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FACULTY OF AGRICULTURE AND ENVIRONMENTAL
SCIENCES

DEPARTMENT OF CROP SCIENCE

THE EFFECTS OF VARYING GIBBERELIC ACID (GA₃) LEVELS ON GERMINATION
AND SEEDLING GROWTH IN DIFFERENT WHEAT (*Triticum aestivum* L) VARIETIES.



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ABSTRACT

Wheat (*Triticum aestivum* .L) is one of the most important crop in the world. Despite global advancement in farming technology, Zimbabwean farmers are still lagging in adopting new systems and the use of new products in wheat production. Gibberellic acid (GA₃), an eco- friendly bio regulator that is widely used to enhance the productivity and phenotypic characteristics of multiple crops. A 4x4 factorial RCBD study was conducted at DR&SS to showcase the benefits of using Gibberellic Acid on germination and seedling growth of wheat. The study involved 4 different wheat varieties which were Dande, Runde, Save and Ncema and 4 different GA₃ levels which were no GA₃, 1ml, 2mls and 4mls, diluted with 2litres of water respectively. The parameters assessed were germination percentage, seedling vigour index, stem height, tiller number and leaf area index. Data collected during the experiment was subjected to statistical analysis of variance using GenStat package 18th Edition version and LSD at 5% level. The results indicated that varied levels of Gibberellic Acid affects different wheat varieties differently. The effective use of GA₃ at 4mls is effective to the Save, Dande and Ncema varieties only the Runde variety proved to do well when 2mls of GA₃ was applied. The application of Gibberellic Acid can, therefore, be used to enhance germination and seedling growth of wheat and hence combat food insecurity amongst communities of Zimbabwe.

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DEDICATION

I dedicate this work to my lovely family, especially my mom and my uncle, for making sacrifices during the period of my studies. Would also want to dedicate this work to my friends for the moral support they gave me during the research period.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
DR&SS	Department of Research and Specialists Services
FAO	Food and Agriculture Organization
GA ₃	Gibberellic Acid
/ha	per hectare
ml	Millilitres
cm	Centimetres
g	Grams
%	Percent
CRD	Completely Randomized Design
GP	Germination percentage
LAI	Leaf Area Index
SVI	Seedling Vigor Index
CBI	Crop Breeding Institute

CHAPTER 1: INTRODUCTION

1.1 Background

Wheat (*Triticum aestivum* L.) is a winter annual grain grass, classified in the Poaceae family, (Kumar, 2017). Wheat is an essential crop in the world and about 35% of the world's population survive on it (Grote *et al.*, 2021). It is considered an essential source of carbohydrates and numerous essential nutrition. Wheat is cultivated as a cash crop, as it produces a good yield per unit area. It is the second most produced cereal grain behind maize (*Zea mays* L.) and the global trade is greater than all other crops combined (Food and Agriculture, 2020). In 2020 the total global wheat production was around 760 million tonnes (World population review, 2020). China, India and Russia are the three largest wheat producers in the world (World population review, 2020). In 2020 Zimbabwe managed to produce 180 000 tonnes of wheat (Knoema, 2020). In order to meet flour demands per year Zimbabwe needs 400 000 tonnes of wheat so is the need import more than 220 000 tonnes of wheat because wheat production in Zimbabwe is decreasing yearly (Knoema, 2020).

Wheat farmers and breeders are facing compromised yields in wheat production, its production is constantly threatened by various abiotic and biotic stresses. This stresses results in poor germination, and poor seedling growth which will eventually lead to compromised yields thus a decrease in production (Bleach, 2019). In order to curb this problem Zimbabwean farmers and breeders need to adopt new systems and use of new products in wheat production. Gibberellic acid (GA₃), an eco-friendly bio regulator is widely used to enhance the productivity and phenotypic characteristics of a number of crops.

Gibberellic acid is a hormone found in plants and fungi. The plant hormone Gibberellic acid has been used to improve seed germination and seedling growth of different crop species, such as rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.), (Chunthaburee *et al.*, 2014). Gibberellic acid plays a very important role in several plant growth and development processes, including seed germination, stem elongation, and leaf expansion (Khan and Chaudhry, 2006). The use of the plant

growth regulator Gibberellic acid (GA₃) in cereal production is now becoming common as it ensures efficient production. It is being used to manipulate growth thus resulting in an increased crop yield, (Sarkar *et al*, 2009).

GA₃ has been reported to increase germination percentage and seedling growth and overcome the preventive effects of the salt stress on germination (Nasril, 2012). Iftikhar, (2019) after doing a research on the effects of GA₃ noticed that Gibberellic Acid has an effect on wheat as it increases in plant height, increases yield, increases chlorophyll contents and it also increases antioxidant enzymes. Pavlista, (2014) also suggested that Gibberellic Acid stimulates the growth of stems in wheat production.

The study on varying levels of Gibberellic Acid on different wheat varieties aims to evaluate the effect of different doses of GA₃ on different wheat varieties. The study scrutinize various wheat varieties with different genetic makeups and growth habits. The study's overall goal is to determine whether the application of GA₃ can be used to optimize the growth and yield of wheat varieties. It involved the use of different levels of GA₃ to observe the physiological and biochemical changes in the different wheat varieties.

1.2 PROBLEM STATEMENT

Germination of seeds is one of the most important phase in the growth cycle of wheat plant, as it determines plant establishment and final yield .Due too poor germination and seedling growth challenges, they has been a global advancement to use gibberellic acid to enhance germination and phenotypic characteristics on wheat. For Gibberellic acid to be more effective it has to be applied at a certain dosage as different wheat cultivars react different to different dosages .If too much of it is applied it sometimes kill the seeds and if too little is applied it might fail to work as required of.

1.3 JUSTIFICATION OF THE STUDY

The use of Gibberellic Acid in wheat production will improve the germination rate and seedling growth in different wheat cultivars so as to recommend wheat farmers and minimise costs on seed expenses. Different wheat cultivars respond differently to varying GA₃ levels (Pavlista *et al.*, 2013). The differential response of wheat varieties to GA₃ holds promise for the identification and release of superior cultivars. . The findings from this study will be useful for wheat farmers and researchers, as they will provide insights into how to improve wheat yields and optimize the application of GA₃ by selecting the most appropriate varieties and GA₃ dosages.

1.4 MAIN OBJECTIVE

To determine the effects of varying Gibberellic Acid (GA₃) levels on germination and seedling growth in different wheat (*Triticum aestivum* L) varieties.

1.4.1 SPECIFIC OBJECTIVES

To assess the effects of GA₃ on germination percentage of wheat (*Triticum aestivum* L).

To assess the effects of GA₃ on the growth (seedling vigour index, leaf area index, stem height and tiller number.) of wheat (*Triticum aestivum* L).

1.5 HYPOTHESIS

H1= Varied varieties of wheat shows changes in germination when different quantities of GA₃ are administered.

H0= Varied varieties of wheat does not show changes in germination when different quantities of GA₃ are administered.

H1= There is a difference in seedling growth between various wheat varieties when varying quantities of GA₃ are administered.

H0= There is no difference in seedling growth between various wheat varieties when varying quantities of GA₃ are administered.

