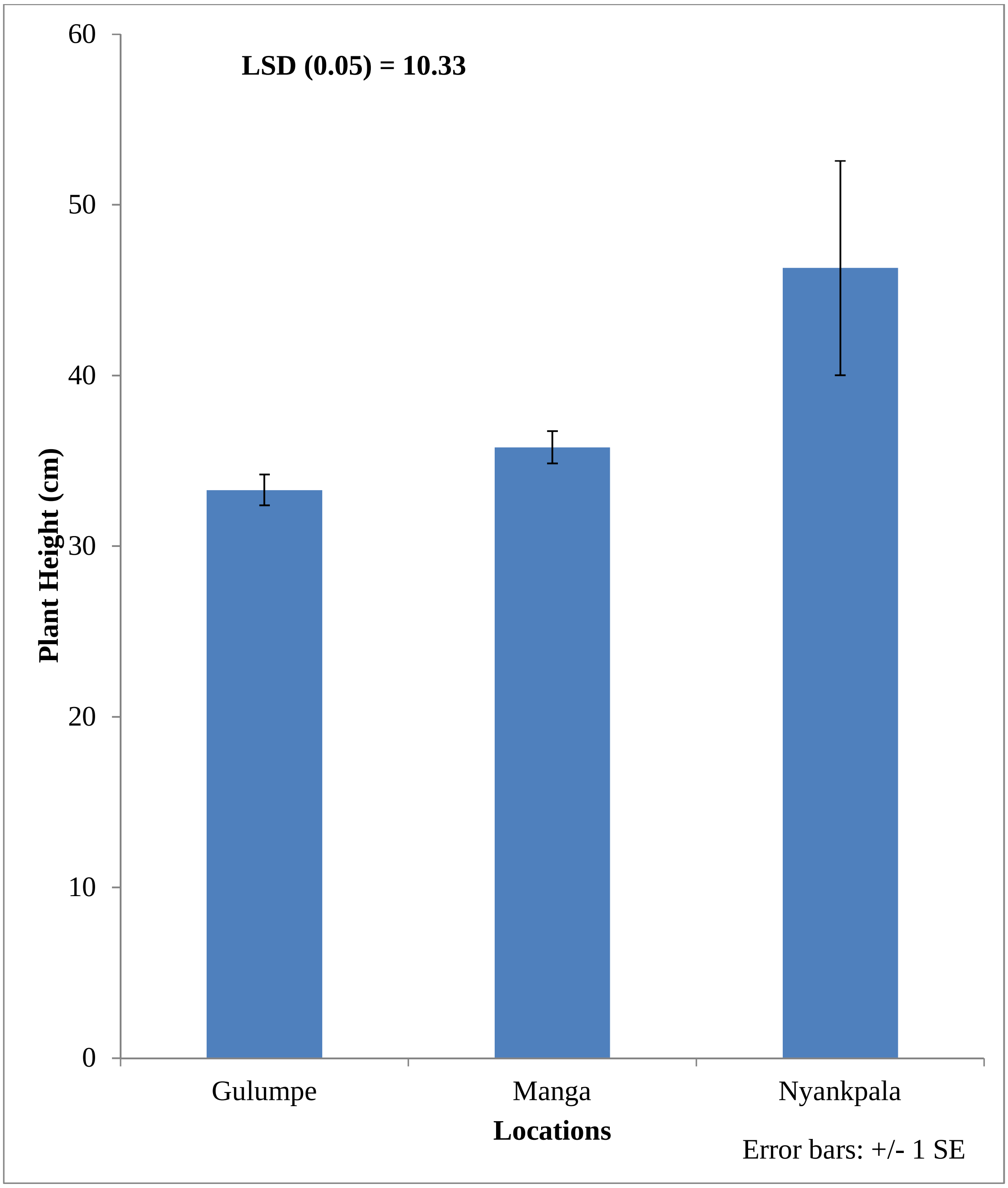

Figure 6: Variation in PH of soybean genotypes at the various locations 8 WAP

At week 8, the 0 Gy recorded the highest average plant height of 53.1 cm followed by the 300 Gy (37.1 cm) among the mutant genotypes. The 150 Gy, 200 Gy, 250 Gy and the 300 Gy however recorded similar heights which were significantly different from the 0 Gy (standard check) (Figure 7)

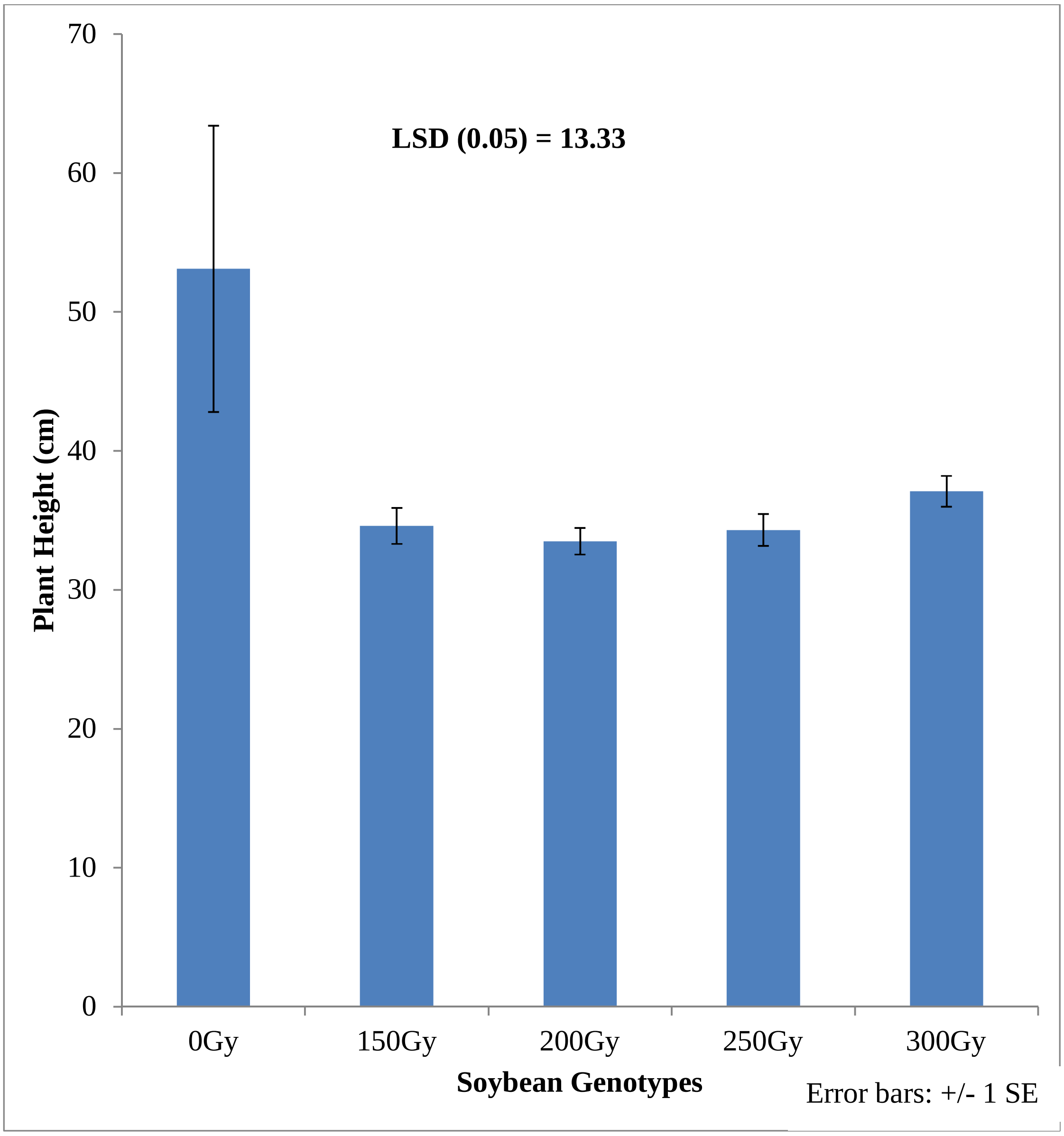

Figure 7: Variation in PH of soybean genotypes at 8 WAP

0 Gy = Jenguma (unirradiated)

## 4.2 Number of leaves

The number of leaves of the mutant genotypes showed significant ($P < 0.05$) difference among the various locations at 4 weeks after planting. Nyankpala recorded the highest number of leaves, whilst Gulumpe recorded the least number of leaves but however performed significantly similar to that of Manga but significantly similar but different from the performance in Nyankpala for the number of leaves of soybean genotype (Figure 8).

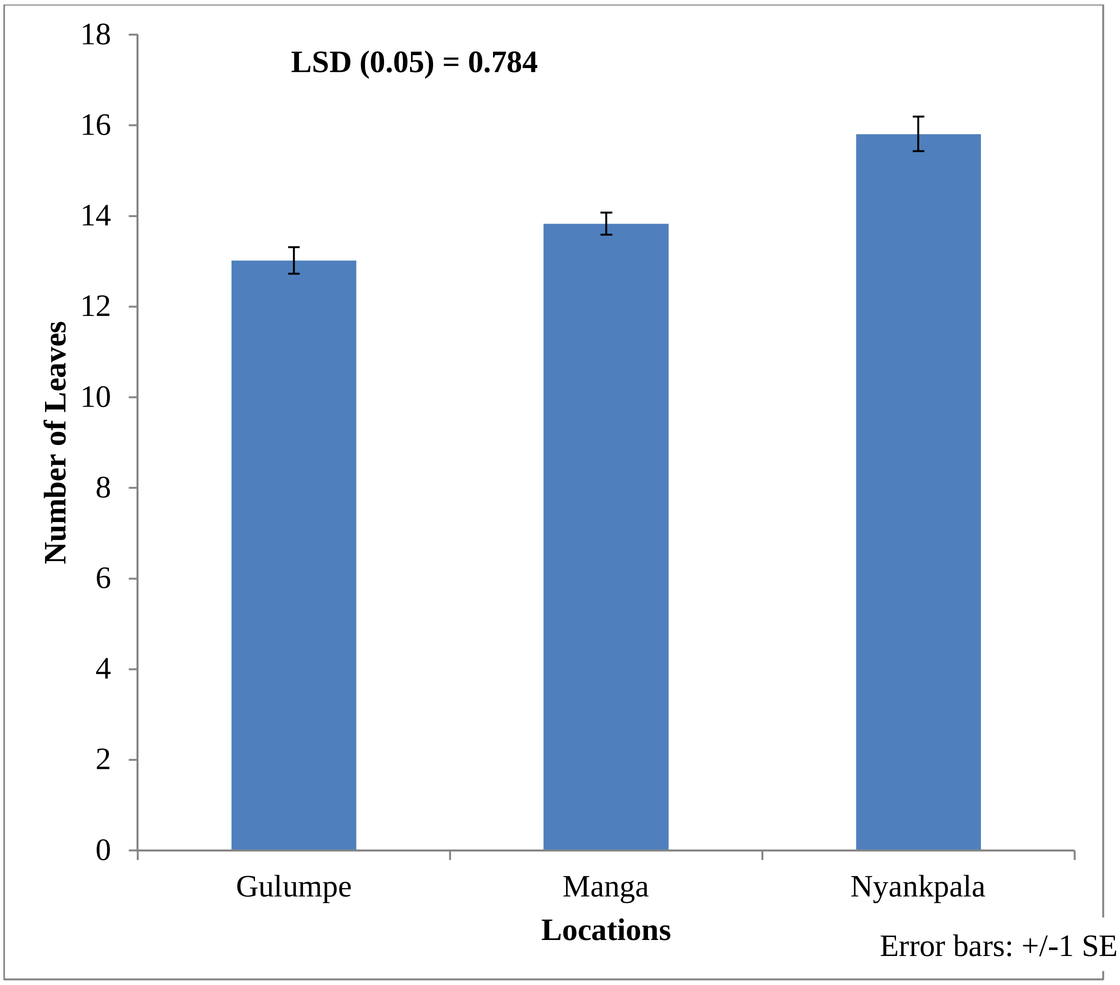

Figure 8: Variation in NL of soybean genotypes at various locations 4 WAP

At week 4, the number of leaves recorded for the various levels of TSP fertilizer application rates showed significant ($P < 0.05$) differences. 0 kg/ha (14.62 cm) and 60 kg/ha (14.72 cm) showed similar results and was not significantly different from the 45 kg/ha (13.98 cm) unlike the 75 kg/ha (13.57 cm). Interestingly, there was significantly similar performance between the 45 kg/ha (13.98 cm) and that of the 75 kg/ha (13.57 cm) (Figure 9).

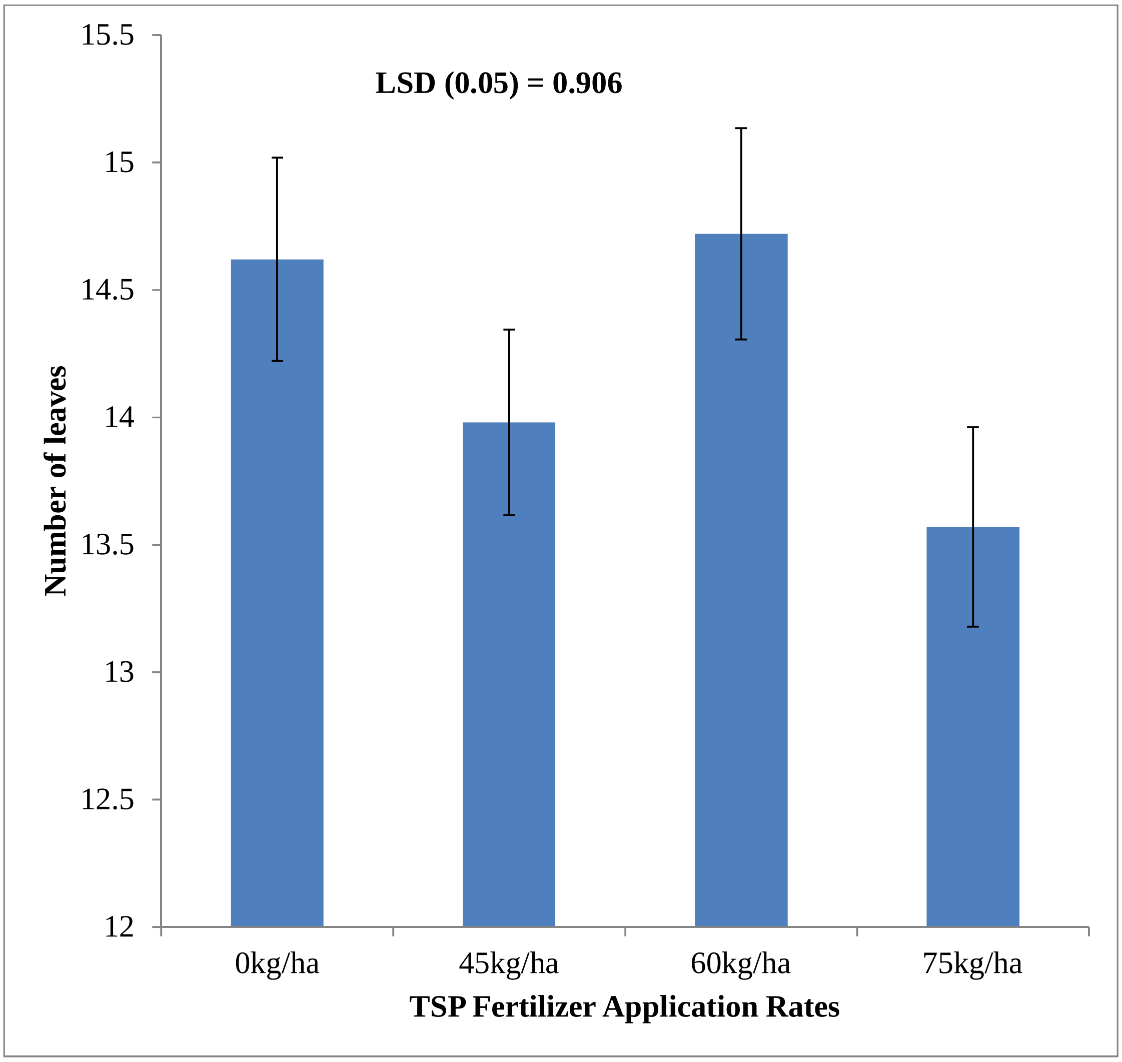

Figure 9: Variation in NL of soybean genotypes on TSP Application rates 4 WAP.

0 kg/ha = No application of TSP Fertilizer (control)

At week 4, there was an interaction effect ($P < 0.05$) on the number of leaves for soybean genotypes and locations. The 150 Gy performed lowest at Gulumpe and among all other mutant genotypes. The highest number of leaves was however recorded at Nyankpala for the 0 Gy and closely followed by the 300 Gy at the same location. At Gulumpe, apart from the 150 Gy the rest of the mutant genotypes did not differ significantly and the trend was same at Manga where only the 0 Gy differed significantly the rest showed similar performance. In the case of Nyankpala however, significant differences among mutant genotypes was recorded with the 0 Gy being significantly different from the 250 Gy which had similar performance with the 150 Gy, 200 Gy and the 300 Gy (Table 5).

Table 5: Interaction of soybean genotypes and locations for NL 4 WAP

| **Soybean Genotypes** | **Location** | | |
|---|---|---|---|
| | Gulumpe | Manga | Nyankpala |
| **0 Gy** | 13.23 | 12.92 | 17.4 |
| **150 Gy** | 11.4 | 14.07 | 14.88 |
| **200 Gy** | 13.28 | 13.42 | 15.62 |
| **250 Gy** | 13.79 | 14.02 | 14.82 |
| **300 Gy** | 13.42 | 14.68 | 16.33 |

LSD (0.05): Soybean genotypes x Location = 1.754; 0 Gy = Jenguma (unirradiated)

There was significant difference (P < 0.05) for the interaction of the fertilizer application rate, soybean genotypes and the locations for number of leaves of soybean mutant genotypes (Tables 6, 8, and 10). The 0 Gy plants at 60 kg/ha of TSP fertilizer rate from Nyankpala during week 4 recorded the highest number of leaves whilst plants from 150 Gy mutant at 75 kg/ha of fertilizer rate from Gulumpe at week 4 recorded the lowest number of leaves (Table 6).