CHAPTER 2: LITERATURE REVIEW

2.1 ORIGINS AND TAXONOMY

Around 10,000 years ago, in the southeast of Turkey, wheat first appeared. National Wheat Growers Association, 2021. According to Damania (2013), wheat (*Triticum durum* Desf.) was one of the earliest plants to be domesticated and arrived to us from the Ethiopian Highlands and the Levant Region of the Near East about 10,000 years ago. There are various varieties of wheat that have $2n = 14, 28, \text{ or } 42$ and are diploid, tetraploid, or hexaploid, respectively. *T. aestivum* ($2n = 42$), popularly known as bread wheat, *T. durum* ($2n = 28$), also known as durum wheat, *T. dicoccum*, and *T. sphaerococcum* are the four species of common wheat. *T. aestivum* and *T. durum*, which are commonly referred to as spring wheat, may grow in temperate and subtropical climates, respectively. According to Boloch et al, (2022).

2.2 IMPORTANCE OF THE CROP

The majority of the calories, proteins, and micronutrients consumed worldwide that support growth and development come from foods made from wheat. According to Strugnell (2018), both whole and refined grain wheat products promote healthy nutrition on a worldwide scale. The majority of the world's temperate and subtropical regions rely on wheat as their main crop. The flour needed to make bread, biscuits, cookies, chapatti, etc. is made from wheat. In the production of starch, gluten, malt, and distilled spirits, it is employed. Wheat bran is a good cattle feed because it is high in protein. Corrugated board is made from straw (Singh, 2022).

2.3 NUTRITIONAL VALUE OF THE CROP

The nutritional value of wheat is grouped into two components which are major nutrient and minor nutrient components. These components have carbohydrates, proteins and lipids, for major nutrients, and vitamins, minerals and phytochemicals for minor nutrients. Macronutrients, grains consist of approximately 75% carbohydrate have been proven that they are of importance of

carbohydrate and fiber within wheat takes precedence over their concentrations of vitamins, minerals, and phytochemicals , (Brennan,2021) .

2.4 PRODUCTION TREND IN THE WORLD

According to Cossani and Reynolds (2012), wheat has been a staple food for major civilizations in Europe, North Africa, and West Asia for the past 8000 years. It is cultivated in approximately 220 million hectares of land, which accounts for 30% of the world's total cereal production area. Egypt being the largest wheat producer in Africa, produces approximately 9 million tons per annum, followed by Algeria with 4 million tons per annum, which is nearly half of Egypt's production (Tadesse et al., 2019). Sub-Saharan African countries import approximately 17 billion tons of wheat annually.

Erenstein et al. (2022) estimated that in 2018, 730 million metric tons of wheat were harvested from an estimated 217 million hectares of cultivation worldwide. The total global wheat production volume for the marketing year 2020/2023 was around 781 million metric tons. This represents an increase compared to the previous marketing year of 2021-2022, which had 779.33 million metric tons. This indicates a rising trend in wheat output internationally as the harvest continues to increase (Shahbandedh, 2023).

2.5 PRODUCTION TREND IN AFRICA

According to the Department of Agriculture, Land Reform and Rural Development (DALRRD, 2015) and the Food and Agriculture Organization (FAO, 2020), wheat is the second most significant grain grown in Southern Africa. However, there has been a decline in national wheat production in South Africa, with a decrease of approximately 740,000 tons between 2002 and 2012 (Dube et al., 2019). This decline in production has led to a deficit of about 1 million tonnes per year, which needs to be filled through imports. Over the past two decades, the wheat acreage in South Africa has decreased by around 500,000 hectares, totaling approximately a million hectares overall.

Wheat has been a staple food for major civilizations in Europe, North Africa, and West Asia for the past 8000 years, cultivated on approximately 220 million hectares of land, representing 30% of the world's total cereal production area (Cossani and Reynolds, 2012). In Africa, Egypt is the largest wheat producer, with an annual production of around 9 million tons, followed by Algeria with 4 million tons, which is almost half of Egypt's wheat production (Tadesse et al., 2019). Sub-Saharan African countries import approximately 17 billion tons of wheat annually.

2.6 WHEAT PRODUCTION IN ZIMBABWE

Wheat production in Zimbabwe started as early as 1925. It is one of the few crops that can be grown in winter. Wheat has become an important crop in Zimbabwe as urbanization, the general standard of living and family incomes increase. Many farmers have developed irrigation infrastructure and wheat provides a means of maximizing returns from their investments.

Initially, wheat production was very low, in 1956, it was about 12 000 tonnes. By 1960, it dropped to 500 tonnes. In 1966, the government in response to the threat of sanctions after the Unilateral Declaration of Independence, initiated a farm Irrigation Fund to help farmers enter into irrigated wheat production. This paid off with output rising from 25 000 tonnes in 1968 to 85 000 tonnes by 1972, (DR&SS, 2015).

After independence, wheat production reached a record low of 99 000 tonnes in 1984. This was due to serious droughts in the preceding summers of 1982/83 and 1983/84 which reduced wheat hectares. The government responded by setting up a National Irrigation Fund to stimulate election of national water reservoirs as security against drought and to motivate farmers to enter irrigated wheat production. By 1986, production had reached 225 000 tonnes. Wheat farmers were also paid incentive producer prices. This led to more farmers entering into wheat production and also increasing the area under the crop. The production of wheat has increased by the years this has been a success due the introduction of improved varieties.

2.7 GIBBERELLIC ACID (GA)

Gibberellic acid is a hormone present in plants and fungi that plays a crucial role in stimulating their growth and development. It has various effects, including promoting seed germination,

triggering transitions from meristem to shoot growth, influencing leaf stages from juvenile to adult, facilitating the transition from vegetative to flowering stage, and influencing sex expression and grain development. Chemically, it is a tetracyclic diterpenoid compound with a chemical formula of $C_{19}H_{22}O_6$ and a molar mass of 346.37 g/mol. When purified, it appears as a white to pale-yellow solid. While plants naturally produce significant amounts of GA3, it is also possible to produce this hormone industrially using microorganisms.

According to Garden Fundamentals (2023), gibberellic acid can be used to accelerate seed germination. However, excessive use of the hormone can lead to seed exposure and potential seed death. In some cases, seedlings may grow too quickly and become weak and elongated, while in others, no noticeable differences may be observed (Iftikhar et al., 2019). Research by Pavlista (2014) suggests that gibberellic acid stimulates stem growth in wheat production. It has also been observed by Smith (2001) that gibberellic acid persists in the soil for only about six weeks.

2.8 VARIETIES

Runde is a cultivar known for its short stature and erect flag leaf. It has large red seeds with medium anthocyanin coloration on the flag leaf auricle. This early maturing cultivar is tolerant to rust and has an average yield. Its unique feature is its high tolerance to rusts, thanks to the presence of resistance genes such as 'Lr34, Sr2, and Lr68'. This resistance reduces the need for fungicide sprays, resulting in cost savings for farmers. Runde also has a high potential for flour extraction, good dough mixing characteristics, and a high flour protein content. It is well-adapted to various wheat-growing regions in Zimbabwe (DR&SS, 2015).

Ncema, on the other hand, is a white-seeded variety with moderate anthocyanin coloration on the flag leaf auricle. It is a semi-dwarf cultivar with a semi-erect growth habit and a floppy flag leaf. Ncema has a medium maturity period of 121 days, similar to Kana, Smart, and Sky varieties. It has high yields, particularly 9.2 tons per hectare in highveld areas, 5.5 tons per hectare in middleveld areas, and 5.2 tons per hectare in lowveld areas. It exhibits moderate resistance to rusts and powdery mildew. This cultivar is recommended for wheat production in all growing areas,

especially under irrigation in high and middlelevel regions. It possesses good milling and baking qualities (DR&SS, 2015).

Dande is characterized by its white oval-shaped grains and an erect growth habit with medium height. It has a semi-compact tillering capacity and is a high-yielding and medium-maturing cultivar. Dande also possesses good milling and baking qualities. It shows moderate resistance to rusts and powdery mildew biotypes. This cultivar is recommended for cultivation in all irrigated winter wheat-growing regions, particularly in high and mid-level areas (DR&SS, 2015).

2.9 PLANT POPULATIONS

The plant population density of wheat is influenced by the number of seeds sown and the success of seed establishment. Interestingly, there seems to be a decrease in the proportion of seeds that emerge as the number of seeds sown per square meter increases, although the reasons behind this phenomenon are not yet clear. It is crucial to provide sufficient fertilizer nitrogen (N) for poorly established crops. In fact, the use of fertilizer N may help compensate for poor establishment by promoting tillering and increasing the survival of tillers. It is notable that very few plants die after winter, and the structure of the crop is significantly influenced by the number of surviving plants per square meter (Agriculture and Horticulture Development Board, 2023).

2.10 PLANT MORPHOLOGY

Wheat plants have a length of 3 to 10 mm, with straight and cylindrical stems (Cossani and Reynolds, 2012). They consist of both root and shoot systems, characterized by long and slender leaves and hollow stems in most varieties (Setter and Carlton, 2000). The wheat grain is composed of a germ, embryo, and endosperm, with a typical size of 3 to 10 mm in length and 3 to 5 mm in diameter (Kumar et al., 2017).

The germination process in wheat occurs after a brief period of dormancy in the seeds (Kumar et al., 2017). Wheat seeds are known for having low dormancy levels that are easily broken down. The duration of dormancy can vary from 3 to 7 months after the seed coat is removed, depending on the cultivar (Dane, 2020).

The initiation of germination happens when the seed absorbs moisture. It requires a relative humidity of approximately 97.7% and a moisture content of 35 to 45% of its dry weight (Jagdish, 2020).

2.11 CHALLENGES IN WHEAT PRODUCTION

In 2019, wheat production experienced a significant decline to 1.5 million tons due to severe drought events, resulting in a nearly 50% loss in production. The Western Cape Province in South Africa contributed 650,000 tons of wheat in 2020, accounting for 42.3% of the total crop, compared to the previous season's 47.7% (SAGL, 2020). The Free State province, with a wheat production of 326,000 tons, experienced a year-on-year decline of 15% but still maintained the second-highest provincial production figure (SAGL, 2020). According to the South African Grain Information Service (SAGL, 2020), the irrigation areas of the Northern Cape, which is the third-largest wheat-producing region, experienced a decrease of 11% in production compared to the 2018/2019 season. In Limpopo, the wheat residue produced decreased by 6% (SAGL, 2020). Similarly, the North West region experienced a 7% decrease in production (SAGL, 2020). On the other hand, the July 2020 harvest showed a production upturn due to favourable weather conditions and an above-average planted area, according to the Food and Agriculture Organization (FAO, 2020). Overall, the 2020 wheat cereal output was forecasted to be 18.6 million tons, which is nearly 30% higher than the five-year average and the second-largest output on record (FAO, 2020).

2.12 PLANT HORMONES ON SEED GERMINATION

Plant hormones are a class of natural or synthetic substances that regulate plant development. They act as chemical messengers, controlling various cellular activities and facilitating communication between different parts of the plant. These hormones play a crucial role in plant growth, reproduction, and survival mechanisms, as well as in seed germination and resistance against biotic and abiotic stress. Phytohormones such as cytokinins, abscisic acid, and gibberellins are particularly important in modulating physiological and molecular responses, thereby ensuring the plant's survival and promoting growth and yield under different environmental conditions (Sajjad

et al., 2017; Vob et al., 2014; Verhage et al., 2010; De Vleeschauwer et al., 2013; Kazan, 2015; Colebrook et al., 2014; Xu et al., 2016; Bücken-Neto et al., 2017; Fahad et al., 2015).

2.13 FERTILIZER REQUIREMENTS

2.13.1 Nitrogen in wheat production

According to Schlatter et al. (2020), it is important to ensure an adequate supply of nitrogen (N) throughout the different stages of wheat plant development. Splitting N applications is recommended as it improves N use efficiency, reduces investment risk, and protects the environment. To maximize production efficiency, growers should apply top dress N early, before the joining phase. The timing, placement, and nitrogen source should be adjusted based on factors such as climatic conditions, soil type, and tillage system. Additionally, Wang (2020) suggested that even if the N supply is low, plant growth can be restored by administering gibberellic acid.

2.13.2 Phosphorus in wheat production

According to Schlatter et al. (2020), sufficient phosphorus (P) fertility in crops has several benefits, including increased tillering and grain head numbers, reduced winter-killing, improved water-use efficiency, accelerated maturity, and lower grain moisture at harvest. Winter wheat, for instance, requires approximately 0.6 to 0.7 pounds of phosphorus pentoxide (P_2O_5) per bushel of grain. To effectively address low to medium soil phosphorus levels, banded or starter applications are commonly recommended as they promote faster plant establishment and help mitigate the negative effects of soil acidity. Broadcast applications of phosphorus should be incorporated to enhance positional availability. Additionally, adequate phosphorus levels contribute to improved nitrogen (N) recovery and utilization efficiency, which is crucial in today's agricultural context. In a related study by Wang (2020), it was suggested that GA3 (gibberellic acid) plays a role in regulating phosphate uptake. When plants experience phosphorus deficiency, GA3 assists in the accumulation of DELLAs (a class of growth-regulating proteins) in the roots. This DELLA-mediated signaling pathway contributes to anthocyanin accumulation, a process that influences plant pigmentation and other physiological responses

2.13.3 Potassium in wheat production

According to Schlatter et al. (2020), potassium (K) in wheat production is linked to improved moisture and nitrogen (N) use efficiency, as well as reduced disease incidence and lodging. The recommended amount of K is approximately equal to that of N. Unlike phosphorus (P), the placement of K is not as crucial since it is more mobile in soils. In high-rainfall areas with deep sandy soils, split applications of K should be made to enhance its utilization efficiency.

Furthermore, Wang (2020) suggests that low potassium levels, when gibberellic acid is applied, promote the accumulation of DELLA protein in the roots and the expression of high affinity potassium transporter.

2.14 SOIL AND CLIMATIC REQUIREMENTS

Wheat is a widely cultivated crop that can grow successfully in various types of soil and large land areas. When gibberellic acid is applied, it remains in the soil for about 6 weeks. The crop requires an average annual rainfall of 254 mm during the growing stage, but it can adapt to different climates. Wheat thrives in cool regions with temperatures ranging from 10 to 24 °C and prefers deep, fertile, well-drained soil with a pH level between 5.5 and 7.5. According to Moshe (1989), gibberellic acid is most effective at temperatures above 7 °C. Wheat is a vital staple cereal crop that provides a significant source of energy for approximately 4 billion people worldwide

CHAPTER3: MATERIALS AND METHODS

3.1 DESCRIPTION OF THE STUDY SITE

The pot experiment was carried out at the Department of Research and Specialist Services at the Crop Breeding Institute, corner Fifth Street Extension Street and Downe Avenue opposite the Harare Golf club. The station is in natural region IIa and receives about 800mm of rain per annum, Harare. The Global Positioning System coordinates of the site are: Latitude 17°48' 31.9"S and Longitude 31°3'8.42"E.