Table 6: Interaction of TSP application, genotypes and locations for NL at 4 WAP

| Location | Soybean | TSP Fertilizer Application Rate (kg/ha) | | | |
|---|---|---|---|---|---|
| | Genotypes | 0 | 45 | 60 | 75 |
| Gulumpe | 0 Gy | 13.22 | 13.00 | 12.60 | 14.10 |
| | 150 Gy | 11.60 | 12.10 | 13.24 | 8.67 |
| | 200 Gy | 13.60 | 11.67 | 13.03 | 14.80 |
| | 250 Gy | 15.13 | 13.87 | 15.40 | 10.76 |
| | 300 Gy | 12.07 | 13.20 | 15.00 | 13.40 |
| Manga | 0 Gy | 13.10 | 12.40 | 11.50 | 14.70 |
| | 150 Gy | 14.80 | 13.00 | 15.80 | 12.70 |
| | 200 Gy | 14.10 | 13.10 | 14.10 | 12.40 |
| | 250 Gy | 14.70 | 14.80 | 14.40 | 12.20 |
| | 300 Gy | 13.23 | 15.50 | 15.90 | 14.10 |
| Nyankpala | 0 Gy | 17.10 | 16.50 | 19.80 | 16.20 |
| | 150 Gy | 15.60 | 13.50 | 17.10 | 13.33 |
| | 200 Gy | 16.50 | 15.60 | 17.40 | 13.00 |
| | 250 Gy | 15.90 | 15.43 | 11.34 | 16.59 |
| | 300 Gy | 18.60 | 16.00 | 14.20 | 16.53 |

LSD (0.05) ): Location x genotype x TSP application = 3.51; 0 Gy = Jenguma (unirradiated); 0 kg/ha = No application of TSP Fertilizer (control)

At week 6 the number of leaves showed significant ($P < 0.05$) differences among the locations. The results indicate that Manga recorded the highest number of leaves and Gulumpe recording the lowest number of leaves. There was however no significant difference between Manga and Nyankpala in terms of number of leaves of the mutant genotypes (Figure 10).

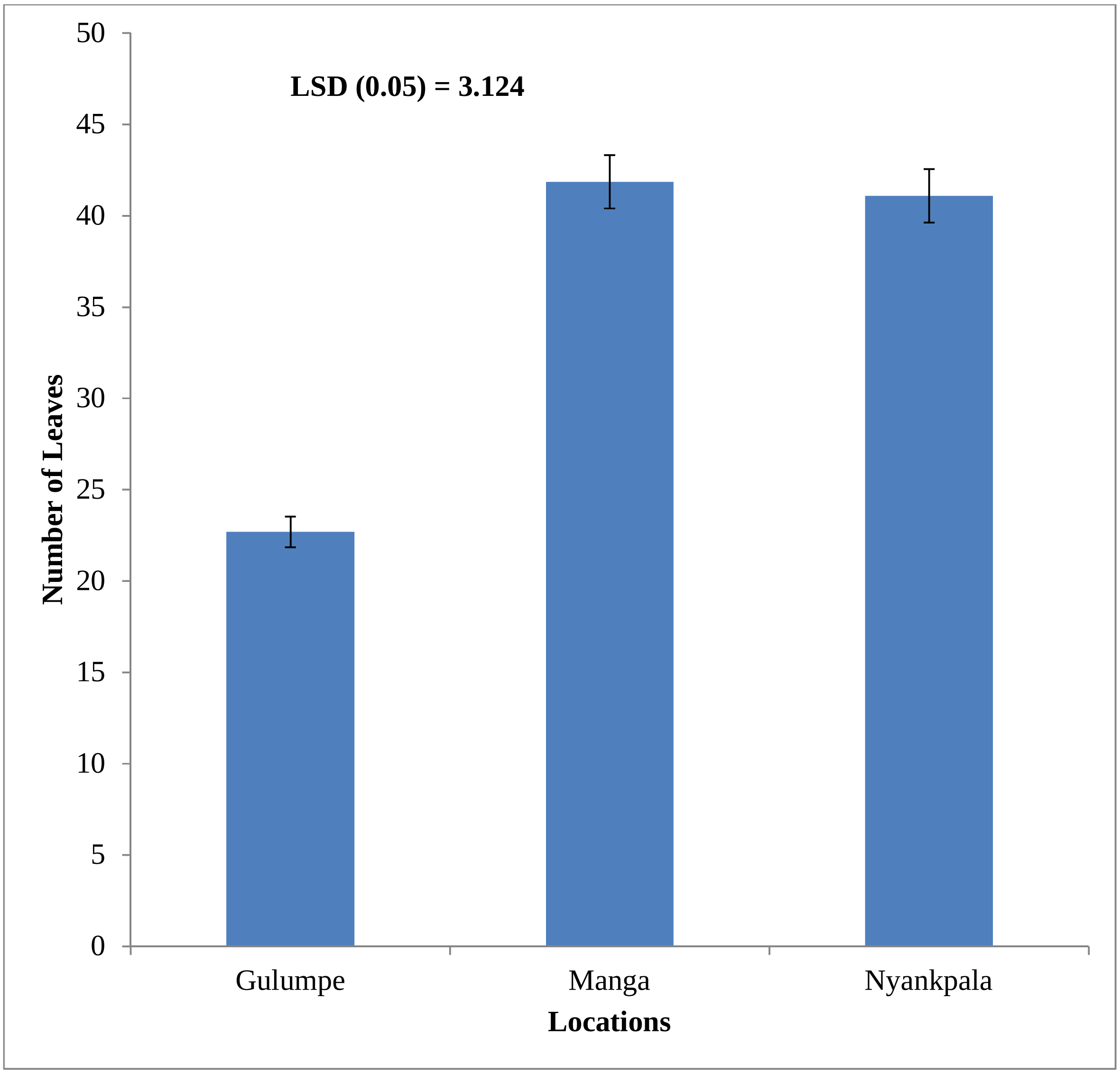

Figure 10: Variation in NL of soybean genotypes at the various locations 6 WAP

On the basis of TSP fertilizer application rates at week 6, the 60 kg/ha showed significant ($P < 0.05$) difference with the 75 kg/ha. However, 0 kg/ha, 45 kg/ha and the 75 kg/ha showed no significant difference (Figure 11).

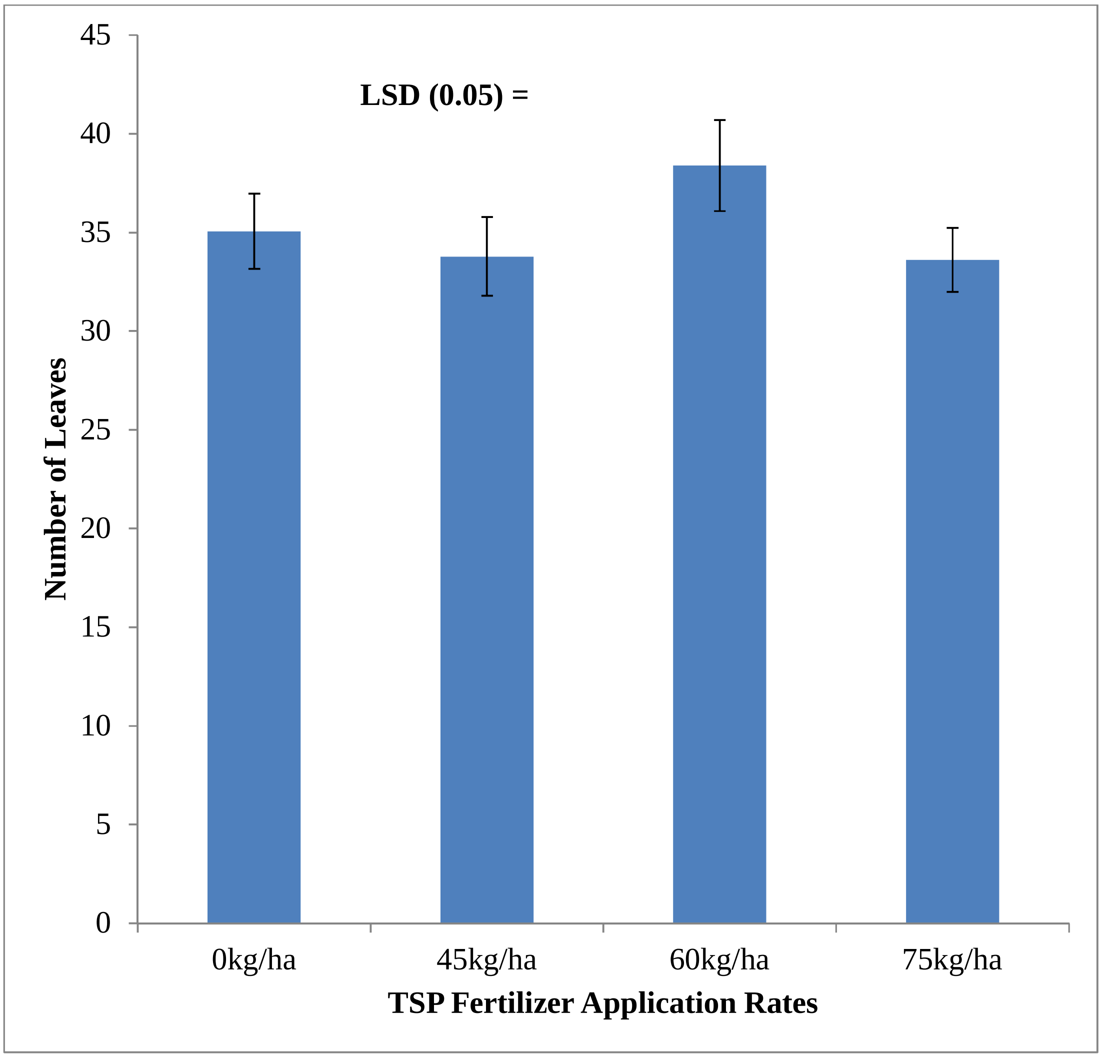

Figure 11: Variation in NL of soybean genotypes on TSP Application rates 6 WAP.

0 kg/ha = No application of TSP Fertilizer (control)

At week 6 again, there was significant ($P < 0.05$) interaction effect between soybean genotypes and locations for the number of leaves. The highest number of leaves was recorded at Nyankpala for the 0 Gy followed by the 150 Gy at Manga and the 150 Gy recorded the least number of leaves at Gulumpe. Among the same soybean genotypes across the three locations, significant differences were recorded in almost all the genotypes but similar performances were observed among the various genotypes at each location except in the specific case of Nyankpala (Table 7).

Table 7: Interaction of soybean genotypes and locations for NL 6 WAP

| **Soybean Genotypes** | **Location** | | |
|---|---|---|---|
| | Gulumpe | Manga | Nyankpala |
| **0 Gy** | 24.7 | 35.04 | 46.72 |
| **150 Gy** | 18.04 | 45.24 | 38.51 |
| **200 Gy** | 23.56 | 41.48 | 42.67 |
| **250 Gy** | 24.87 | 42.85 | 41.18 |
| **300 Gy** | 22.26 | 44.62 | 36.37 |

LSD (0.05): Soybean genotypes x Location = 6.986; 0 Gy = Jenguma (unirradiated)

The 0 Gy mutant genotypes at 60 kg/ha of TSP fertilizer rate from Nyankpala for week 6 recorded the highest number of leaves followed by the 300 Gy at 60 kg/ha fertilizer rate at Manga. The least number of leaves among all the locations were recorded at Gulumpe from the 150 Gy mutant plants fertilized with 75 kg/ha of TSP (Table 8).

Table 8: Interaction of TSP application, genotypes and locations for NL at 6 WAP

| Location | Soybean | TSP Fertilizer Application Rate (kg/ha) | | | |
|---|---|---|---|---|---|
| | Genotypes | 0 | 45 | 60 | 75 |
| Gulumpe | 0 Gy | 27.71 | 22.82 | 23.26 | 25.01 |
| | 150 Gy | 18.52 | 18.34 | 23.15 | 12.14 |
| | 200 Gy | 23.07 | 21.30 | 23.32 | 26.56 |
| | 250 Gy | 25.31 | 21.63 | 27.18 | 25.36 |
| | 300 Gy | 17.53 | 19.88 | 25.83 | 25.81 |
| Manga | 0 Gy | 36.90 | 33.80 | 26.87 | 42.60 |
| | 150 Gy | 46.50 | 39.57 | 51.80 | 43.10 |
| | 200 Gy | 42.40 | 41.10 | 47.23 | 35.20 |
| | 250 Gy | 47.67 | 45.60 | 44.63 | 33.50 |
| | 300 Gy | 30.30 | 47.43 | 53.50 | 47.27 |
| Nyankpala | 0 Gy | 37.50 | 43.10 | 67.80 | 38.50 |
| | 150 Gy | 38.90 | 33.97 | 47.17 | 34.00 |
| | 200 Gy | 47.40 | 38.60 | 51.20 | 33.50 |
| | 250 Gy | 42.00 | 44.73 | 31.50 | 46.50 |
| | 300 Gy | 44.20 | 34.90 | 31.27 | 35.10 |

LSD (0.05) ): Location x genotype x TSP application = 13.97; 0 Gy = Jenguma (unirradiated); 0 kg/ha = No application of TSP Fertilizer (control)

At week 8 the number leaves for the various locations showed there were significant ($P < 0.05$) differences. Nyankpala recorded the highest number of leaves and Gulumpe recorded the least number of leaves. Manga performed averagely between Nyankpala and Gulumpe but was significantly lower than the performance at Nyankpala (Figure 12).

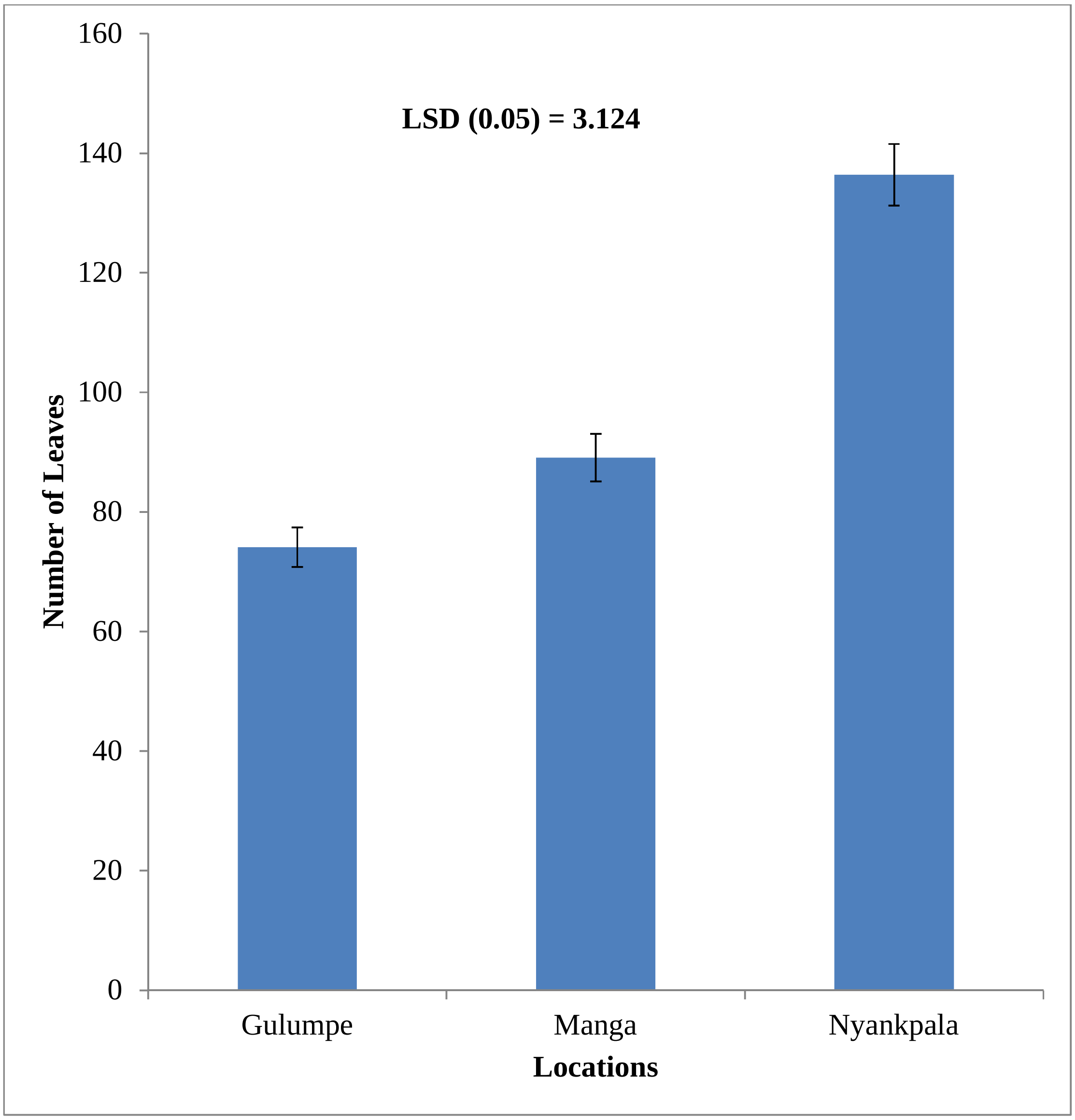

Figure 12: Variation in NL of soybean genotypes at the various locations 8 WAP

There was significant ($P < 0.05$) difference in number of leaves for the soybean genotypes at the three locations. It is observed that the highest number of leaves was recorded for the 200 Gy at Nyankpala and the least number of leaves was recorded at the Gulumpe for the 150 Gy. It was observed that even among the same genotypes across the different locations, there was significant difference in the number of leaves (Table 9).