3.2 EXPERIMENTAL DESIGN

The experiment was laid out as a 4*4 factorial experiment in a randomized complete block design (RCBD) with 3 replicates. Factor 1 was 4 wheat (genotypes (Save, Dande, Runde and Ncema. Factor 2 was the different GA₃ levels. No GA₃ which was the control was level 1, (1ml / 1litre) which was less than standard was level 2, (2ml/ litre) the standard was level 3 and more than standard (4ml/litre), was level 4.

3.3 EXPERIMENTAL PROCEDURE

The experiment was conducted over a period of seventy days. The wheat seeds were obtained from the Crop Breeding Institute (CBI), clay loamy soil was filled in forty-eight plastic pots. Solutions of 2 litres water (G1), 2litres of water and 1ml of GA₃ (G2), 2 litres water and 2ml of GA₃ (G3), 2 litres water and 4ml of GA₃ (G4) was prepared. Ten seeds per variety were soaked in the 4 different solutions in 16 different plastic containers for 3 days. Compound D fertilizer was applied in pots at the rate of 5grams per pot. Ten soaked seeds were planted per pot. The pots were watered until the plants germinated. Five days after emergence seedlings were thinned to four seedling per pot. The germinating weeds were uprooted so that they did not compete with the wheat plants for water and nutrients .Ammonium nitrate fertilizer was applied 3 weeks after germination. All basic agronomic practices were done until the plants reached the tillering stage.

3.4 DATA COLLECTION

Data was collected in segments firstly germination characters then seedling characters. All 48 pots were used to collect data.

3.4.1 Germination percentage

Germination records were expressed as a percentage. Germination percentage (GP) was calculated by counting the number of emerged seeds 5 days after planting and then dividing the number by the number of seeds planted. The formula used to attain germination percentage was $GP = \frac{N^i}{N} * 100$

3.4.2 Seedling vigour index

The seedling vigour index objective was achieved by thinning the wheat seedlings. Thinning was done because the germinated seeds varied within the pot, so in order to reduce bias within the results a uniform number of seedlings in the pot had to be worked with. The seedlings in the pots were thinned to 4 seedlings per pot. From the thinned seedlings shoot length and root length was measure using a sting and a ruler it was then multiplied by the germination percentage. The formula used was:

Seedling vigour index (SVI),

$$SVI = \text{shoot length} + \text{root length} \times GP\%$$

3.4.3 Leaf Area index

The leaf area index objective was achieved by measuring the leaf length and width and to get the area it was multiplied together, to then get then leaf area index the leaf area was divided by the ground area. The formula used was $LAI = \text{leaf area} / \text{ground area}$

3.4.4 Stem height

The stem height was measured 7 days after emergence, 14 days after emergence and 21 days after emergence. The stem height was measured from the root crown to the apex of the last leaf using a string and a ruler. All the four seedlings per pot were measured and the average of the four was recorded.

3.4.5 Tiller number

To get the tiller number, the number of tillers were also counted from each pot. Tillers were counted from the four plants in the pots and averaged then they were averaged to get the average tiller number per pot and then recorded.

3.5 DATA ANALYSIS

Analysis of variance (ANOVA) was used for data analysis using GenStat version 18 and Least Square Difference (LSD) was used to separate the means at 0.05 level of significance where there was significant difference.

CHAPTER 4: RESULTS

4.1 Effects of GA₃ levels on germination percentage of wheat varieties

There was a significant difference on the germination percentage (GP) on wheat varieties $p < 0.001$. Dande had the highest germination percentage at G4 (90%), followed by Ncema (83.3%), Save had (70%), and Runde had the lowest germination percentage of 36, 7%. The error bars indicated that Save at G1 and Runde at G1 had a significant difference. Dande G1 and Runde G1 had a significant difference. Dande G1 and Ncema G1 also showed a significant difference. Looking at G2, Save and Dande showed a significant difference, also Dande and Runde showed a significant difference. At G3 Dande and Runde and Runde and Ncema showed a significant difference.

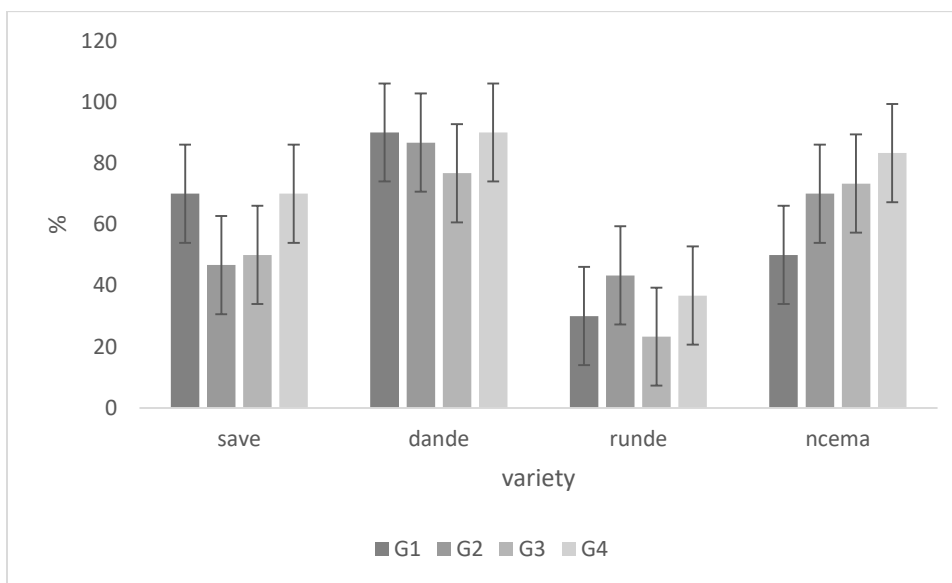


Figure 4.1: Effects of GA levels on germination percentage on wheat varieties

4.2 Effects of GA₃ levels on seedling vigour index on wheat varieties.

The seedling vigour index amongst the wheat varieties showed a significant difference at $p < 0.001$. The Runde variety showed the least seedling vigour index and the Dande variety showed the least difference within the 4 different levels of GA₃. The error bars at G1 showed that Dande and Runde had a significant difference. Dande at G2 and Runde at G2 also had a significant difference. Save at G3 level and Dande at G3 showed a slight significant difference and Dande and Runde also

showed a significant difference. At G4 Save and Runde, Dande and Runde and Runde and Ncema showed a significant difference.