Table 9: Interaction of soybean genotypes and locations for NL produced at 8 WAP

| **Soybean Genotypes** | **Location** | | |
|---|---|---|---|
| | Gulumpe | Manga | Nyankpala |
| **0 Gy** | 79.3 | 76.3 | 141.6 |
| **150 Gy** | 52.9 | 96.4 | 121.6 |
| **200 Gy** | 73.8 | 89.2 | 149.5 |
| **250 Gy** | 90.6 | 87.7 | 149.2 |
| **300 Gy** | 73.7 | 95.8 | 120 |

LSD (0.05): Soybean genotypes x Location = 22.78; 0 Gy = Jenguma (unirradiated)

Again, the 0 Gy genotype from 60 kg/ha of TSP fertilizer rate from Nyankpala for week 8 recorded the highest number of leaves whilst plants from 150 Gy mutants at 75 kg/ha of TSP fertilizer rate from Gulumpe of week 8 recorded the lowest number of leaves (Table 10).

Table 10: Interaction of TSP application, genotypes and locations for NL at 8 WAP

| Location | Soybean Genotypes | TSP Fertilizer Application Rate (kg/ha) 0 | 45 | 60 | 75 |
|---|---|---|---|---|---|
| Gulumpe | 0 Gy | 84.80 | 82.60 | 73.20 | 76.80 |
| | 150 Gy | 62.90 | 56.80 | 55.70 | 36.10 |
| | 200 Gy | 74.50 | 61.80 | 60.90 | 98.00 |
| | 250 Gy | 104.00 | 71.30 | 107.60 | 79.40 |
| | 300 Gy | 53.40 | 69.20 | 80.80 | 91.30 |
| Manga | 0 Gy | 77.20 | 74.40 | 57.10 | 96.60 |
| | 150 Gy | 108.70 | 85.60 | 110.80 | 80.60 |
| | 200 Gy | 97.90 | 79.00 | 103.10 | 76.60 |
| | 250 Gy | 98.80 | 88.40 | 92.40 | 71.10 |
| | 300 Gy | 57.40 | 84.30 | 123.10 | 118.40 |
| Nyankpala | 0 Gy | 99.80 | 146.70 | 211.00 | 109.00 |
| | 150 Gy | 142.30 | 96.70 | 128.50 | 119.00 |
| | 200 Gy | 192.80 | 129.30 | 159.40 | 116.50 |
| | 250 Gy | 147.80 | 167.60 | 115.80 | 165.70 |
| | 300 Gy | 156.30 | 125.70 | 93.20 | 104.90 |

LSD (0.05): Location x genotype x TSP application = 45.57; 0 Gy = Jenguma (unirradiated); 0 kg/ha = No application of TSP Fertilizer (control)

### 4.3 Number of branches

Number of branches at week 6 showed significant ($P < 0.05$) difference among locations with Nyankpala recording the highest number of branches followed by Manga and Gulumpe (Table 12). There were interaction effects between the TSP fertilizer application rates and the soybean genotypes. The 150 Gy at 60 kg/ha TSP fertilizer application produced the highest number of branches followed by the 200 Gy at 0 kg/ha (Table 11). Interestingly, the 150 Gy which produced the highest number of branches at 60 kg/ha TSP fertilizer application rate also recorded the least number of branches at 45 kg/ha TSP fertilizer application rate (Table 11).

Table 11: Interaction of TSP Application and Genotypes for NB at 6 WAP

| **TSP Fertilizer Application Rate (kg/ha)** | **Soybean Genotypes** | | | | |
|---|---|---|---|---|---|
| | 0 Gy | 150 Gy | 200 Gy | 250 Gy | 300 Gy |
| **0** | 3.323 | 3.344 | 4.86 | 3.529 | 2.708 |
| **45** | 3.026 | 2.553 | 3.833 | 4.468 | 3.23 |
| **60** | 3.343 | 4.951 | 4.052 | 3.293 | 3.751 |
| **75** | 3.772 | 3.423 | 2.947 | 3.705 | 3.426 |

LSD (0.05): TSP Fertilizer Application Rate x Soybean Genotypes = 0.99; 0 Gy = Jenguma (unirradiated); 0 kg/ha = No application of TSP Fertilizer (control)

Similarly, there were interaction effects between the soybean genotypes and locations for the number of branches (Table 12). Nyankpala recorded the highest number of branches across all the TSP fertilizer application rates and Gulumpe performed lowest among the three locations. However, across the three locations for the same soybean genotype showed some significant differences being observed. The genotype150 Gy at the Gulumpe station recorded the least number of branches (Table 12).

Table 12: Interaction of Soybean Genotypes and Locations for NL at 6 WAP

| **Soybean Genotypes** | **Location** | | |
|---|---|---|---|
| | Gulumpe | Manga | Nyankpala |
| **0 Gy** | 2.76 | 2.50 | 4.84 |
| **150 Gy** | 2.12 | 3.96 | 4.63 |
| **200 Gy** | 2.81 | 3.70 | 5.03 |
| **250 Gy** | 2.46 | 3.71 | 5.08 |
| **300 Gy** | 3.32 | 3.40 | 4.12 |

LSD (0.05): Soybean Genotypes x Locations = 0.857; 0 Gy = Jenguma (unirradiated)

Significant difference ($P < 0.05$) was observed for the interaction of TSP fertilizer application rate, soybean genotypes and locations for number of branches (Tables 13 and 14). The 200 Gy plants at 0 kg/ha of TSP fertilizer application rate from Nyankpala recorded the highest average number of branches followed by the 250 Gy plants at 45 kg/ha at the same location at 6 weeks after planting. The 0 Gy plants at 60 kg/ha at Manga at 6 weeks after planting recorded the lowest average number of branches (Table 13).

Table 13: Average NB at 6 WAP

| Location | Soybean Genotypes | TSP Fertilizer Application Rate (kg/ha) | | | |
|---|---|---|---|---|---|
| | | 0 | 45 | 60 | 75 |
| Gulumpe | 0 Gy | 2.94 | 2.41 | 2.30 | 3.38 |
| | 150 Gy | 1.63 | 1.39 | 3.99 | 1.47 |
| | 200 Gy | 3.55 | 3.30 | 2.19 | 2.21 |
| | 250 Gy | 1.99 | 2.80 | 2.31 | 2.74 |
| | 300 Gy | 1.56 | 2.19 | 2.92 | 2.61 |
| Manga | 0 Gy | 2.83 | 2.57 | 1.33 | 3.27 |
| | 150 Gy | 4.07 | 2.93 | 4.77 | 4.07 |
| | 200 Gy | 3.73 | 3.57 | 4.37 | 3.13 |
| | 250 Gy | 4.03 | 3.87 | 4.30 | 2.63 |
| | 300 Gy | 1.73 | 3.53 | 4.47 | 3.87 |
| Nyankpala | 0 Gy | 4.20 | 4.10 | 6.40 | 4.67 |
| | 150 Gy | 4.33 | 3.33 | 6.10 | 4.73 |
| | 200 Gy | 7.30 | 4.63 | 5.60 | 3.50 |
| | 250 Gy | 4.57 | 6.73 | 3.27 | 5.74 |
| | 300 Gy | 4.83 | 3.97 | 3.87 | 3.80 |

LSD (0.05): Location x genotype x TSP application = 1.71; 0 Gy = Jenguma (unirradiated); 0 kg/ha = No application of TSP Fertilizer (control)

There was significant (P < 0.05) difference among mutant genotypes at week 8 in terms of the number of branches. The results show similar performances between the 200 Gy and 250 Gy on one hand and the 0 Gy, 150 Gy, and 300 Gy on the other hand. There was however, significant difference between the 200 Gy and 250 Gy, and that of the 0 Gy, 150 Gy, and 300 Gy. Nonetheless, the 250 Gy performed better and the 0 Gy showed the worst performance in terms of number of branches at week 8 (Figure 13).

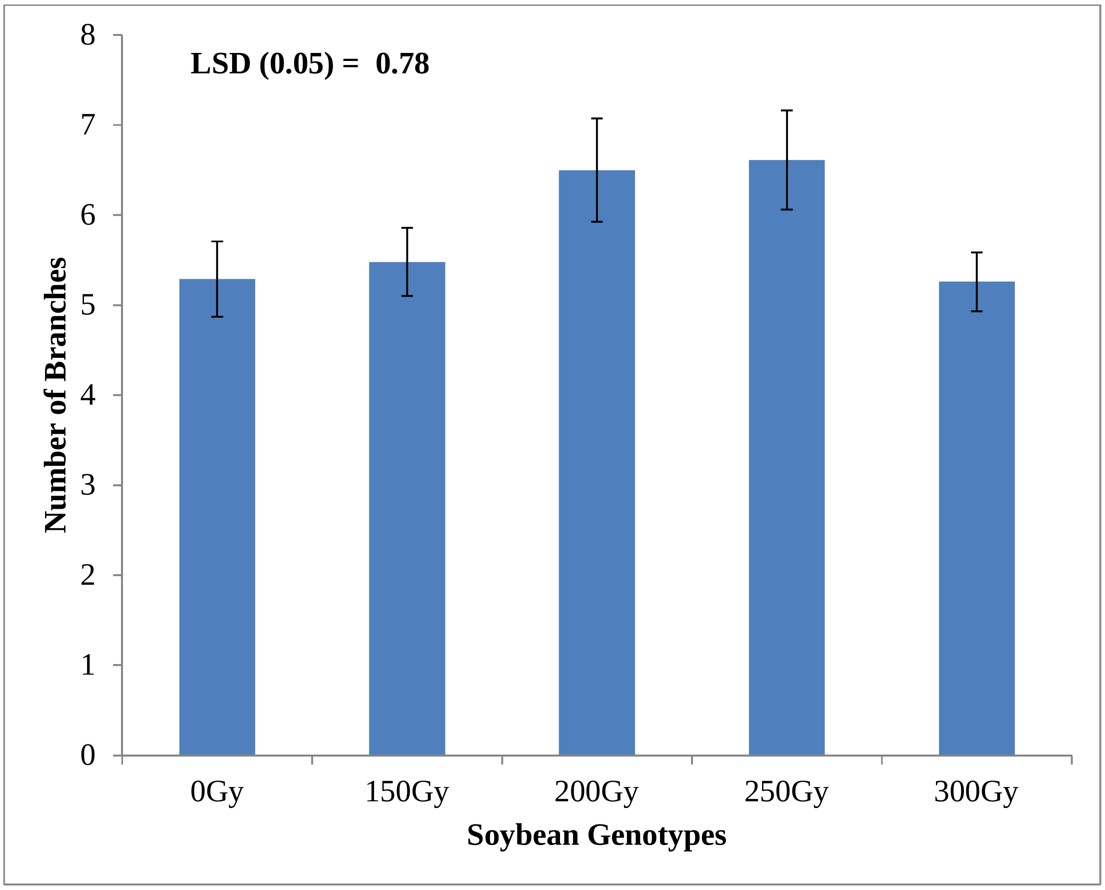

Figure 13: Variation in NB of soybean genotypes 8 WAP

0 Gy = Jenguma (unirradiated).

At week 8 the results showed significant ($P < 0.05$) difference among locations for the number of branches. Nyankpala recorded the highest number of branches and the other two; Gulumpe and Manga recorded the least but similar number of branches (Figure 14).

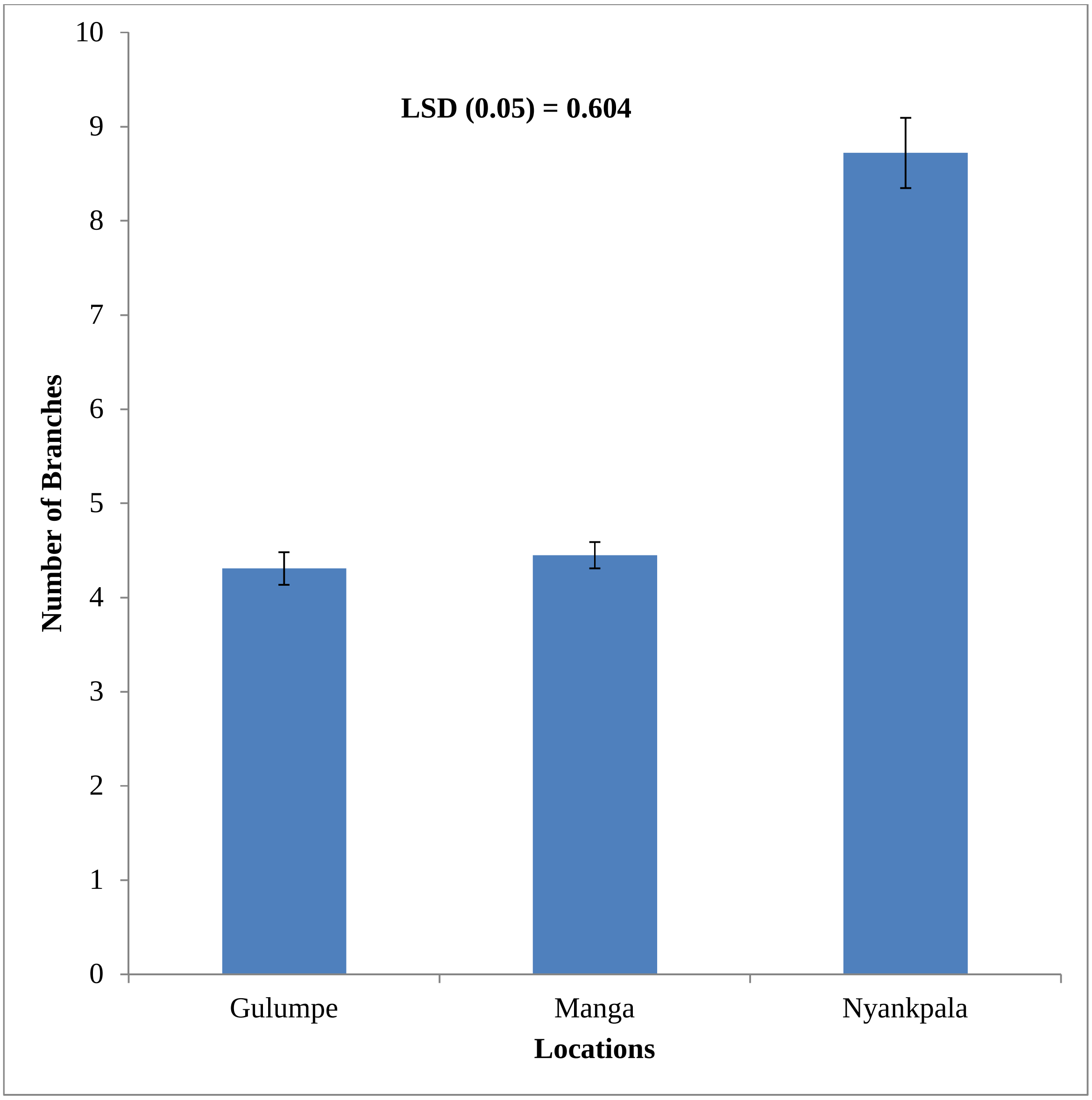

Figure 14: Variation in NB of soybean genotypes at the various locations 8 WAP

At 8 weeks after planting, the 200 Gy plants at 0 kg/ha of TSP fertilizer application rate from Nyankpala recorded the highest average number of branches of 14 followed by the 250 Gy at 45 kg/ha of the same location. The 0 Gy plants fertilized with 60 kg/ha at Manga at 8 weeks after planting recorded the lowest average number of branches of 2 (Table 14).

Table 14: Average NB at 8 WAP.

| Location | Soybean Genotypes | TSP Fertilizer Application Rate (kg/ha) | | | |
|---|---|---|---|---|---|
| | | 0 | 45 | 60 | 75 |
| Gulumpe | 0 Gy | 4.43 | 4.33 | 3.93 | 5.10 |
| | 150 Gy | 3.27 | 3.27 | 4.75 | 2.70 |
| | 200 Gy | 4.67 | 4.20 | 4.58 | 5.01 |
| | 250 Gy | 4.37 | 5.49 | 5.17 | 4.73 |
| | 300 Gy | 2.94 | 4.07 | 4.73 | 4.53 |
| Manga | 0 Gy | 4.33 | 3.17 | 2.48 | 3.87 |
| | 150 Gy | 4.67 | 4.56 | 5.17 | 4.93 |
| | 200 Gy | 4.98 | 4.30 | 5.46 | 4.43 |
| | 250 Gy | 5.03 | 5.27 | 5.10 | 3.83 |
| | 300 Gy | 3.07 | 4.17 | 4.97 | 5.13 |
| Nyankpala | 0 Gy | 6.27 | 7.30 | 11.20 | 7.03 |
| | 150 Gy | 9.17 | 6.90 | 7.43 | 8.97 |
| | 200 Gy | 13.57 | 7.93 | 10.40 | 8.43 |
| | 250 Gy | 9.93 | 12.97 | 7.10 | 10.37 |
| | 300 Gy | 8.60 | 8.00 | 6.27 | 6.63 |

LSD (0.05): Location x genotype x TSP application = 2.70; 0 Gy = Jenguma (unirradiated); 0 kg/ha = No application of TSP Fertilizer (control)

### 4.4 Days to 50% flowering

Among the soybean genotypes, there was significant difference ($P < 0.05$) in the days to 50 % flowering. The 200 Gy, 150 Gy and 250 Gy mutant plants took least number of days to reach 50% flowering as compared to the 300 Gy and 0 Gy plants which took relatively higher number of days to reach 50% flowering (Figure 15). However, the single effect of locations, the interaction between soybean genotypes and locations; and the single effect of fertilizer application rate on genotypes did not differ significantly ($P > 0.05$) for this trait.