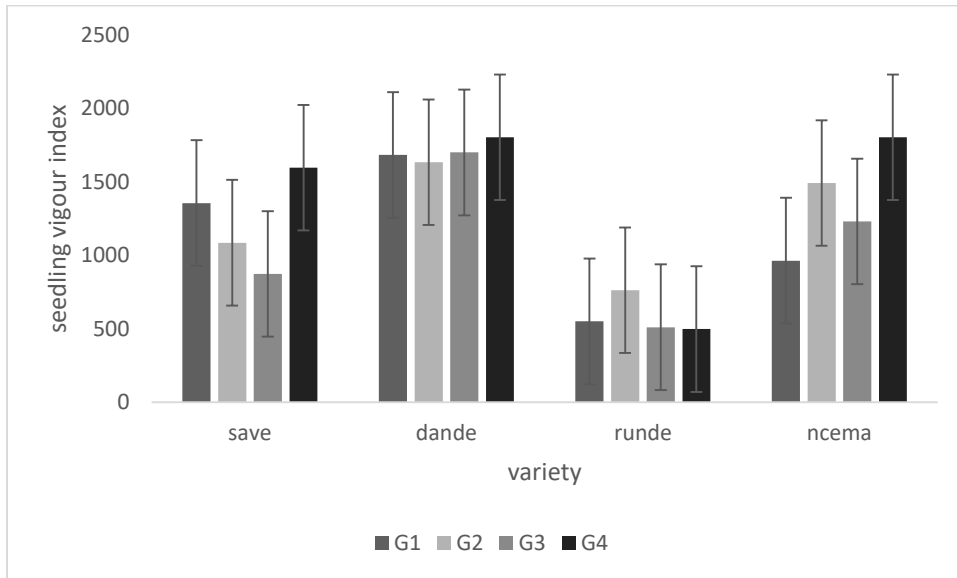


Figure4.2 Effects of GA₃ levels on seedling vigour index on wheat varieties

4.3 Effects of GA₃ levels on leaf area index on wheat varieties

The leaf area index did not have a significant difference at P value = 0.301. Only the Dande variety in GA₃ showed to have the highest leaf area index. Dande at G3 had the highest leaf area index.

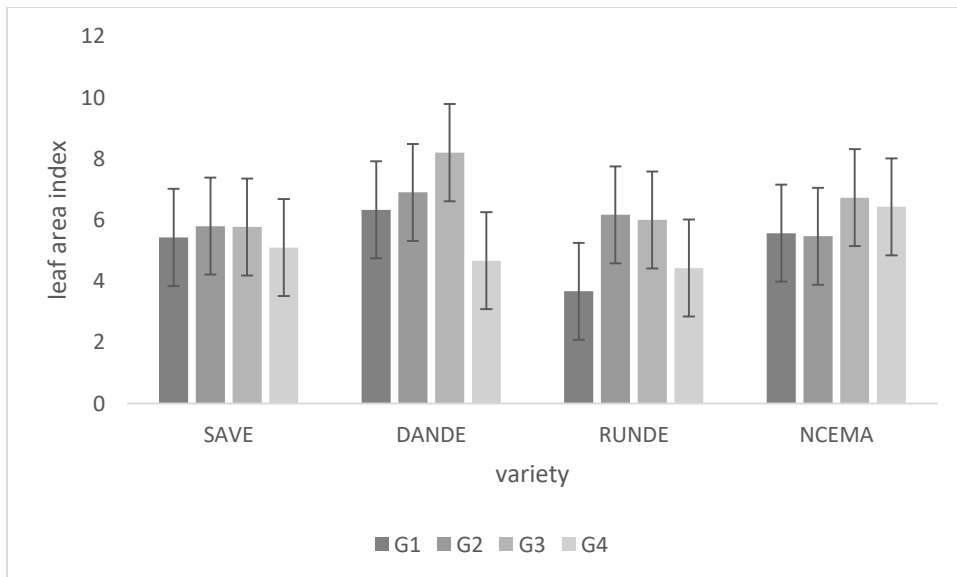


Figure4. 3 Effects of GA₃ levels on leaf area index on wheat varieties.

4.4 Effects of GA₃ levels the stem height on wheat varieties at 7days after emergence.

The stem height of wheat measured seven days after emergency had a significant difference, $p=0.029$. The Save variety at level 4 had the highest stem height of 4.6cm compared to the Dande variety that had 4.32cm. Runde in level 4 of GA₃ had the least stem height of 1.67cm. Error bars at G4 Save and Runde had a significant difference. Dande and Runde had a significant difference. Runde and Ncema had a significant difference.

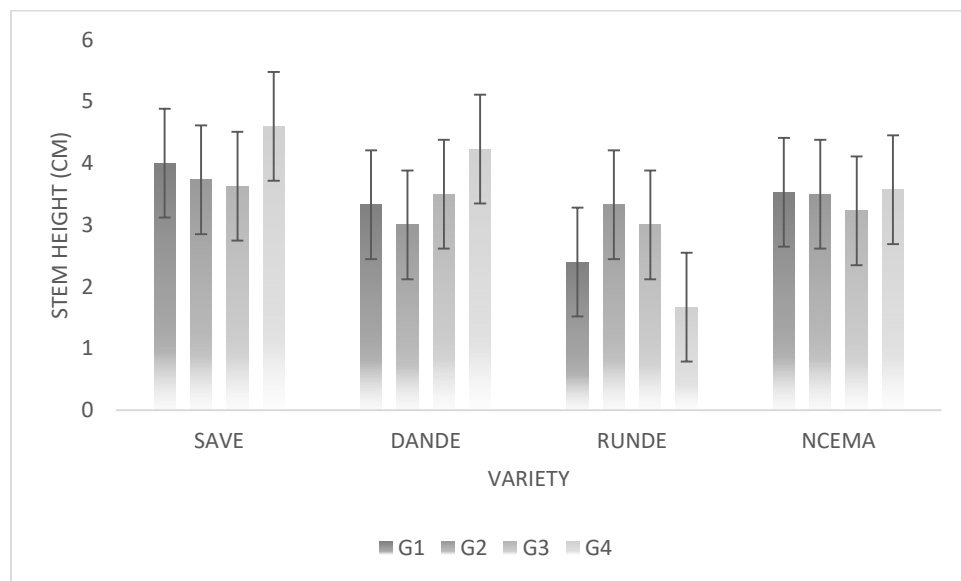


Figure 4.4 Effects of GA₃ levels the first stem height on wheat varieties.

4.5 Effects of GA₃ levels on the stem height on wheat varieties at 14 days after emergence

The stem height of wheat in different GA₃ levels at 14days after emergence had no a significant difference, $P=0.501$. The stem height of the wheat varieties showed little difference except for the runde variety at G3 that had a stem height.

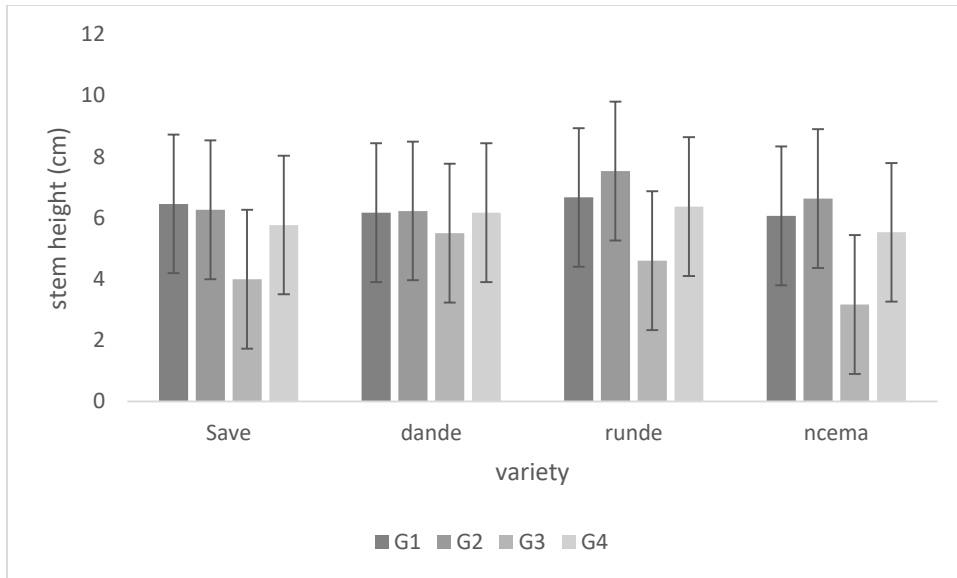


Figure 4.5: Effects of GA₃ levels on the second stem height on wheat varieties.

4.6 Effects of GA₃ levels on the third stem height on wheat varieties at 21 days after emergence

The stem height of wheat in different GA₃ levels at 21 days after emergence did not show any significant differences ($p < 0.001$). The Save variety in level 1 of GA₃ showed the highest stem height of 18.07 cm. The least stem height was the Runde variety with GA₃ level 1, showing 8.07 cm. Error bars indicated that there were significant differences at Save and Runde at G1, Save and Ncema at G1, Dande G4 and Runde G4 also showed a significant difference.

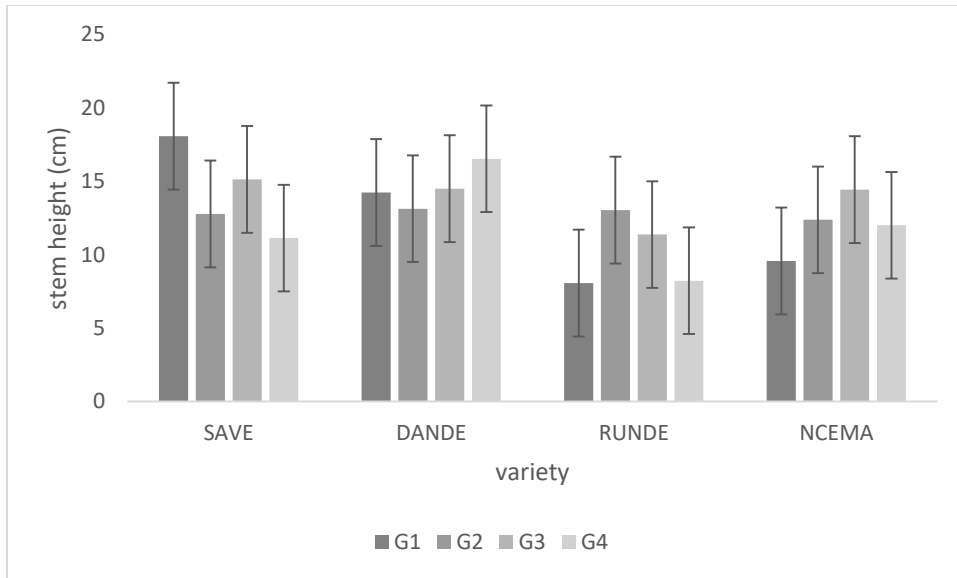


Figure 4.6 Effects of GA₃ levels on the third stem height on wheat varieties

4.7 Effects of GA₃ levels on tiller number on wheat varieties.

The tiller number of different varieties of wheat in different GA₃ levels showed that they was no significant difference, the P =0.097.

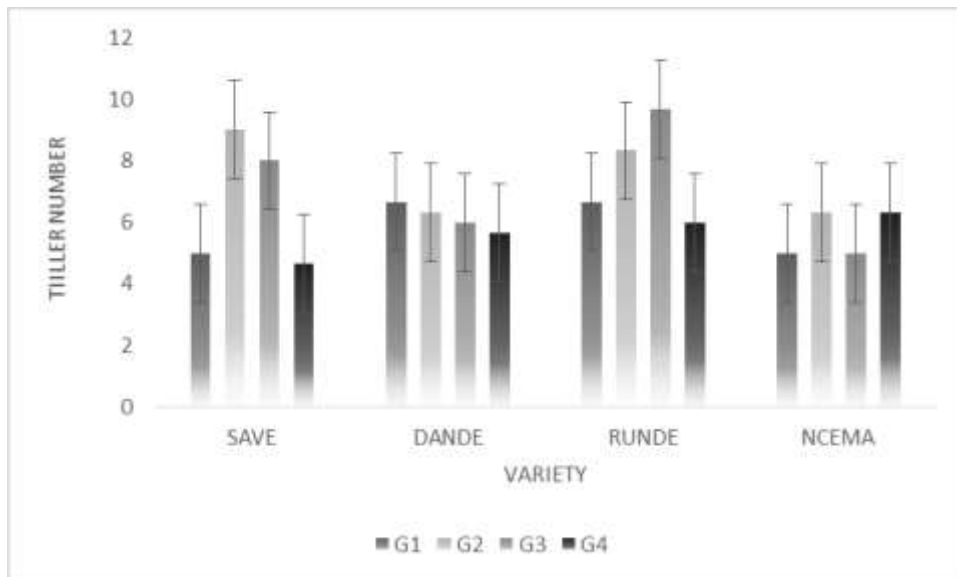


Figure 4.7 Effects of GA₃ levels on tiller number on wheat varieties.

CHAPTER 5: DISCUSSION

5.1 Effects of GA₃ levels on germination percentage on wheat varieties.

According to Figure 4.1, GA₃ had a significant impact on germination. The study observed that different wheat varieties responded differently to varying levels of Gibberellic Acid (GA₃) on germination, supporting the findings of Pavlista et al. (2013). This variation in response is due to genetic differences within the wheat varieties. The results indicate that the amount of GA₃ applied affects the germination percentage until it reaches a saturation point. Maximum effectiveness was observed at 2 ml and 4 ml of GA₃.

The study also demonstrated that GA₃, as a natural or synthetic plant growth hormone, can regulate plant development by controlling various cellular activities in plants, as mentioned by Sajjad et al. (2017). Germination percentage was enhanced when certain wheat varieties were treated with GA₃ using the soaking method. This method stimulates biochemical processes necessary for germination, such as hydrolysis, metabolism of growth inhibitors, and enzyme activation. Xu et al. (2016) also acknowledge the essential role of GA₃ in seed germination and its contribution to resistance against biotic and abiotic stress in wheat plants.

However, it is important to note that GA₃ can elicit different responses in different wheat varieties. For example, the runde variety showed a negative reaction compared to other varieties, while the Dande variety performed well in the absence of GA₃. Furthermore, the study demonstrated that incorporating GA₃ can reduce germination days, which was also supported by Ayaz et al. (2019).

5.2 Effects of GA₃ levels on seedling vigour index on wheat varieties

According to Iftikhar et al. (2016), the Save and Ncema varieties exhibited the highest seedling vigour index when treated with Gibberellic acid at level 4 (G4). The researchers suggest that the use of Gibberellic acid may have stimulated both root and shoot growth, resulting in enhanced seedling vigour index. Seedling vigour index is crucial for crop yield and resource utilization efficiency, as it determines the successful establishment of plants in the field and their ability to germinate and develop seedlings rapidly and uniformly across various environmental conditions.