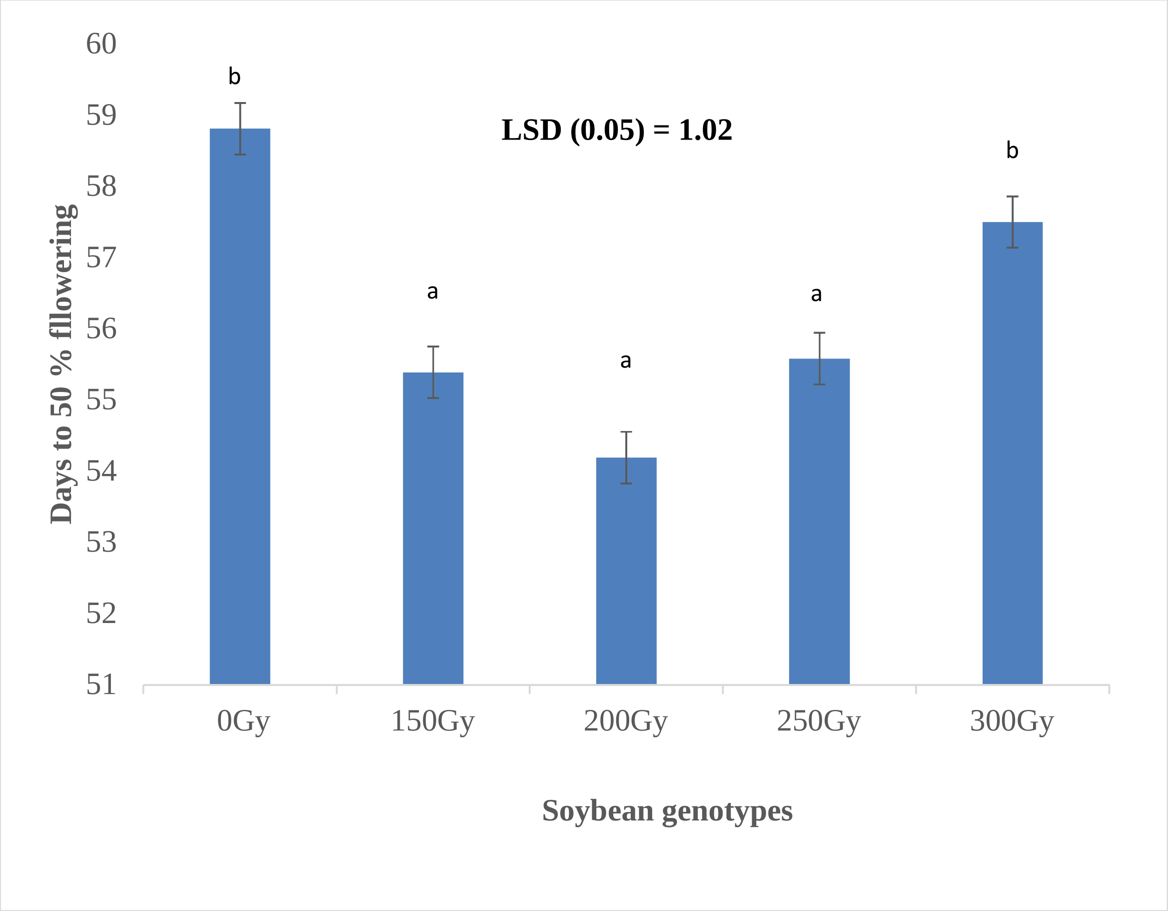

Figure 15: Variation in days to 50% flowering of soybean genotypes.

0 Gy = Jenguma (unirradiated).

However, the interaction between fertilizer application rate and the soybean genotypes varied significantly ($P < 0.05$) for days to 50 % flowering. The 250 Gy mutant plants at 0 kg/ha and 200 Gy at 45 kg/ha took the least number of days to reach 50% flowering while 0 Gy at 45 kg/ha took highest number of days to reach 50% flowering. Interestingly, the 250 Gy and 300 Gy at 60 kg/ha performed similarly for this trait (Table 15).

Table 15: Interaction of TSP application and genotypes for days to 50% flowering

| **Soybean Genotypes** | **TSP Fertilizer Application Rate (kg/ha)** | | | |
|---|---|---|---|---|
| | 0 | 45 | 60 | 75 |
| **0 Gy** | 58.00 | 59.78 | 58.59 | 58.56 |
| **150 Gy** | 57.44 | 54.11 | 54.22 | 55.78 |
| **200 Gy** | 54.11 | 53.33 | 55.00 | 54.33 |
| **250 Gy** | 53.00 | 55.22 | 56.00 | 58.11 |
| **300 Gy** | 58.89 | 57.67 | 56.22 | 57.22 |

LSD (0.05): Location x genotype x TSP application = 2.04; 0 Gy = Jenguma (unirradiated); 0 kg/ha = No application of TSP Fertilizer (control)

### 4.5 Number of pods per plant

Among the locations (main effect for locations) the number of pods per plant of soybean genotypes varied significantly (P < 0.05). The soybean genotypes at both Manga and Nyankpala recorded higher and similar number of pods per plant than those from Gulumpe which recorded relatively lower number of pods per plant (Figure 16) Neither the fertilizer application rate nor soybean genotypes nor any of these interactions differed significantly (P > 0.05).

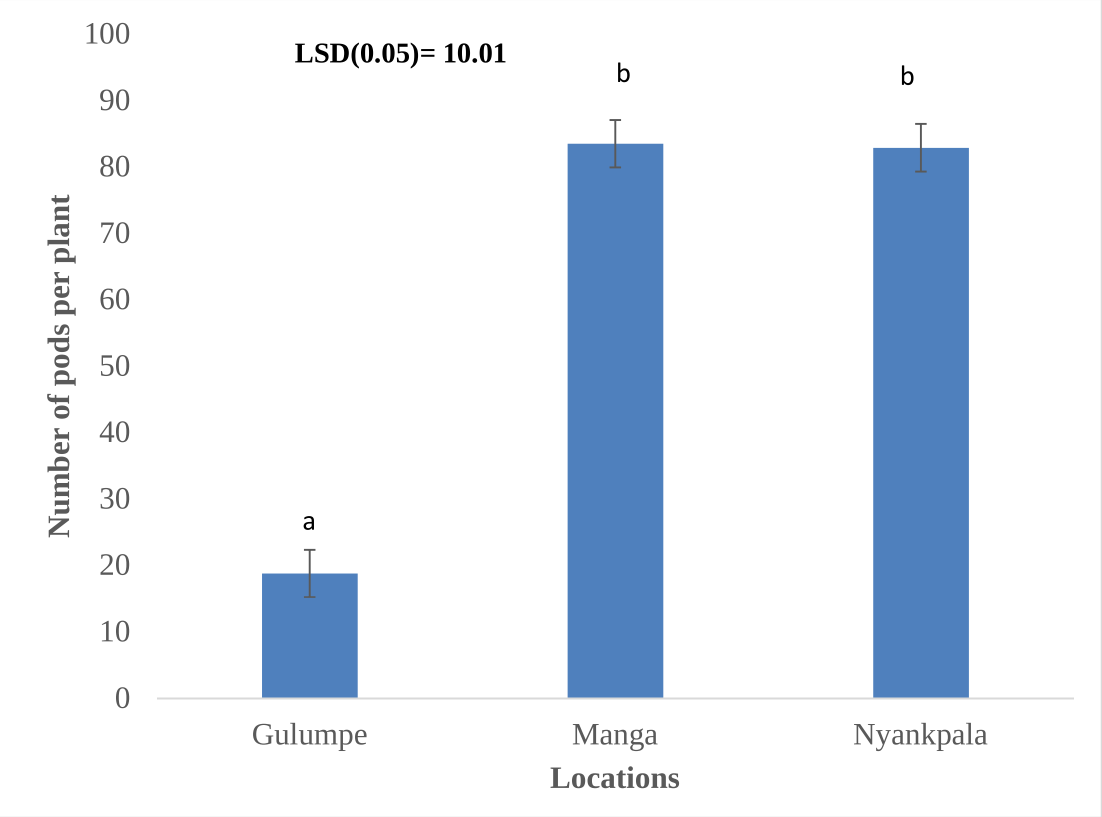

Figure 16: Variation in NP per plant of soybean genotypes.

0 Gy = Jenguma (unirradiated).

### 4.6 100-seed weight

The variation among the soybean genotypes (main effect of genotypes) for 100-seed weight was significant ($P < 0.05$). The 200 Gy and 250 Gy plants recorded higher but similar values for 100-seed weight while plants from 0 Gy recorded relatively low 100-seed weight (Figure 17).

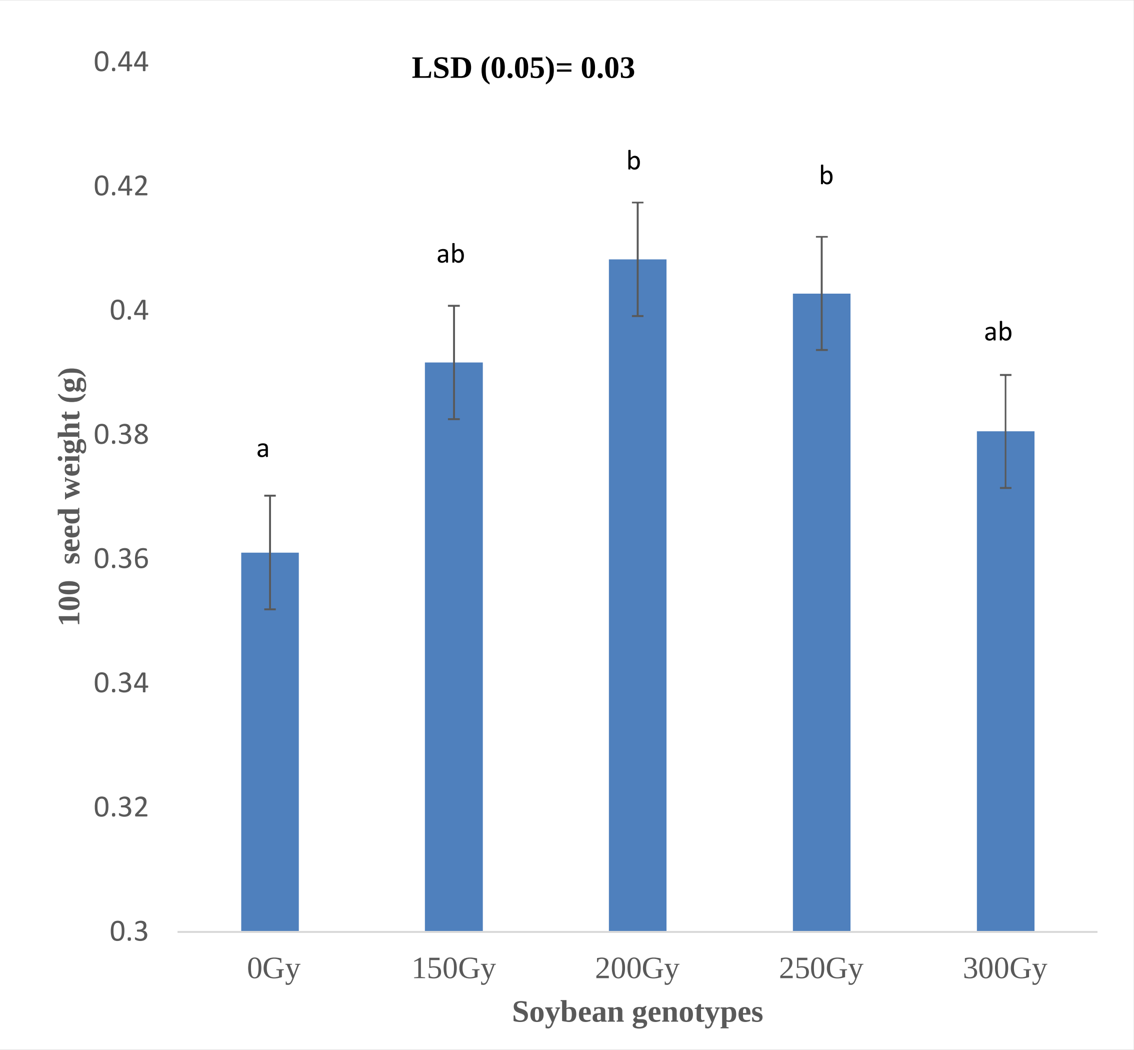

Figure 17: Variation in 100-seed weight of soybean genotypes

0 Gy = Jenguma (unirradiated).

The single effect of locations for 100-seed weight also varied significantly ($P < 0.05$). Nyankpala and Manga recorded significantly higher and similar values of 100-seed weights as compared to Gulumpe which recorded lower 100 seeds weight (Figure 18).

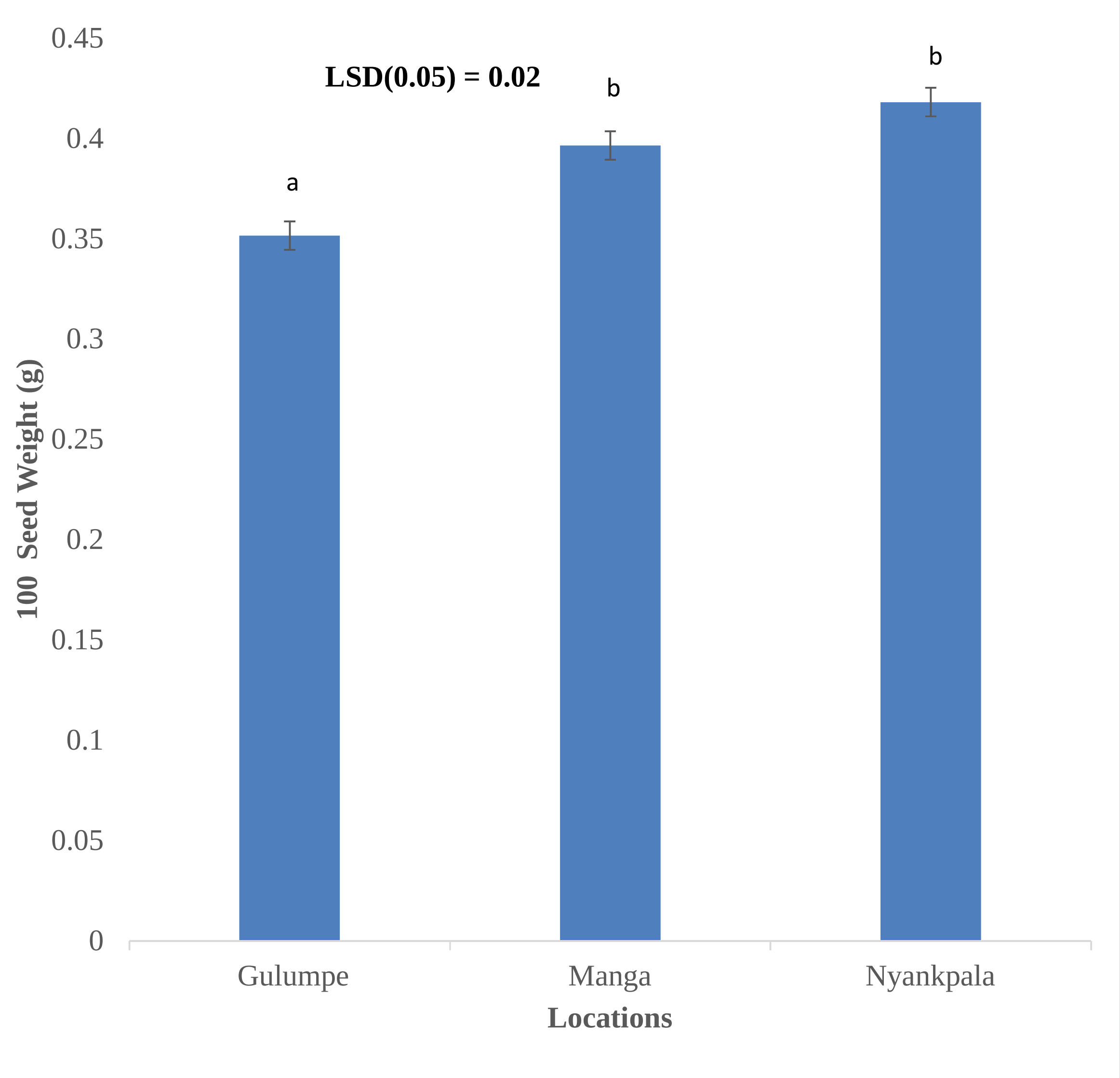

Figure 18: Variation in 100-seed weight of soybean genotypes

0 Gy = Jenguma (unirradiated).

### 4.7 Total grain yield (t/ha)

The mutant genotypes showed significant ($P < 0.05$) differences for total grain yield. All the mutant genotypes performed better than the control. The 250 Gy which performed best was however not significantly different from both 150 Gy and 200 Gy; nonetheless it was significantly different from the 300 Gy (Figure 19).