Similar findings were reported by Nawel (2012), who also observed improved seedling vigour with the application of Gibberellic acid. Additionally, Ozturk and Unal (2023) and Archard (2013) acknowledge that GA₃, a type of Gibberellic acid, regulates gene expression through DELLA proteins and promotes germination and shoot development by facilitating the degradation of the growth suppressor DELLA.

5.3 Effects of GA₃ levels the stem height on wheat varieties.

The stem height and development showed that it was sensitive to GA₃. The data in fig 4.4 showed that there is significant growth on the wheat varieties if a maximum of 4ml GA₃ was used. This agrees with the work of (Iftikhar *et al* ,2019) who also noticed that Gibberellic Acid has an effect on wheat as it increases in plant height However despite the results showing that they was no significant difference on the last stem height the varieties reacted differently to the GA₃ levels. On the stem height the runde and Ncema varieties are dwarf varieties so the study does prove that GA₃ can surpass genomic makeup.

Also the stem height might have increased because, GA₃ induces internode lengthening, and a study conducted by Li et al. (2019) supports these findings, as he also investigated the role of Gibberellic Acid (GA₃) in regulating internode elongation and stem height showed that. GA₃ promote internode elongation by increasing cell division and elongation in the stem. Stem height might have also increased due to increased rate of photosynthesis, which ensures that the plant has enough nutrients to support growth of the plant. The study conducted by Wang et al. (2014) also supports these findings .In his investigations he discovered that GA₃ can increase the rate of photosynthesis by enhancing the efficiency of the photosynthetic electron transport chain. GA₃ was found to increase the activity of photosystem II (PSII), which is responsible for the initial light absorption and electron transfer in the photosynthetic process.

In addition to GA₃ effects on photosynthesis, GA₃ has also been found to play a role in nitrogen assimilation in plants. Nitrogen assimilation is the process by which plants take up and use nitrogen to synthesize amino acids and other essential compounds. GA₃ has been shown to increase the

activity of nitrate reductase, an enzyme involved in the conversion of nitrate to ammonium, which is then used in the synthesis of amino acids. This was demonstrated in a study by Wang et al. (2015), which found that GA₃ treatment increased the activity of nitrate reductase in wheat plants.

5.5 Effects of GA₃ levels on tiller number and leaf area index on wheat varieties.

Due to the fact that GA₃ stays in the soils only for 6 weeks as cited by Smith, (2001), it does not cause any significant effect on the tiller number and leaf area index of wheat varieties. From these results highlights the importance of careful experimental design and statistical analysis to ensure that any observed differences are meaningful and not simply due to chance.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Increasing GA₃ levels increased the germination and seedling growth on different wheat varieties to all varieties except for the Save variety. The germination percentage of plants treated with GA₃ was increased significantly as compared to the ones not treated ones in all the other varieties, only Save showed to be affected when gibberellic acid was applied. The first stem height (7 days) and the second stem height 14 days after emergency showed significant improvement when the plants were treated with GA₃. This may indicate that treating seed with GA₃ enhances growth and development in wheat varieties. However GA₃ did not cause any significant changes on the stem height 21 days after emergency leaf area index, tiller number of the wheat varieties. This shows that GA₃ does have a period it persist in the soil as did not have significant differences.

6.2 RECOMMENDATIONS

The experimental data showed how GA₃ affects different wheat varieties differently, so I recommend farmers and breeders to use GA₃ during production of wheat. If a one is to grow the Save, Dande and Ncema variety, I recommend they soak the seeds in a GA₃ and water solution at a rate of 4ml of GA₃:2 litres of water and if one is to grow the Runde variety the seeds must be soaked in a solution of 2ml of GA₃:2 litres.

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APPENDICES

1.1 APPENDIX 1:

Genstat Release 18.1 (PC/Windows 8) 15 May 2023 09:22:26

Copyright 2015, VSN International Ltd.

Registered to: ICARDA

```
3 "Data taken from unsaved spreadsheet: New Data;1"  
4 DELETE [REDEFINE=yes] _stitle_: TEXT _stitle_  
5 READ [PRINT=*; SETNVALUES=yes] _stitle_  
8 PRINT [IPRINT=*] _stitle_; JUST=left
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Data imported from Clipboard

on: 15-May-2023 9:23:15

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9 DELETE [REDEFINE=yes] block,wheat,GA,GP,SVI,SH1,SH2,SH3,LAI,CB,TLN  
10 UNITS [NVALUES=*]  
11 FACTOR [MODIFY=no; NVALUES=48; LEVELS=3; LABELS=*; REFERENCE=1] block  
12 READ block; FREPRESENTATION=ordinal
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Identifier	Values	Missing	Levels
block	48	0	3

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15 FACTOR [MODIFY=no; NVALUES=48; LEVELS=4; LABELS=*; REFERENCE=1] wheat  
16 READ wheat; FREPRESENTATION=ordinal
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wheat	48	0	4

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20 READ GA; FREPRESENTATION=ordinal
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GA	48	0	4

```
23 VARIATE [NVALUES=48] GP  
24 READ GP
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Identifier	Minimum	Mean	Maximum	Values	Missing
GP	0.0000	61.88	100.0	48	0

```
27 VARIATE [NVALUES=48] SVI  
28 READ SVI
```

Identifier	Minimum	Mean	Maximum	Values	Missing
SVI	0.0000	1221	2450	48	0

```
32 VARIATE [NVALUES=48] SH1  
33 READ SH1
```


Identifier	Minimum	Mean	Maximum	Values	Missing
SH1	0.0000	3.392	5.800	48	0

```
36 VARIATE [NVALUES=48] SH2
37 READ SH2
```

Identifier	Minimum	Mean	Maximum	Values	Missing	Skew
SH2	0.0000	7.487	84.90	48	0	

```
41 VARIATE [NVALUES=48] SH3
42 READ SH3
```

Identifier	Minimum	Mean	Maximum	Values	Missing
SH3	0.0000	12.79	22.10	48	0

```
46 VARIATE [NVALUES=48] LAI
47 READ LAI
```

Identifier	Minimum	Mean	Maximum	Values	Missing
LAI	0.0000	5.792	11.10	48	0

```
51 VARIATE [NVALUES=48] CB
52 READ CB
```

Identifier	Minimum	Mean	Maximum	Values	Missing
CB	0.0000	40.14	81.30	48	0

```
56 VARIATE [NVALUES=48] TLN
57 READ TLN
```