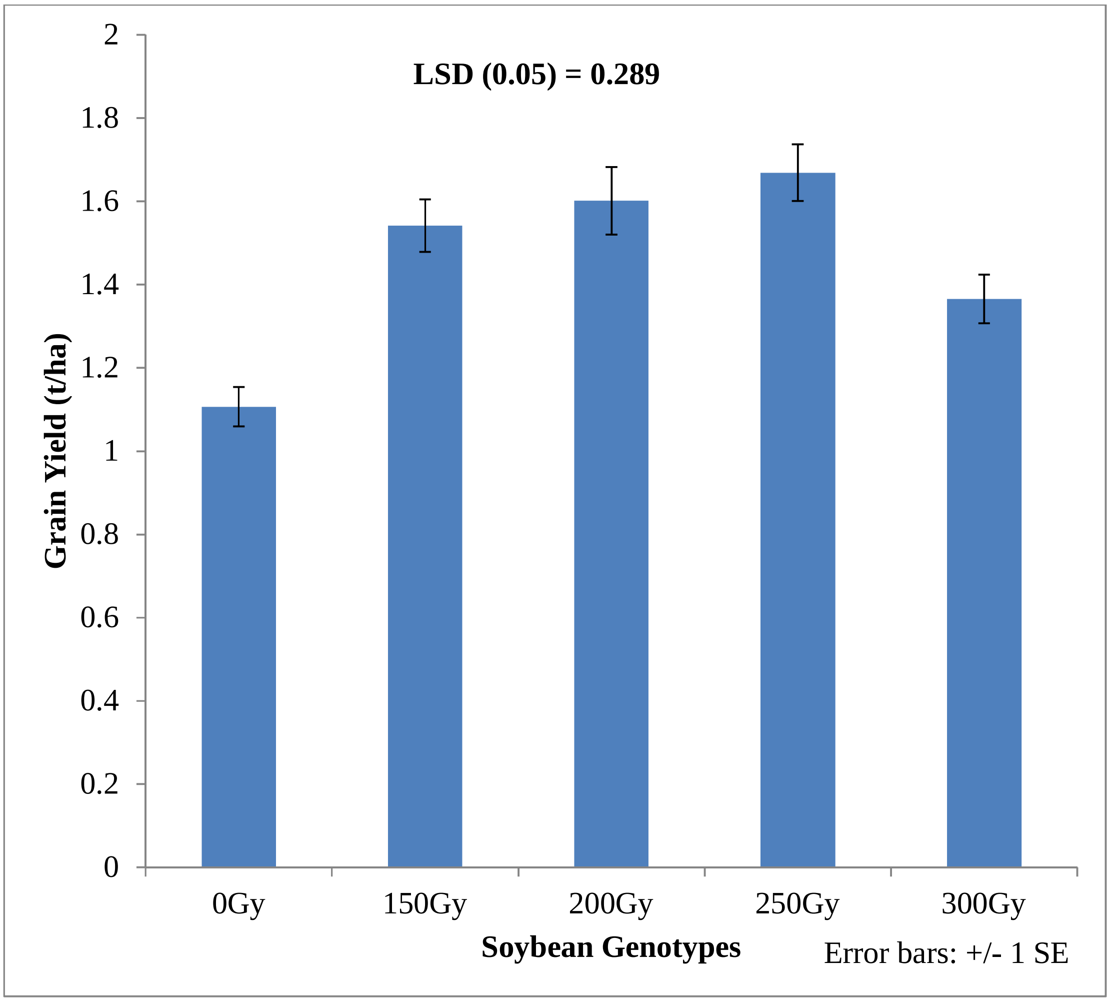

Figure 19: Variation in Grain yield (t/ha) of soybean genotypes

0 Gy = Jenguma (unirradiated).

There were highly significant ($P < 0.001$) differences among the locations for total grain yield. Nyankpala had the highest performance in terms of grain yield followed by Manga with Gulumpe recording the lowest in terms of grain yield (Figure 20).

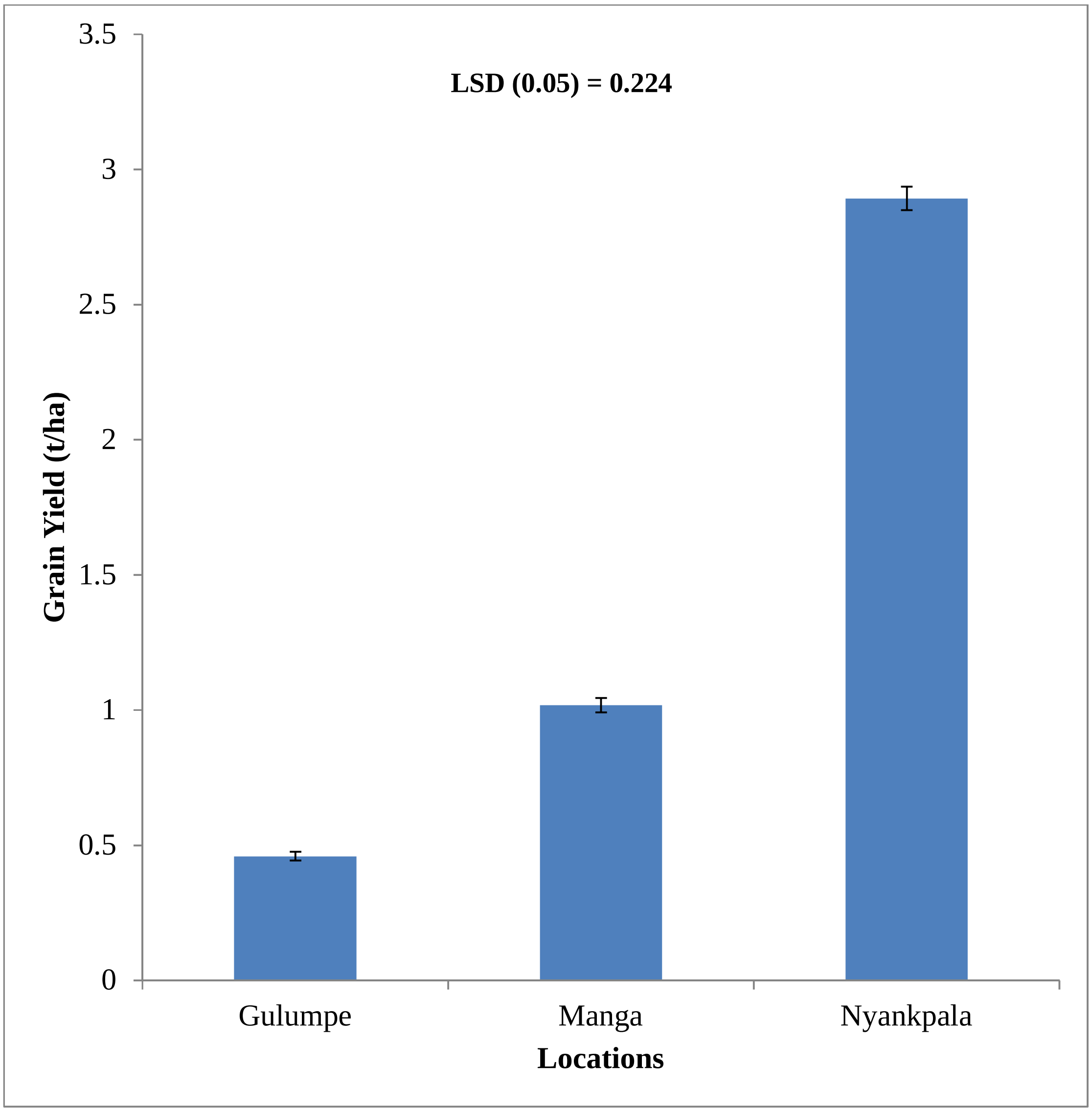

Figure 20: Variation in Grain yield (t/ha) at various locations

There were significant ($P < 0.05$) differences between the soybean genotypes and the TSP fertilizer application rates. The 200 Gy produced the highest grain yield (2.29 t/ha) at 60 kg/ha application rate of the TSP fertilizer, followed by the 250 Gy (1.85 t/ha) and 150 Gy (1.85 t/ha) with (1.85 t/ha) at 45 kg/ha and 60 kg/ha respectively. The worst performance of 0.76 t/ha of grain yield was recorded for the 0 Gy at 0 kg/ha TSP fertilizer application rate (Table 16).

Table 16: Interaction of TSP application and genotypes for Total grain yield (t/ha).

| **Soybean Genotype** | **TSP Fertilizer Application Rate (kg/ha)** | | | |
|---|---|---|---|---|
| | 0 | 45 | 60 | 75 |
| **0 Gy** | 0.76 | 1.39 | 1.00 | 1.27 |
| **150 Gy** | 1.67 | 1.19 | 1.85 | 1.47 |
| **200 Gy** | 1.67 | 1.19 | 2.29 | 1.26 |
| **250 Gy** | 1.83 | 1.85 | 1.62 | 1.37 |
| **300 Gy** | 1.47 | 1.41 | 1.3 | 1.28 |

LSD (0.05): Soybean genotype x TSP fertilizer application rate = 0.58; 0 Gy = Jenguma (unirradiated); 0 kg/ha = No application of TSP Fertilizer (control)

There were significant ($P < 0.05$) differences between the soybean genotypes and the various locations. The 200 Gy produced the highest grain yield (3.52 t/ha) at Nyankpala followed by the 250 Gy and 150 Gy with 3.25 t/ha and 3.07 at the same location. The worst performance of 0.25 t/ha of grain yield was recorded for the 300 Gy at Gulumpe. In fact, all the genotypes performed better at Nyankpala than Manga and Gulumpe in descending order (Table 17).

Table 17: Interaction of soybean genotypes and locations for Total grain yield (t/ha)

| **Soybean Genotype** | **Location** | | |
|---|---|---|---|
| | Gulumpe | Manga | Nyankpala |
| **0 Gy** | 0.80 | 0.43 | 2.09 |
| **150 Gy** | 0.32 | 1.23 | 3.07 |
| **200 Gy** | 0.42 | 0.87 | 3.52 |
| **250 Gy** | 0.5 | 1.26 | 3.25 |
| **300 Gy** | 0.25 | 1.31 | 2.53 |

LSD (0.05): Soybean genotype x Location = 0.50; 0 Gy = Jenguma (unirradiated)

The interaction of soybean genotypes, fertilizer application rate and locations for total grain yield varied highly significantly (P < 0.001). The 200 Gy plants fertilized with 60 kg/ha of TSP from Nyankpala recorded the highest total grain yield of 4.83 t/ha whilst the 300 Gy plants at 0 kg/ha from Gulumpe and 0 Gy at 60 kg/ha of fertilizer application at Manga recorded the lowest total grain yields of 0.14 t/ha and 0.15 t/ha respectively (Table 18).

Table 18: Interaction of TSP application, genotypes and locations for Total grain yield (t/ha).

| Location | Soybean Genotypes | TSP Fertilizer Application Rate (kg/ha) | | | |
|---|---|---|---|---|---|
| | | 0 | 45 | 60 | 75 |
| Gulumpe | 0 Gy | 0.73 | 0.78 | 0.49 | 0.89 |
| | 150 Gy | 0.40 | 0.20 | 0.30 | 0.21 |
| | 200 Gy | 0.20 | 0.19 | 0.28 | 0.78 |
| | 250 Gy | 0.30 | 0.32 | 1.10 | 0.09 |
| | 300 Gy | 0.14 | 0.15 | 0.25 | 0.36 |
| Manga | 0 Gy | 0.31 | 0.33 | 0.15 | 0.73 |
| | 150 Gy | 1.20 | 0.73 | 1.50 | 0.89 |
| | 200 Gy | 0.89 | 0.57 | 1.08 | 0.52 |
| | 250 Gy | 1.45 | 1.27 | 1.36 | 0.44 |
| | 300 Gy | 0.78 | 1.45 | 1.29 | 1.19 |
| Nyankpala | 0 Gy | 1.02 | 2.64 | 2.06 | 1.81 |
| | 150 Gy | 2.90 | 2.22 | 3.19 | 2.75 |
| | 200 Gy | 3.33 | 2.47 | 4.83 | 2.04 |
| | 250 Gy | 3.18 | 3.41 | 1.92 | 3.18 |
| | 300 Gy | 3.02 | 2.22 | 1.97 | 1.91 |

LSD (0.05): Location x genotype x TSP application = 1.00; 0 Gy = Jenguma (unirradiated); 0 kg/ha = No application of TSP Fertilizer (control).

# CHAPTER FIVE

# DISCUSSION

## 5.1 Growth parameters

Higher height of a soybean plant is a disadvantage in terms of lodging during heavy rains and winds. This in fact is a trait that breeders would wish reduced in most crops to avoid lodging. The recorded increase in plant height of the 300 Gy plants might be due to the deleterious effects of the gamma dose which led to augmented cellular propagation or cell division at cellular level. This in fact conforms to the findings of Lysenkov et al. (1989) who induced a wide range of viable mutants and observed increase in wheat height. A similar result was also reported by Adamu et al. (2002) when they exposed the seeds of five varieties of groundnut (*Arachis hypogaea*) to gamma ray from Cobalt 60 source. Also, Khan and Tyagi (2013) exposed the seeds of the soybean line B-89/J I to gamma rays and thermal neutrons and observed that most of the soybean genotypes in $M_2$-$M_4$ were taller than the control line of B-89/11. Fahmy et al. (1997) also reported that the increasing doses of gamma-rays were deleteriously concomitant with plant height. Kundi et al. (1997) however, reported that after irradiation of three varieties of soybean viz: PK 416, SL96 and PB Soybean No.1 with three doses of gamma rays viz: 10, 20 and 30 kR, there was negligible increase in mean values for plant height.

In the present study, plants from 150 Gy, 200 Gy, and 250 Gy were seen to have had shorter heights thereby making them stronger and resistant to lodging during heavy rains and winds and thus significant improvement over the parent cultivar (Jenguma). Keep (2013) reported that reduced plant height and lodging resistance have been found to improve seed yield in soybeans, and the findings of this present study confirms same, as the yield of the soybean genotypes from shorter plant heights were higher than the unirradiated control (0 Gy, Jenguma). Mian et al. (2008) reported on the contrary that increased plant height is a desirable attribute for cultivars used for late planting, because a greater vegetative growth before flowering is regarded as an advantage for producing higher seed yield and a more effective tool for mechanical harvest. This trait of height is also recognized as a desirable character for low-yielding environments where stress conditions hinder plant growth (Fleury *et al.*, 2010).

Mudibu et al. (2012) also stated that the effectiveness of gamma radiation on plant growth improvement, seed quality, cooking time as well as other physiological processes is highly associated with the level of doses used. In this study there were differences in the height among soybean genotypes where the 200 Gy recorded the least height with plants from 300 Gy recording a height next only to the 0 Gy which was the highest in terms of plant height.

The interaction effect of location, gamma irradiation and fertilizer application was significant and the pattern of observed results was similar to that of gamma irradiation at week 4. Differences in soil physico-chemical properties of the three locations and variation in weather parameters might have influenced the response of the soybean plants to fertilizer application as was observed at week 6. This could further be the reason why maximum plant height was not observed with application of 75 kg/ha TSP fertilizer. The effect of TSP fertilizer application rate might have influenced the height of soybean genotypes and the control positively. It was seen that at 4 weeks after planting, the 0 Gy at Gulumpe at no TSP fertilizer application recorded the highest height followed by 250 Gy with 60 kg/ha of TSP fertilizer application.

The present study showed that plants from the 200 Gy and 250 Gy produced the highest number of leaves as compared to the other genotypes and consequently the number of pods formed in these two soybean genotypes happened to be more than the rest. This finding gives credence to what was reported by Isoda et al. (2010) that the leaf canopy had a positive correlation with the number of pods produced by a soybean plant, and also what was reported by Mian et al. (2008) also observed that fast and strong early growth and rapid canopy development can be effective in subduing weed invasion of crop plants. The results for number of leaves have revealed that an increase in fertilizer rate caused a decrease in the leaf number. This result was unexpected as increased nutrient availability was expected to cause an increase in the number of leaves. Certain soil factors influencing the assimilation of the P fertilizer by soybean could have been the cause of this anomaly (Bucci *et al.*, 2006). Another reason that might have caused this phenomenon could be presence of excess P which might have inversely affected the development of leaves by the soybean plants (Vance *et al.*, 2003).

Genotypic differences positively affected the number of branches and this conforms to the findings of Iqbal et al. (2003) that more densely branched mutants were recorded in X-ray irradiated material. Furthermore, higher number of branches was observed in plants in Nyankpala as compared to the other locations which reiterate the importance of agroecology on production of arable crops. This trend was also observed with the number of leaves but not with height. This could imply that there is payoff with respect to plant height on one hand and number of leaves and branches on the other hand. This could be due to the ability of the soybean plant to partition the distribution of photosynthates among all parts of the plant (Marcelis, 1996).

## 5.2 Earliness in flowering

In soybean production, reproductive growth as in most other grain crops is initiated by flowering and a period of pod or seed set. The number of days that it takes to get these phases of growth attained is therefore very important. The number of pods or seeds that the crop produces is determined by flowering and the number of flowers it bears to a large extent determines the final grain yield (Egli, 1998). Flower production and seed set therefore are stages in the potential yield production process, but one that is not well understood (Egli, 2005). Plants from 200 Gy and 250 Gy mutants flowered within six weeks after planting and reached earlier maturity than those from 300 Gy and 150 Gy which reached flowering and maturity later. The 0 Gy (unirradiated Jenguma) was late flowering and it also matured later than the soybean mutant genotypes and ultimately this also delayed pods and seeds formation of the former. The number of flowers borne by plants does not necessarily translate into matured pods due to abortion and abscission (Nico *et al*., 2015). These incidences can take place at several phases of reproductive growth and development (Kato *et al.*,1955; Dybing and Huff, 1980; and Heitholt et al. 1986) and immature pods (McBlain and Hume 1981) being the most susceptible to reproductive failure.

Mutagenesis has reduced the number of days to flowering compared with the unirradiated Jenguma which served as control. This finding is in agreement with that of Mensah et al. (2007) and Mathew et al. (2014) who reported that increase in colchicine concentration and para-dichlorobenzene during induced mutation decreased number of days to flowering and increased leaf number. The decrease in number of days to flowering in the present study might be due to inhibitory effects of the mutants and physiological changes in the plant as a result of faster cellular division prior to flowering and reproductive stage especially at higher doses and concentration of gamma radiation (Koornneefa and Zabel, 1990).

### 5.3 Components of yield and total grain yield

According to Liu et al. (2010), the seed yield of soybean encompasses several components, including the number of plants per unit area, number of pods per plant, number of seeds per pod, and the seed size. They were of the view that, enriched light in field conditions could lead to an increase in the number of plants per unit area, which in turn leads to reactions of other components.

It was observed that in terms of yield, previous and present study showed that the parental line (Jenguma) did not produce high grain yield as compared to the mutant genotypes. More pods were formed from plants of 250 Gy and 200 Gy genotypes as well as those of 150 Gy and 300 Gy. Their performance could be attributed to the number of leaves recorded for these genotypes. The overall performance of the soybean genotypes across the three locations showed that Nyankpala in the guinea savannah agro-ecological zone had the highest number of pods formed than the other two ecological zones. It is probably so as a result of G x E interaction and the number of leaves that was recorded at the Nyankpala site as against the Gulumpe and Manga. The interaction effect of G and E cannot be ruled out as reported by Bellaloui et al. (2015)

that soybean genotypes grown in various locations showed significant differences in oil, protein and fatty acid composition. Similarly, soybean grown on irrigated land resulted in higher polyunsaturated fatty acids. Interestingly, the performance of the soybean genotypes in the two locations other than Nyankpala was similar but all genotypes performed better than the parental Jenguma plant (0 Gy). In any case, the average number of seeds per pod did not influence total grain yield among locations. Fewer pods were however produced by the 0 Gy (Jenguma) and some pods were immature and it caused a reduction in seed yield. This is attributable to what Egli (2005) reported in his work that immature seeds are more likely to be aborted than large seeds.

# CHAPTER SIX

# CONCLUSION AND RECOMMENDATIONS

## 6.1 Conclusion

Based on the findings of the study, the following conclusion could be made: mutagenesis had effects on plant growth parameters and yield of soybean. The results give an indication that variation in genotypes caused by induced mutation may have had effects on agronomic performance of soybean.

Treatments with higher doses of gamma rays are known to be inhibitory, whilst lower exposures are occasionally instigatory. Mutation thus affects plant morphology, anatomy, biochemistry, and physiology depending on the irradiation dose employed.

The 200 Gy mutant plants recorded the least number of days to flowering and hence showed a positive improvement as an early flowering plant, a trait that is good for short rainy season ecological zones as well as easy adaptability to areas with prolonged drought.

The reduction in the height of plants from 200 Gy and the 250 Gy mutant genotypes was encouraging as shorter heights have the tendency of improving the plants' vigor against destruction by heavy winds and run off thus effectively checking lodging in plants. This indirectly, possibly was responsible for the profuse branching in the 200 Gy and the 250 Gy mutant genotypes which is a desired trait. Profuse branching in plants may improve the number of pods borne by the soybean plant as against taller plants.

In general, mutagenesis increased the yield potential of the 200 Gy and 250 Gy genotypes and number of seeds. More desirable traits were seen in these plants where grain yield was also high. The field performance of the 150 Gy, 200 Gy, 250 Gy and

300 Gy were all higher than the parental variety (Jenguma, 0 Gy). The 200 Gy and 250 Gy mutant genotypes matured earlier and had shorter stems as compared to the Jenguma variety which served as control and standard check. The 200 Gy and 250 Gy mutants were seen to be performing well for all the growth and yield parameters observed.

## 6.2 Recommendations

The current research shows that the soybean genotypes (200 Gy and 250 Gy) could also be screened for other equally important traits such as disease resistance and tolerance to drought conditions. Results from the present study also shows that the 200 Gy and 250 Gy genotypes are highly promising and can be worked on for immediate release as improved varieties to farmers in the study area particularly Nyankpala.

Further studies to determine whether mutagenesis has had effect on nutritional values and at what levels of irradiation is acceptable should be carried out.

## REFERENCES

**Acquaah, G. (2015).** Conventional plant breeding principles and techniques. *Breeding, Biotechnology and Molecular Tools* (pp. 115-158). Springer, Cham.

**Adamu, A.K., Oluranju, P.E., Bate, J.A. and Ogunlade, O.T. (2002)**. Radiosensitivity and effective dose determination in groundnut (*Arachis hypogaea* L.) irradiated with gamma-rays. *Journal of Agriculture and Environ*ment, 3: 17-84.

**Adeniyah, O.N. and Ayoola, O. T. (2007)**. Evaluation of four improved soybean varieties under different planting date in relayed cropping system with maize under soybean / maize / cassava intercrop. *African Journal of Biotechnology*, *6*(19): 2220–2224.

**Agada, M. (2015)**. Constraints to increase soybean production in Benue State, Nigeria. *Asian Journal of Agricultural Extension, Economics and Sociology*, *4*(4): 277-284.

**Agriculture in Ghana-Facts and figures (2012)**. Ministry of Food and Agriculture (MoFA)-Statistics, Research and Information Directorate (SRID). MoFA, S. R. I. D. (2013).

**Ahiakpa, J. K., Adjei-Nsiah, S., Alabi, B. U., and Kanampiu, F. (2018).** Response of grain legumes to phosphorus application in the guinea savanna agro-ecological zones of Ghana. *Agronomy Journal*, *110*(3): 1089-1096.

**Akpapunam, M. A., Igbedioh, S. O. and Aremo, I. (1996).** Effect of malting time on chemical composition and functional properties of soybean and bambara groundnut flours. *International journal of food sciences and nutrition*, *47*(1): 27-33.

**Alhassan, S., Mohammed, A. R. and Amegashie, D. P. K. (2016)**. Technical efficiency of soybean farmers in the Northern region of Ghana. *Africa Development and Resources Research Institute*, 2 (11): 20-38.

**Ali, N., and Singh, G. (2010).** Soybean processing and utilization. The soybean: botany, production and uses. *Indian Council of Agricultural Research, KAB-II,* Pusa, New Delhi, India. pp. 345–374. CABI.

**Amtmann, A., Hammond, J. P., Armengaud, P. and White, P. J. (2006).** Nutrient sensing and signalling in plants: potassium and phosphorus. *Advances in Botanical Research*, *43*, 209-257.

**Amtmann, A., Troufflard, S., and Armengaud, P. (2008)**. The effect of potassium nutrition on pest and disease resistance in plants. *Physiologia plantarum*, *133*(4), 682-691.

**AQUASTAT 2005:** Agricultural water management and poverty linkages. *Agricultural water management*, *97*(4): 520-527.

**Arefrad, M., Nematzadeh, G., Babaian Jelodar, N. and Kazemitabar, S. K. (2012).** Improvement of qualitative and quantitative traits in soybean [Glycine Max (L.) Merrill] through gamma irradiation. *Journal of Plant Molecular Breeding*, *1*(1): 10-15.

**Ariga, J., Jayne, T. S., and Nyoro, J. K. (2006).** Factors driving the growth in fertilizer consumption in Kenya, 1990-2005: Sustaining the momentum in

Kenya and lessons for broader replicability in Sub-Saharan Africa (No. 1093-2016-87794).

**Arshad, M., Ali, N., and Ghafoor, A. (2006).** Character correlation and path coefficient in soybean Glycine max (L.) Merrill. *Pakistan Journal of Botany*, *38*(1): 121–130.

**Batista, R. O., Hamawaki, R. L., Sousa, L. B., Nogueira, A. P. O. and Hamawaki, O. T. (2015)**. Adaptability and stability of soybean genotypes in off-season cultivation. *Genetics and Molecular Research*, *14*(3): 9633–9645.

**Bellaloui, N., Bruns, H. A., Abbas, H. K., Mengistu, A., Fisher, D. K. and Reddy, K. N. (2015)**. Effects of row-type, row-spacing, seeding rate, soil-type, and cultivar differences on soybean seed nutrition under U.S. Mississippi Delta conditions. *PloS one*, *10*(6), e0129913.

**Bewley, J. D., and Black, M. (2012)**. Physiology and biochemistry of seeds in relation to germination: viability, dormancy and environmental control. *Springer Science and Business Media*, 2, 25 p.

**Bindura, M. and Bindura, E. (2014).** An assessment of performance of soya bean ( *Glycine max* ) variety in low rainfall areas of Zimbabwe. *International Journal of Agronomy and Agricultural Research*, *5*(4): 1–6.

**Bonato, A. L. V., Calvo, E. S., Geraldi, I. O. and Arias, C. A. A. (2006)**. Genetic similarity among soybean (Glycine max (L) Merrill) cultivars released in Brazil using AFLP markers. *Genetics and Molecular Biology*, *29*(4): 692-704.

**Bridges, E. M. and Van Baren, J. H. V. (1997).** Soil: an overlooked, undervalued and vital part of the human environment. *Environmentalist*, *17*(1): 15-20.

**Bucci, R., Tava, A., Vitali, C., Rosato, A., Bialy, Z. and Jurzysta, M. (2006)**. Antimicrobial activity of saponins from *Medicago spp*: structure-activity relationship. *Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives*, *20*(6): 454-457.

**Burton, J. W. (1997)**. Soyabean (Glycine max (L.) Merr.). *Field Crops Research, 53*(1-3): 171-186.

**Byerlee, D. R., Spielman, D. J., Alemu, D. and Gautam, M. (2007)**. Policies to promote cereal intensification in Ethiopia*: A review of evidence and experience* (No. 589-2016-39815).

**Cai, J. (2012).** Long-term storage of soybean in nitrogen and air. Doctoral Thesis, Agricultural Chemistry, Faculty of Agriculture and Environment - University of Sydney.

**Calderwood, H. (1997).** McGraw-Hill Encyclopaedia of Science and Technology. *Permittivity, McGraw-Hill*, 249-253.

**Chete, L. N., Adeoti, J. O., Adeyinka, F. M. and Ogundele, O. (2014)**. *Industrial development and growth in Nigeria: Lessons and challenges* (No. 2014/019). WIDER working paper.

**Ciamporová, M. (2002)**. Morphological and structural responses of plant roots to aluminium at organ, tissue, and cellular levels. *Biologia Plantarum*, *45*(2): 161-171.

**CRI. (2010)**. CRI *Annual Report 2010.* Council for Scientific and Industrial Research, Ghana.

**Cruz, C.D., Regazzi, A.J. and Carneiro, P.C.S. (2004)**. Modelos Biométricos Aplicados ao Melhoramento Genético. Third Edition, Editora UFV, Viçosa, 480-488 p.

Coe, M., Soares-Filho, B., Rajão, R., Macedo, M., Carneiro, A., Costa, W., and Alencar, A. (2014). Cracking Brazil's forest code. *Science, 344*(6182): 363-364.

**Dasan, A. S. (2012)**. Compatibility of agrochemicals on the growth of phosphorous mobilizing bacteria Bacillus megaterium var. phosphaticum potassium mobilizing bacteria Frateuria aurantia. *Appl Res Dev Inst J, 6*(13), 118-34.

**Dashiell, K. E. (2008).** Soybean production and utilization in Nigeria. Paper presented at the national workshop on small scale and industrial level for processing of soybean held at IITA, Ibadan, Nigeria.

**de Avila, A. M. H., Farias, J. R. B., Pinto, H. S. and Pilau, F. G. (2013)**. Climatic restrictions for maximizing soybean yields. In *A comprehensive survey of international soybean research-Genetics, Physiology, Agronomy and Nitrogen Relationships*. IntechOpen.

**De Bruin, J. L. and Pedersen, P. (2008)**. Soybean seed yield response to planting date and seeding rate in the Upper Midwest. *Agronomy Journal, 100*(3): 696-703.

**Dei, H. K. (2011)**. Soybean as a feed ingredient for livestock and poultry. In *Recent trends for enhancing the diversity and quality of soybean products*. IntechOpen.

**Deshmukh, A. N. and Deshmukh, S. J. (2013)**. Constraints in production and marketing of soybean. *Agriculture Update, 8*(1/2): 64-66.

**Dlamini, A. P. (2015)**. Soybean (Glycine max L. Merr) productivity in varying agro-ecological zones (Doctoral dissertation, Faculty of Natural and Agricultural Sciences, University of Pretoria, South Africa).

**Dogbe, W., Etwire, P. M., Martey, E., Etwire, J. C., Baba, I. I. and Siise, A. (2013).** Economics of soybean production: evidence from Saboba and Chereponi districts of Northern region of Ghana. *Journal of Agricultural Science, 5*(12): 38.

**Dunbar (1975).** The Annual Crops of Uganda. Second Edition. East African Literature Bureau. pp. 66.

**Dybing, C. D. and Huff, A. (1980)**. Factors affecting shedding of flowers in soybean (*Glycine max* (L.) Merrill). *Journal of Experimental Botany, 31*(3): 751-762.

**Egli D. B. (1998).** Yield components regulation by seed. In seed biology and the yield of grain crop, CAB Int., New York, 113-153.

**Egli, D. B. (2005)**. Flowering, pod set and reproductive success in soya bean. *Journal of Agronomy and crop science, 191*(4): 283-291.

**Egli, D. B. and Cornelius, P. L. (2009)**. A regional analysis of the response of soybean yield to planting date. *Agronomy Journal, 101*(2): 330-335.

**Fasoula, V. A. and Fasoula, D. A. (2002).** Principles underlying genetic improvement for high and stable crop yield potential. *Field Crops Research, 75*(2-3): 191-209.

**Fahmy, E. M., Rashed, M. A., Sharabash, M. T. M., Hammad, A. H. A. and El-Demerdash, H. M. (1997)**. Effect of gamma rays on yield and its components for some soybean cultivars, Glycine max L. *Arab Universities Journal of Agricultural Science (Egypt).*

**Food and Agriculture Organization (2014)**. Compendium for sustainable crop production intensification. Available at: www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/scpi-home/framework/en. Retrieved; 17/11/2017.

**FAO (2012)**. Food and Agriculture Organization of the United Nations. *FAOSTAT*. Available at: www.faostat.org. Retrieved: 12/03/2018.

**FAO. (2011)**. Food and Agriculture Organization of the United Nations. *FAOSTAT*. Available at: http://faostat.fao.org/default.aspx. Retrieved: 14/03/2018

**FAO (1983)**. *FAO Production Yearbook, 1982* (Vol. 26). Food and Agriculture Organization of the United Nations. FAO, Rome, Italy.

**Fehlenberg, V., Baumann, M., Gasparri, N. I., Piquer-Rodriguez, M., Gavier-Pizarro, G. and Kuemmerle, T. (2017)**. The role of soybean production as an underlying driver of deforestation in the South American Chaco. *Global environmental change*, *45*, 24-34.

**Ferguson, R. B. (2003)**. *Fertilizer recommendations for soybeans*. Cooperative Extension, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, USA.

**Fleury, D., Jefferies, S., Kuchel, H. and Langridge, P. (2010).** Genetic and genomic tools to improve drought tolerance in wheat. *Journal of experimental botany*, *61*(12), 3211-3222.

**Freiria, G. H., Lima, W. F., Leite, R. S., Mandarino, J. M. G., Silva, J. B. D. and Prete, C. E. C. (2016).** Productivity and chemical composition of food-type soybeans sown on different dates. *Acta Scientiarum Agronomy*, *38*(3): 371-377.

**Fukuda, Y. (1933).** Cytogenetical studies on the wild and cultivated Manchurian soybeans (Glycine L.). *Japanese Journal of Botany.*, *6*, 489-506.

**Ghana Statistical Service. (2014)**. *2010 population and housing census report*. Ghana Statistical Service.

**Giller, K. E., and Wilson, K. J. (2011).** *Nitrogen fixation in tropical cropping systems* (No. 631.84 G481n). Oxon, GB: CAB International, 1991.

**Glauber, J. W., and Effland, A. (2016).** *United States agricultural policy: Its evolution and impact* (Vol. 1543). Intl Food Policy Res Inst.

**Glenn, L. M. (2013).** Ethical Issues in Genetic Engineering and Transgenics. *Action bioscience*,501(c): 1-5.

**Goldsmith, P. D. (2008)**. Economics of soybean production, marketing, and utilization. In *Soybeans* (pp. 117-150). AOCS Press.

**Goldsmith, P. D., Martins, A. G. and de Moura, A. D. (2015).** The economics of post-harvest loss: a case study of the new large soybean??- maize producers in tropical Brazil. *Food Security*, *7*(4): 875–888.

**Goldsmith. (2017).** Economics of Soybean Production, Marketing, and Utilization. *Research Gate*, 150. Available at:https://doi.org/10.1016/B978-1-893997-64-6.50008-1. Retrieved: 25/02/2019.

**Gopal, J. and Iwama, K. (2007)**. In vitro screening of potato against water-stress mediated through sorbitol and polyethylene glycol. *Plant cell reports*, *26*(5): 693-700.

**Gopinath, P., and Pavadai, P. (2015).** Morphology and Yield parameters and Biochemical analysis of Soybean ( *Glycine max* ( L .) Mrr .) Using Gamma rays

, EMS and DES treatment. *International Letters of Natural Sciences*, 8(35): 50–58.

**Groot, S. P. C., Surki, A. A., De Vos, R. C. H. and Kodde, J. (2012).** Seed storage at elevated partial pressure of oxygen, a fast method for analysing seed ageing under dry conditions. *Annals of Botany*, *110*(6): 1149-1159.

**Guilherme, C., Carvalho, P. De, Alberto, C., Arias, A. and De, J. F. F. (2002)**. Adaptability and stability study of soybean lines developed for high yield in Paraná State using four methodologies. *Embrapa Soja-Artigo em periódico indexado (ALICE)*. 247–256.

**Guo, J., Wang, Y., Song, C., Zhou, J., Qiu, L., Huang, H. and Wang, Y. (2010)**. A single origin and moderate bottleneck during domestication of soybean (*Glycine max*): implications from microsatellites and nucleotide sequences. *Annals of Botany*, *106* (3): 505-514.

**Hanna, H. M. and Quick, G. R. (2007)**. Grain harvesting machinery design. *Handbook of farm, dairy and food machinery* (Kutz M, ed). William Andrew Inc, Delmar, NY. 93-111pp.

**Harper, J. L., Lovell, P. H. and Moore, K. G. (1970).** The shapes and sizes of seeds. *Annual review of ecology and systematics*, *1*(1): 327-356.

**Hartman, G. L., West, E. D. and Herman, T. K. (2011).** Crops that feed the World 2. Soybean—worldwide production, use, and constraints caused by pathogens and pests. *Food Security*, *3*(1): 5-17.

**Harvey, M. and Pilgrim, S. (2011)**. The new competition for land: Food, energy, and climate change. *Food policy*, *36*, S40-S51.

**Hassan, S. M. (2013).** Soybean, nutrition and health. *Soybean–Bio-Active Compounds. London, United Kingdom: InTech*, 453-73.

**Hayat, R., Ali, S., Amara, U., Khalid, R. and Ahmed, I. (2010).** Soil beneficial bacteria and their role in plant growth promotion: a review. *Annals of microbiology*, *60*(4), 579-598

**Helget, R. L. (2016).** Soybean Yield and Plant Response to Phosphorus Fertilization. Masters Thesis- South Dakota State University-USA.

**Heitholt, J. J., Egli, D. B., Leggett, J. E. and MacKown, C. T. (1986).** Role of Assimilate and Carbon-14 Photosynthates Partitioning in Soybean Reproductive Abortion 1. *Crop science*, *26*(5): 999-1004.

**Hill, E., Myers, C., Jones, A. and Kiely, T. (2014).** Benefits of neonicotinoid seed treatments to soybean production. *United States Environmental Protection Agency*, 1, 1-18.

**Ho, P. T. (1955).** The introduction of American food plants into China. *American Anthropologist*, *57*(2): 191-201.

**Horst, W.J. and Klotz, F. (2002)**. *Screening Soybean for Aluminum Tolerance and Adaptation to Acid Soils,* in: Genetic Aspects of Plant Mineral Nutrition, Kluwer Academic Publisher, Netherlands (1990) 335. 50. M. Ciamporová, Organ. Biol. Plant, 45- 161.

**Hymowitz, T. and Harlan, J. R. (1983).** Introduction of soybean to North America by Samuel Bowen in 1765. *Economic Botany*, *37*(4): 371-379.

**Hymowitz, T., and Shurtleff, W. R. (2005)**. Debunking Soybean Myths and Legends in the Historical and Popular Literature, *Crop science*, *45*(2): 473-476.

**Igiehon, N. O. and Babalola, O. O. (2018)**. Below-ground-above-ground plant-microbial interactions: focusing on soybean, rhizobacteria and mycorrhizal fungi. *The Open Microbiology Journal*, *12*: 261.

**Iqbal, S., Mahmood, T., Tahira, M., Ali, M., Anwar, M. and Sarwar, M. (2003).** Path coefficient analysis in different genotypes of soybean (Glycine max (L) Merril). *Pakistan Journal of Biological Science*, *6*(12): 1085-1087.

**Isoda, A., Mao, H., Li, Z. and Wang, P. (2010).** Growth of High-Yielding Soybeans and its Relation to Air Temperature in Xinjiang, China. *Plant Production Science*, *13*(2): 209–217.

**Jain, S.M., (2010)**. Mutagenesis in crop improvement under the climate change. Romania Biotech. Lett., 15: 88-106.

**Kato, Y., Togari, Y. and Ebata, M. (1955).** Studies on the Yield Analysis of Soybean:[I] Changes in Principal Chemical Constituents of the Soybean Plant in Relation to Its Growth. *Japanese Journal of Crop Science*, *24*(2): 103-107.

**Keep, N. R. (2013)**. Characterization of physiological parameters in soybean with genetic improvement in seed yield, Doctoral Thesis, Kansas State University-USA.

**Khan, M. H. and Tyagi, S. D. (2013)**. A review on induced mutagenesis in soybean. *Journal of Cereals and Oilseeds*, *4*(2): 19-25.

**Khojely, D. M., Ibrahim, S. E., Sapey, E. and Han, T. (2018)**. History, current status, and prospects of soybean production and research in sub-Saharan Africa. *The Crop Journal*, *6*(3): 1–10.

**Kombiok, J. M., Buah, S. S. J., Dzomeku, L. K. and Abdulai, H. (2012)**. Sources of pod yield losses in groundnut in the Northern Savanna zone of Ghana. *West African Journal of Applied Ecology*, *20*(2): 53-63.

**Koornneefa, M., and Zabel, P. (1990).** A new look at old linkage data of chromosome 6. *TGC Rep*, *40*, 17-19.

**Krupinsky, J. M., Bailey, K. L., McMullen, M. P., Gossen, B. D. and Turkington, T. K. (2002)**. Managing plant disease risk in diversified cropping systems. *Agronomy Journal*, *94*(2): 198-209.

**Kundi R. S., Gill M. S., Singh, T. P., Phaul, P. S. (1997)**. Radiation induced variability for quantitative traits in soybean *(Glycine max.* (L) Merrill). Crop Improv. 24(2): 23-1234.

**Lawson, I. Y. D., Issahaku, A., Acheampong, S. K., Adams, B. and Tuffour, V. (2013).** Time of planting and weed suppression abilities of some legumes intercropped with maize in the Guinea savanna zone of Ghana. *Agricultural Biology Journal of North America*, *4*, 358-363.

Lee, C., Knott, C., Ritchey, E. and Sciences, S. (2014). *AGR-129: Soybean Variety Selection*.

**Leon, J. and Becker, H. C. (1988)**. Stability analysis in plant breeding. *Plant breeding*, *101*(1): 1-23.

**Li, J., Zhao, G., Liu, Y. and Yin, A. (1998)**. Germination of embryo in soybean anther culture. *Chinese science bulletin*, *43*(23): 1991-1995.

**Liu, B., Liu, X. B., Wang, C., Li, Y. S., Jin, J., and Herbert, S. J. (2010).** Soybean yield and yield component distribution across the main axis in response to light enrichment and shading under different densities. *Plant, Soil and Environment, 56*(8): 384–392.

**Lundqvist, U., Franckowiak, J. D. and Forster, B. P. (2012)**. Mutation Categories. *Plant Mutation Breeding and Biotechnology*, *53*(9): 47–55.

**Lysenko, V. S., Valakh, M. Y., Nazarov, A. N., Rudko, G. Y., Tkachenko, A. S. and Shakhraychuk, N. I. (1989)**. Enhanced activation of implanted phosphorus in silicon under different plasma treatment. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, *44*(2): 146-148.

**Mahmood, N. and Javaid, A. R. S. H. A. D. (2010)**. Growth, nodulation and yield response of soybean to biofertilizers and organic manures. *Pakistan Journal of Botany*, *42*(2): 863-871.

**Marcelis, L. F. M. (1996)**. Sink strength as a determinant of dry matter partitioning in the whole plant. *Journal of Experimental Botany*, 1281-1291.

**Marchiori, R., Hamawaki, O. T., Jorge, G. L., Mundim, F., Nogueira, A. P. O., Hamawaki, R. L. and de Sousa, L. B. (2015)**. Adaptability and stability of transgenic soybean lines and cultivars in the Brazilian macroregion 3 assessed by using parametric and nonparametric methods. *African Journal of Biotechnology*, *14*(49): 3248-3256.

**Martin, F. W. (1988)**. Soybean; Echo Technical notes. *Echo, 17391Durrance Rd. North Ft. Meyers FL, 33917*, 1-5.

**Masuda, T. and Goldsmith, P. D. (2009).** World soybean production: area harvested, yield, and long-term projections. *International food and agribusiness management review*, *12*(1030-2016-82753), 1-20.

Mathew, F. M., Heitkamp, E. C., Lamppa, R. S., Lambrecht, P. A., Harveson, R. M. and Markell, S. G. (2014). First Report of Bacterial Pustule on Soybeans in North Dakota. *Plant health progress*, *15*(4): 155-156.

**Mbanya, W. (2011).** Assessment of the Constraints in Soybean Production : A Case of Northern region , Ghana. *Journal of Devlopment in Sustainable Agriculture*, *6*(2): 199–214.

**McBlain, B. A. and Hume, D. J. (1981).** Reproductive abortion, yield components and nitrogen content in three early soybean cultivars. *Canadian Journal of Plant Science*, *61*(3): 499-505.

**McAfee, J. (2008).** Potassium, a key nutrient for plant growth. Department of Soil and Crop Sciences: http://jimmcafee. tamu. edu/files/potassium.

**McGrath, M. A., Sherry Jr, J. F., and Heisley, D. D. (1993).** An ethnographic study of an urban periodic marketplace: Lessons from the Midville farmers' market. *Journal of Retailing*, *69*(3), 280-319

**Mensah, C., Chen, C. Y., Gu, C., Nelson, R. L. and Wang, D. (2007)**. SSR marker diversity of soybean aphid resistance sources in North America. *Genome*, *50*(12): 1104-1111.

**Mian, M. A., Missaoui, A. M., Walker, D. R., Phillips, D. V. and Boerma, H. R. (2008).** Frogeye leaf spot of soybean: A review and proposed race designations for isolates of *Cercospora sojina* Hara. *Crop Science*. 48:14-24.

**MoFA (Ministry of Food and Agriculture) (1998).** National soil fertility management action plan. Directorate of Crop Services. Accra, Ghana.

**MoFA (Ministry of Food and Agriculture) (2017)**. *Agriculture in ghana facts and figures*. Statisticsl, Research and Information Directorate of MoFA. Accra, Ghana.

**Mohammed, H. (2010)**. *Genetic Analysis of Resistance to Pod Shattering in Soybean (Glycine Max.(L) Merrill)* Doctoral Thesis - Kwame Nkrumah University of Science an Technology, Kumasi - Ghana.

**Morgan, Y. (2017)**. Evaluation of some selected mutant lines of soybeans for improved agronomic traits in the guinea savannah agro ecological zone of Ghana. First Degree Thesis, University for Development Studies, Tamale - Ghana.

**Mudibu, J., Nkongolo, K. K., Kalonji-Mbuyi, A. and Kizungu, R. V. (2012)**. Effect of gamma irradiation on morpho-agronomic characteristics of soybeans (Glycine max L.). *American Journal of Plant Sciences*, *3*(03): 331p.

**Murphy, P. A., Song, T., Buseman, G., Barua, K., Beecher, G. R., Trainer, D. and Holden, J. (1999).** Isoflavones in retail and institutional soy foods. *Journal of agricultural and food chemistry*, *47*(7), 2697-2704.

**Mutegi, J. and Zingore, S. I. (2014)**. Boosting soybean production for improved food security and incomes in Africa. *Nairobi: the International Plant Nutrition Institute (IPNI), sub-Saharan Africa program*, 1–8pp.

**Naik, G. and Gleason J. (2010)**. Improved soy-processing technology to help alleviate protein malnutrition. Cornel University, New York. *Journal of Economic study* 34:2-5

**Nico, M., Miralles, D. J. and Kantolic, A. G. (2015).** Post-flowering photoperiod and radiation interaction in soybean yield determination: Direct and indirect photoperiodic effects. *Field Crops Research*, *176*, 45-55.

**Nicolás, M. F., Hungria, M. and Arias, C. A. (2006)**. Identification of quantitative trait loci controlling nodulation and shoot mass in progenies from two Brazilian soybean cultivars. *Field Crops Research*, *95*(2-3): 355-366.

**Njeze, P. B. (1993)**. Learn How to Grow Soybean. Nairobi, Kenya. CTA Publ. 21 pp.

**Nkwiine, C. and Zake, J. Y. (1990).** Effect of Soybean-Maize Cropping Rotation On Soybean Rhizobial Population And Soybean Nodulation, Doctoral Thesis, Makerere University.Tanzania.

**Oosterhuis, D. M., Scott, H. D., Hampton, R. E. and Wullschleger, S. D. (1990).** Physiological responses of two soybean [*Glycine max* (L.) Merr] cultivars to short-term flooding. *Environmental and Experimental Botany*, *30*(1): 85-92.

**Ogunsumi, L. O., Ewuola, S. O. and Daramola, A. G. (2005),** Socio- Economic Impact Assessment of Maize Production Technology on Farmers' Welfare in South West, Nigeria. *Journal of Central Europe Agriculture*, 6 (1):15-26.

**Osman, M. (2011)**. Growth and yield response of early and medium maturity soybean (Glycine max (L) Merrill) varieties to row spacing, Doctoral Thesis- Kwame Nkrumah University of Science an Technology, Kumasi - Ghana.

**Palacios, M. F., Easter, R. A., Soltwedel, K. T., Parsons, C. M., Douglas, M. W., Hymowitz, T. and Pettigrew, J. E. (2004)**. Effect of soybean variety and processing on growth performance of young chicks and pigs. *Journal of animal science*, *82*(4): 1108-1114.

**Palmer, R. G., Zhang, L., Huang, Z. and Xu, M. (2008)**. Allelism and molecular mapping of soybean necrotic root mutants. *Genome*, *51*(4): 243-250.

**Pathan, M. S. and Sleper, D. A. (2008)**: Advances in plant breeding. *In* G. Stacey (Ed.): Genetics and genomics of soybean (pp. 113-134). Springer Science and Business Media.

**Penalba, O. C., Bettolli, M. L. and Vargas, W. M. (2007)**. The impact of climate variability on soybean yields in Argentina. Multivariate regression. *Meteorological Applications: A journal of forecasting, practical applications, training techniques and modelling*, *14*(1): 3-14.

**Pettigrew, W. T. (2008)**. Potassium influences on yield and quality production for maize, wheat, soybean and cotton. *Physiologia plantarum*, *133*(4), 670-681.

**Phua, C. K. H., Abdul Wahid, A. N. and Abdul Rahim, K. (2012)**. Development of Multifunctional Biofertilizer Formulation from Indigenous Microorganisms and Evaluation of Their N 2-Fixing Capabilities on Chinese Cabbage Using 15 N Tracer Technique. *Pertanika Journal of Tropical Agricultural Science*, *35*(3).

**Piper, C. V. and Morse, W. J. (1923).** *The soybean*. McGraw-Hill book Company, Incorporated. SoyInfoCenter, USA.

**Plahar, W. A. (2006)**. Overview of the soybean industry in Ghana. In *workshop on soybean for human nutrition and health, Accra, Ghana* (Vol. 28). September, 2006.

**Probert, R. J. (2003)**. Seed viability under ambient conditions, and the importance of drying. *Seed conservation: turning science into practice*, 337-365.

**Probst, A. H. and Judd. R. W. (1973).** Origin, U.S. history and development, and world distribution. In: B. E. Caldwell (Ed). Soybeans: Improvement, Production and Uses. American Society of Agronomy, Madison, WI. pp. 115.

**Qing-Y-Z, Zhang, F. H., Fan-Zhan B. and Huang-X. L. (1996)**. Studies on the radiation effect of $^{60}$Co gamma -rays on the soybean plant. J. Henan Agricultural Science. 6:15-17.

**Raes, K., De Smet, S. and Demeyer, D. (2004).** Effect of dietary fatty acids on incorporation of long chain polyunsaturated fatty acids and conjugated linoleic acid in lamb, beef and pork meat: a review. *Animal feed science and technology*, *113*(1-4): 199-221.

**Raina, A., Laskar, R. A., Khursheed, S., Amin, R., Tantray, Y. R., Parveen, K. and Khan, S. (2016).** Role of mutation breeding in crop improvement-past, present and future. *Asian Research Journal of Agr*onomy *2*, 1-13.

**Ramalho, M. A. P., Santos, J. B., Abreu, A. F. B. and Nunes, J. A. R. (2012)**. Aplicações da genética quantitativa no melhoramento de plantas autógamas. 1st edition. Universidade Federal de Lavras, Lavras.

**Ramesh, K., Aher, S. B., Lakaria, B. L., Kaleshananda, S., Singh, A. B., Ramana, S. and Thakur, J. K. (2015).** Effect of organic farming practices on soil and performance of soybean (Glycine max) under semi-arid tropical conditions in Central India. *Journal of Applied and Natural Science*, *7*(1): 67-71.

**Rao, A. S. and Reddy, K. S. (2010).** Nutrient management in soybean. *The soybean: botany, production and uses*, Indian Institute of Soil Science, Nabi Bagh, Bhopal, Madhya Pradesh, India. pp. 161-190.

**Rienke, N. and Joke, N. (2005)**. Cultivation of soya and other legumes. *Agrodok-series No*. 10, 1-7.

**Richardson, L. K. (2016).** Evaluation of agronomic, seed quality traits, and transcript abundance in conventional high oleic soybeans with mutant FAD2-1A and FAD2-1B genes (Masters Thesis - University of Tennessee, Knoxville - USA).

Rocha, L., Dourado, B., Augusto, L., Pascoal, F., Sakomura, N. K., Guilherme, F. and Costa, P. (2008). Soybeans (*Glycine max*) and Soybean Products in Poultry and Swine Nutrition.

**Romero, F. R., Delate, K. and Hannapel, D. J. (2005)**. (404) Effect of Seed Source, Light during Germination, and Cold-moist Stratification on Seed Germination in Three Species of Echinacea. *HortScience*, *40*(4): 1062E-1062.

Rowntree, S. C., Suhre, J. J., Weidenbenner, N. H., Wilson, E. W., Davis, V. M., Naeve, S. L. and Conley, S. P. (2013). Genetic gain x management interactions in soybean: I. Planting date. *Crop Science*, *53*(3): 1128-1138.

**Sa, T. M. and Israel, D. W. (1991)**. Energy status and functioning of phosphorus-deficient soybean nodules. *Plant Physiology*, *97*(3): 928-935.

**Sanginga, N. S. K. S., Danso, S. K. A., Zapata, F. and Bowen, G. D. (1995).** Phosphorus requirements and nitrogen accumulation by $N_2$-fixing and non-N 2-fixing leguminous trees growing in low P soils. *Biology and Fertility of soils*, *20*(3): 205-211.

**Sanginga, N., Okogun, J., Vanlauwe, B., and Dashiell, K. (2002).** The contribution of nitrogen by promiscuous soybeans to maize based cropping the moist savanna of Nigeria. *Plant and soil*, *241*(2): 223-231.

**Sanginga, N., Wasike, V. W., Lesueur, D., Wachira, F. N., Mungai, N. W., Mumera, L. M. and Vanlauwe, B. (2009)**. Genetic diversity of indigenous Bradyrhizobium nodulating promiscuous soybean [Glycine max (L) Merr.] varieties in Kenya: impact of phosphorus and lime fertilization in two contrasting sites. *Plant and soil*, *322*(1-2): 151-163.

**Sanchez, C., Henrotin, Y. E., Deberg, M. A., Piccardi, N., Guillou, G. B., Msika, P., and Reginster, J. Y. L. (2003)**. Avocado/soybean unsaponifiables increase aggrecan synthesis and reduce catabolic and proinflammatory mediator production by human osteoarthritic chondrocytes. *The Journal of rheumatology*, *30*(8): 1825-1834.

**Sarwar, M. F., Sarwar, M. H., Sarwar, M., Qadri, N. A., and Moghal, S. (2013)**. The role of oilseeds nutrition in human health: A critical review. *Journal of Cereals and oilseeds*, *4*(8): 97-100.

Seralathan, M.A., Ravindran, D.M., Thirumaran, A.S. and Sundararajan, S. (1987). Cooking qualities of soybean, TNAU Newsletter 16(9): 2.

**Shiferaw, B. (2004).** Harnessing the Potentials of BNF for Poor Farmers: Technological. *Symbiotic Nitrogen Fixation*, 1, 1-28.

**Shurtleff, W. and Aoyagi, A. (2014).** Early History of Soybeans and Soyfoods Worldwide (1024 BCE to 1899): Extensively Annotated Bibliography and Sourcebook. Soyinfo Center.

**Silva, K. B., Bruzi, A. T., Zuffo, A. M., Zambiazzi, E. V., Soares, I. O., de Rezende, P. M. and Coelho, M. D. O. (2016)**. Adaptability and phenotypic stability of soybean cultivars for grain yield and oil content. *Embrapa Soja-Artigo em periódico indexado (ALICE)*. *204*(2): 1–11.

Sinclair, T. R., Marrou, H., Soltani, A., Vadez, V. and Chandolu, K. C. (2014) Soybean production potential in Africa, Glob. Food Secur. (3): 31–40.

**Smith, K. J. and Huyser W. (1987)**. World distribution and significance of soybean. In: J. R. Wilcox (Ed). Soybeans: Improvement, Production, and Uses. Second Edition. American Society of Agronomy, Madison, WI. pp. 1-22.

**Solomon, T., Pant, L. M. and Angaw, T. (2012)**. Effects of inoculation by Bradyrhizobium japonicum strains on nodulation, nitrogen fixation, and yield of soybean (Glycine max L. Merill) varieties on nitisols of Bako, Western Ethiopia. *ISRN Agronomy*, 2012.

**Sudarić, A., Vratarić, M. and Rajcan, I. (2006)**. Evaluation of agronomic performance of domestic and exotic soybean germplasm in Croatia. *Poljoprivreda*, *12*(2): 17-22.

**Tefera, H. (2010)**. Breeding for promiscuous soybeans at IITA, soybean – molecular aspects of Breeding. Available at:http://www.intechopen.com/books/soybean-molecular-aspects-of-breeding/ breeding-for-promiscuous-soybeans-at-iita. Retrieved: 19/01/2018.

**Thoenes, P. (2006)**. Medium-term Supply and Demand Projections for the Oilseeds Complex. *FAO, Commodities and Trade Division, Rome-Italy*.

**Tóth, S., Dublecz, K., Pál, L., Wágner, L., Bartos, Á. and Bányai, A. (2006).** Differences between the faecal and ileal amino acid digestibility values of soybean meal, determined with broiler chicks at different ages. *World's Poultry Science Journal, Suppl, 62*, 289-290.

**Udimal, T. B. (2015)**. Factors influencing soybeans producers' choice of marketing channels in the Saboba district of Northern region, Ghana, Doctoral dissertation 133pp.

**USDA (United States Department of Agriculture) (2007)**. Pest information platform for extension and education, Available at http://sbrusa.net. Retrieved 12/09/2018.

**Uwaoma, I. G. (2015)**. Economics of small scale soybean processing firms in Anambra state, Nigeria,(University of Nigeria).

**Vance, C. P., Uhde-Stone, C. and Allan, D. L. (2003)**. Phosphorus acquisition and use: critical adaptations by plants for securing a nonrenewable resource. *New Phytologist* 157(3): 423-447.

**Vanlauwe, B., Bationo, A., Chianu, J., Giller, K. E., Merckx, R., Mokwunye, U. and Smaling, E. M. A. (2010).** Integrated soil fertility management: operational definition and consequences for implementation and dissemination. *Outlook on agriculture, 39*(1): 17-24.

**Vertucci, C. W. and Roos, E. E. (1990).** Theoretical basis of protocols for seed storage. *Plant Physiology, 94*(3): 1019-1023.

**Vlahović, B., Ilin, S. and Puškarić, A. (2013)**. Status and Perspectives of Soybean Production Worldwide and in the Republic of Serbia. *Economic Insights-Trends and Challenges, 65*(1).

**Wilcut, J. W., Vencill, W. K. and Monks, C. D. (1995)**. Efficacy and economy of weed management systems for sickle pod (*Senna obtusifolia*) and morning glory (*Ipomoea spp.*) control in soybean (*Glycine max*). *Weed technology*, *9*(3): 456-461.

**White, R. E., Lee, A. B., Shcherbatko, A. D., Lincoln, T. M., Schonbrunn, A. and Armstrong, D. L. (1993).** Potassium channel stimulation by natriuretic peptides through cGMP-dependent dephosphorylation. *Nature*, *361*(6409), 263-266.

**Wilson, R. F. (2008).** Soybean: market driven research needs. In *Genetics and genomics of soybean* (pp. 3-15). Springer, New York, NY.

**Yadav, B. K. and Sidhu, A. S. (2016)**. Dynamics of potassium and their bioavailability for plant nutrition. In *Potassium solubilizing microorganisms for sustainable agriculture* (pp. 187-201). Springer, New Delhi.

**Youssef, G. H., Seddik, W. M. and Osman, M. A. (2010).** Efficiency of natural minerals in presence of different nitrogen forms and potassium dissolving bacteria on peanut and sesame yields. *J Am Sci*, *6*(11), 647-660.

**Yuliasti, Y. and Sudarsono, S. (2011)**. Responses of Soybean Mutant Lines to Aluminium under In Vitro and In Vivo Condition. *Atom Indonesia*, *37*(3): 126-132.

**Zamir, D. (2001)**. Improving plant breeding with exotic genetic libraries. *Nature reviews genetics*, *2*(12): 983-985.

**Zhang, A. M., Zhao, G. Y., Gao, T. G., Wang, W., Li, J., Zhang, S. F. and Zhu, B. C. (2013).** Solubilization of insoluble potassium and phosphate by Paenibacillus kribensis CX-7: a soil microorganism with biological control potential. *African Journal of Microbiology Research*, *7*(1), 41-47.

# APPENDICES

Appendix 1: Analysis of variance for plant height 4WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 2 | 16.135 | 8.068 | 2.70 | |
| REP.*Units* stratum | | | | | |
| Fertilizer_Rate | 3 | 9.402 | 3.134 | 1.05 | 0.373 |
| Gamma_radiation | 4 | 113.870 | 28.467 | 9.53 | <.001 |
| Location | 2 | 1019.759 | 509.879 | 170.74 | <.001 |
| Fertilizer_Rate.Gamma_radiation | 12 | 19.942 | 1.662 | 0.56 | 0.873 |
| Fertilizer_Rate.Location | 6 | 11.496 | 1.916 | 0.64 | 0.697 |
| Gamma_radiation.Location | 8 | 99.197 | 12.400 | 4.15 | <.001 |
| Fertilizer_Rate.Gamma_radiation.Location | 24 | 155.804 | 6.492 | 2.17 | 0.003 |
| Residual | 118 | 352.379 | 2.986 | | |
| Total | 179 | 1797.983 | | | |

## Appendix 2: Analysis of variance for plant height 6WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 2 | 54.17 | 27.09 | 1.83 | |
| REP.*Units* stratum | | | | | |
| Fertilizer_Rate | 3 | 120.04 | 40.01 | 2.70 | 0.049 |
| Gamma_radiation | 4 | 340.33 | 85.08 | 5.73 | <.001 |
| Location | 2 | 131.76 | 65.88 | 4.44 | 0.014 |
| Fertilizer_Rate.Gamma_radiation | 12 | 74.42 | 6.20 | 0.42 | 0.954 |
| Fertilizer_Rate.Location | 6 | 54.33 | 9.06 | 0.61 | 0.722 |
| Gamma_radiation.Location | 8 | 271.80 | 33.98 | 2.29 | 0.026 |
| Fertilizer_Rate.Gamma_radiation.Location | 24 | 663.49 | 27.65 | 1.86 | 0.015 |
| Residual | 118 | 1750.90 | 14.84 | | |
| Total | 179 | 3461.26 | | | |

Appendix 3: Analysis of variance for plant height 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 2 | 2036.5 | 1018.2 | 1.25 | |
| REP.*Units* stratum | | | | | |
| Fertilizer_Rate | 3 | 2721.0 | 907.0 | 1.11 | 0.347 |
| Gamma_radiation | 4 | 9833.5 | 2458.4 | 3.01 | 0.021 |
| Location | 2 | 5719.6 | 2859.8 | 3.51 | 0.033 |
| Fertilizer_Rate.Gamma_radiation | 12 | 7261.0 | 605.1 | 0.74 | 0.708 |
| Fertilizer_Rate.Location | 6 | 6027.1 | 1004.5 | 1.23 | 0.295 |
| Gamma_radiation.Location | 8 | 7707.1 | 963.4 | 1.18 | 0.316 |
| Fertilizer_Rate.Gamma_radiation.Location | 24 | 16253.6 | 677.2 | 0.83 | 0.693 |
| Residual | 118 | 96270.4 | 815.9 | | |
| Total | 179 | 153829.7 | | | |

Appendix 4: Analysis of variance for number of leaves 4WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 2 | 24.560 | 12.280 | 2.61 | |
| REP.*Units* stratum | | | | | |
| Fertilizer_Rate | 3 | 40.308 | 13.436 | 2.85 | 0.040 |
| Gamma_radiation | 4 | 37.388 | 9.347 | 1.99 | 0.101 |
| Location | 2 | 247.214 | 123.607 | 26.26 | <.001 |
| Fertilizer_Rate.Gamma_radiation | 12 | 77.084 | 6.424 | 1.36 | 0.193 |
| Fertilizer_Rate.Location | 6 | 10.723 | 1.787 | 0.38 | 0.891 |
| Gamma_radiation.Location | 8 | 82.237 | 10.280 | 2.18 | 0.033 |
| Fertilizer_Rate.Gamma_radiation.Location | 24 | 214.077 | 8.920 | 1.90 | 0.013 |
| Residual | 118 | 555.429 | 4.707 | | |
| Total | 179 | 1289.021 | | | |

Appendix 5: Analysis of variance for number of leaves 6WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 2 | 1180.33 | 590.16 | 7.90 | |
| REP.*Units* stratum | | | | | |
| Fertilizer_Rate | 3 | 660.04 | 220.01 | 2.95 | 0.036 |
| Gamma_radiation | 4 | 144.75 | 36.19 | 0.48 | 0.747 |
| Location | 2 | 14130.35 | 7065.18 | 94.63 | <.001 |
| Fertilizer_Rate.Gamma_radiation | 12 | 928.37 | 77.36 | 1.04 | 0.421 |
| Fertilizer_Rate.Location | 6 | 229.79 | 38.30 | 0.51 | 0.798 |
| Gamma_radiation.Location | 8 | 1791.01 | 223.88 | 3.00 | 0.004 |
| Fertilizer_Rate.Gamma_radiation.Location | 24 | 4219.31 | 175.80 | 2.35 | 0.001 |
| Residual | 118 | 8810.06 | 74.66 | | |
| Total | 179 | 32094.01 | | | |

Appendix 6: Analysis of variance for number of leaves 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 2 | 1237.8 | 618.9 | 0.78 | |
| REP.*Units* stratum | | | | | |
| Fertilizer_Rate | 3 | 3755.8 | 1251.9 | 1.58 | 0.199 |
| Gamma_radiation | 4 | 7491.2 | 1872.8 | 2.36 | 0.057 |
| Location | 2 | 127014.2 | 63507.1 | 79.96 | <.001 |
| Fertilizer_Rate.Gamma_radiation | 12 | 11636.5 | 969.7 | 1.22 | 0.277 |
| Fertilizer_Rate.Location | 6 | 3813.8 | 635.6 | 0.80 | 0.572 |
| Gamma_radiation.Location | 8 | 14872.8 | 1859.1 | 2.34 | 0.023 |
| Fertilizer_Rate.Gamma_radiation.Location | 24 | 54962.2 | 2290.1 | 2.88 | <.001 |
| Residual | 118 | 93716.9 | 794.2 | | |
| Total | 179 | 318501.2 | | | |

Appendix 7: Analysis of variance for number of branches 6WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 2 | 2.292 | 1.146 | 1.02 | |
| REP.*Units* stratum | | | | | |
| Fertilizer_Rate | 3 | 5.866 | 1.955 | 1.74 | 0.163 |
| Gamma_radiation | 4 | 10.181 | 2.545 | 2.26 | 0.066 |
| Location | 2 | 158.654 | 79.327 | 70.56 | <.001 |
| Fertilizer_Rate.Gamma_radiation | 12 | 52.638 | 4.386 | 3.90 | <.001 |
| Fertilizer_Rate.Location | 6 | 2.928 | 0.488 | 0.43 | 0.855 |
| Gamma_radiation.Location | 8 | 18.823 | 2.353 | 2.09 | 0.042 |
| Fertilizer_Rate.Gamma_radiation.Location | 24 | 62.637 | 2.610 | 2.32 | 0.002 |
| Residual | 118 | 132.656 | 1.124 | | |
| Total | 179 | 446.674 | | | |

Appendix 8: Analysis of variance for number of branches 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 2 | 26.722 | 13.361 | 4.79 | |
| REP.*Units* stratum | | | | | |
| Fertilizer_Rate | 3 | 2.077 | 0.692 | 0.25 | 0.862 |
| Gamma_radiation | 4 | 64.805 | 16.201 | 5.81 | <.001 |
| Location | 2 | 755.243 | 377.621 | 135.42 | <.001 |
| Fertilizer_Rate.Gamma_radiation | 12 | 57.882 | 4.823 | 1.73 | 0.069 |
| Fertilizer_Rate.Location | 6 | 15.782 | 2.630 | 0.94 | 0.467 |
| Gamma_radiation.Location | 8 | 44.606 | 5.576 | 2.00 | 0.052 |
| Fertilizer_Rate.Gamma_radiation.Location | 24 | 140.296 | 5.846 | 2.10 | 0.005 |
| Residual | 118 | 329.034 | 2.788 | | |
| Total | 179 | 1436.447 | | | |

Appendix 9: Analysis of variance for days to 50% flowering

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 2 | 83.011 | 41.506 | 8.73 | |
| REP.*Units* stratum | | | | | |
| Fertilizer_Rate | 3 | 17.172 | 5.724 | 1.20 | 0.311 |
| Gamma_radiation | 4 | 485.811 | 121.453 | 25.55 | <.001 |
| Location | 2 | 2.311 | 1.156 | 0.24 | 0.785 |
| Fertilizer_Rate.Gamma_radiation | 12 | 230.189 | 19.182 | 4.03 | <.001 |
| Fertilizer_Rate.Location | 6 | 4.178 | 0.696 | 0.15 | 0.989 |
| Gamma_radiation.Location | 8 | 4.022 | 0.503 | 0.11 | 0.999 |
| Fertilizer_Rate.Gamma_radiation.Location | 24 | 17.711 | 0.738 | 0.16 | 1.000 |
| Residual | 118 | 560.989 | 4.754 | | |
| Total | 179 | 1405.394 | | | |

Appendix 10: Analysis of variance for number of pods per plant

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 2 | 505.3 | 252.7 | 0.33 | |
| REP.*Units* stratum | | | | | |
| Fertilizer_Rate | 3 | 1678.3 | 559.4 | 0.73 | 0.536 |
| Gamma_radiation | 4 | 5575.5 | 1393.9 | 1.82 | 0.130 |
| Location | 2 | 165816.1 | 82908.1 | 108.08 | <.001 |
| Fertilizer_Rate.Gamma_radiation | 12 | 14722.0 | 1226.8 | 1.60 | 0.101 |
| Fertilizer_Rate.Location | 6 | 5229.9 | 871.7 | 1.14 | 0.346 |
| Gamma_radiation.Location | 8 | 6080.8 | 760.1 | 0.99 | 0.447 |
| Fertilizer_Rate.Gamma_radiation.Location | 24 | 28461.8 | 1185.9 | 1.55 | 0.066 |
| Residual | 118 | 90518.1 | 767.1 | | |
| Total | 179 | 318587.9 | | | |

Appendix 11: Analysis of variance for yield in kg/ha

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 2 | 1842386. | 921193. | 2.39 | |
| REP.*Units* stratum | | | | | |
| Fertilizer_Rate | 3 | 1935855. | 645285. | 1.68 | 0.176 |
| Gamma_radiation | 4 | 7347326. | 1836832. | 4.77 | 0.001 |
| Location | 2 | 194947202. | 97473601. | 253.23 | <.001 |
| Fertilizer_Rate.Gamma_radiation | 12 | 10810140. | 900845. | 2.34 | 0.010 |
| Fertilizer_Rate.Location | 6 | 1396204. | 232701. | 0.60 | 0.726 |
| Gamma_radiation.Location | 8 | 17486154. | 2185769. | 5.68 | <.001 |
| Fertilizer_Rate.Gamma_radiation.Location | 24 | 27332643. | 1138860. | 2.96 | <.001 |
| Residual | 118 | 45420333. | 384918. | | |
| Total | 179 | 308518244. | | | |

Appendix 12: Analysis of variance for 100-seed weight (g)

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 2 | 0.000778 | 0.000389 | 0.13 | |
| REP.*Units* stratum | | | | | |
| Fertilizer_Rate | 3 | 0.022667 | 0.007556 | 2.53 | 0.061 |
| Gamma_radiation | 4 | 0.051111 | 0.012778 | 4.28 | 0.003 |
| Location | 2 | 0.138778 | 0.069389 | 23.22 | <.001 |
| Fertilizer_Rate.Gamma_radiation | 12 | 0.032889 | 0.002741 | 0.92 | 0.532 |
| Fertilizer_Rate.Location | 6 | 0.013667 | 0.002278 | 0.76 | 0.601 |
| Gamma_radiation.Location | 8 | 0.027889 | 0.003486 | 1.17 | 0.325 |
| Fertilizer_Rate.Gamma_radiation.Location | 24 | 0.077444 | 0.003227 | 1.08 | 0.377 |
| Residual | 118 | 0.352556 | 0.002988 | | |
| Total | 179 | 0.717778 | | | |