Identifier	Minimum	Mean	Maximum	Values	Missing
TLN	0.0000	6.542	10.00	48	0

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60
61 "Two-way design in randomized blocks"
62 DELETE [REDEFINE=yes] _ibalance
63 A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
64 FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
65 GP; SAVE=_a2save
```

Analysis of variance

Variate: GP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	1950.0	975.0	2.53	
block.*Units* stratum					
GA	3	1272.9	424.3	1.10	0.365
wheat	3	17389.6	5796.5	15.01	<.001
GA.wheat	9	2935.4	326.2	0.84	0.582
Residual	30	11583.3	386.1		
Total	47	35131.2			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

block 1 *units* 2	42.1	s.e. 15.5
block 3 *units* 2	-42.9	s.e. 15.5

Tables of means

Variate: GP

Grand mean 61.9

GA	1	2	3	4	
	60.0	61.7	55.8	70.0	
wheat	1	2	3	4	
	59.2	85.8	33.3	69.2	
GA	wheat	1	2	3	4
1		70.0	90.0	30.0	50.0
2		46.7	86.7	43.3	70.0
3		50.0	76.7	23.3	73.3
4		70.0	90.0	36.7	83.3

Standard errors of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30

e.s.e.	5.67	5.67	11.34
--------	------	------	-------

Standard errors of differences of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	8.02	8.02	16.04

Least significant differences of means (5% level)

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
l.s.d.	16.38	16.38	32.77

Stratum standard errors and coefficients of variation

Variate: GP

Stratum	d.f.	s.e.	cv%
block	2	7.81	12.6
block.*Units*	30	19.65	31.8

```

66 SET [IN=*
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```

72 "Two-way design in randomized blocks"
73 DELETE [REDEFINE=yes] _ibalance
74 A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
75 FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
76 SVI; SAVE=_a2save

```

Analysis of variance

Variate: SVI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	10998.	5499.	0.02	
block.*Units* stratum					
GA	3	833789.	277930.	1.01	0.401
wheat	3	8015750.	2671917.	9.74	<.001
GA.wheat	9	1406413.	156268.	0.57	0.811
Residual	30	8233431.	274448.		
Total	47	18500380.			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

block 1 *units* 7	-979.	s.e. 414.
block 2 *units* 8	-1102.	s.e. 414.

Tables of means

Variate: SVI

Grand mean 1221.

GA	1	2	3	4	
	1138.	1243.	1078.	1425.	
wheat	1	2	3	4	
	1227.	1705.	580.	1372.	
GA	wheat	1	2	3	4
1		1355.	1683.	550.	963.
2		1085.	1633.	762.	1492.
3		873.	1700.	510.	1230.
4		1596.	1803.	498.	1803.

Standard errors of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30

e.s.e.	151.2	151.2	302.5
--------	-------	-------	-------

Standard errors of differences of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	213.9	213.9	427.7

Least significant differences of means (5% level)

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
l.s.d.	436.8	436.8	873.6

Stratum standard errors and coefficients of variation

Variate: SVI

Stratum	d.f.	s.e.	cv%
block	2	18.5	1.5
block.*Units*	30	523.9	42.9

```

77 SET [IN=*
```

```

83 "Two-way design in randomized blocks"
84 DELETE [REDEFINE=yes] _ibalance
85 A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
86 FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
87 LAI; SAVE=_a2save
```

Analysis of variance

Variate: LAI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	45.882	22.941	6.09	
block.*Units* stratum					
GA	3	18.718	6.239	1.66	0.198
wheat	3	14.415	4.805	1.27	0.301
GA.wheat	9	18.450	2.050	0.54	0.831
Residual	30	113.092	3.770		
Total	47	210.557			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

block 1 *units* 12	-3.59	s.e. 1.53
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Tables of means

Variate: LAI

Grand mean 5.79

GA	1	2	3	4	
	5.25	6.08	6.68	5.16	
wheat	1	2	3	4	
	5.53	6.53	5.07	6.05	
GA	wheat	1	2	3	4
1		5.43	6.33	3.67	5.57
2		5.80	6.90	6.17	5.47
3		5.77	8.20	6.00	6.73
4		5.10	4.67	4.43	6.43

Standard errors of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
e.s.e.	0.560	0.560	1.121

Standard errors of differences of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.793	0.793	1.585

Least significant differences of means (5% level)

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
l.s.d.	1.619	1.619	3.238

Stratum standard errors and coefficients of variation

Variate: LAI

Stratum	d.f.	s.e.	cv%
block	2	1.197	20.7
block.*Units*	30	1.942	33.5

```
88 SET [IN=*]
94 "Two-way design in randomized blocks"
95 DELETE [REDEFINE=yes] _ibalance
96 A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
97 FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
98 TLN; SAVE=_a2save
```

Analysis of variance

Variate: TLN

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	20.292	10.146	2.68	
block.*Units* stratum					
GA	3	30.917	10.306	2.72	0.062
wheat	3	26.250	8.750	2.31	0.097
GA.wheat	9	42.750	4.750	1.25	0.302
Residual	30	113.708	3.790		
Total	47	233.917			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

block 1 *units* 9	-5.75	s.e. 1.54
block 1 *units* 12	-5.08	s.e. 1.54

Tables of means

Variate: TLN

Grand mean 6.54

GA	1	2	3	4	
	5.83	7.50	7.17	5.67	
wheat	1	2	3	4	
	6.67	6.17	7.67	5.67	
GA	wheat	1	2	3	4
1		5.00	6.67	6.67	5.00
2		9.00	6.33	8.33	6.33
3		8.00	6.00	9.67	5.00
4		4.67	5.67	6.00	6.33

Standard errors of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30

e.s.e.	0.562	0.562	1.124
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Standard errors of differences of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.795	0.795	1.590

Least significant differences of means (5% level)

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
l.s.d.	1.623	1.623	3.246

Stratum standard errors and coefficients of variation

Variate: TLN

Stratum	d.f.	s.e.	cv%
block	2	0.796	12.2
block.*Units*	30	1.947	29.8

```

99  SET [IN=*
```

```

105  "Two-way design in randomized blocks"
106  DELETE [REDEFINE=yes] _ibalance
107  A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
108  FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
109  SH1; SAVE=_a2save
```

Analysis of variance

Variate: SH1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	3.292	1.646	1.41	
block.*Units* stratum					
GA	3	0.285	0.095	0.08	0.970
wheat	3	12.082	4.027	3.46	0.029
GA.wheat	9	8.890	0.988	0.85	0.579
Residual	30	34.948	1.165		
Total	47	59.497			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

block 1 *units* 9	-2.48	s.e. 0.85
block 3 *units* 9	1.95	s.e. 0.85

Tables of means

Variate: SH1

Grand mean 3.39

GA	1	2	3	4	
	3.32	3.39	3.34	3.52	
wheat	1	2	3	4	
	3.99	3.52	2.60	3.46	
GA	wheat	1	2	3	4
1		4.00	3.33	2.40	3.53
2		3.73	3.00	3.33	3.50
3		3.63	3.50	3.00	3.23
4		4.60	4.23	1.67	3.57

Standard errors of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30

e.s.e.	0.312	0.312	0.623
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Standard errors of differences of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.441	0.441	0.881

Least significant differences of means (5% level)

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
l.s.d.	0.900	0.900	1.800

Stratum standard errors and coefficients of variation

Variate: SH1

Stratum	d.f.	s.e.	cv%
block	2	0.321	9.5
block.*Units*	30	1.079	31.8

```

110 SET [IN=*]
116 "Two-way design in randomized blocks"
117 DELETE [REDEFINE=yes] _ibalance
118 A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
119 FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
120 SH2; SAVE=_a2save

```

Analysis of variance

Variate: SH2

Source of variation	d.f.	s.s.	m.s.	v.r.	F	pr.
block stratum	2	14.292	7.146	3.86		
block.*Units* stratum						
GA	3	6.253	2.084	1.13		0.354
wheat	3	39.186	13.062	7.06		0.887
wheat.GA	9	7.715	0.857	0.46		<.001
Residual	30	55.503	1.850			
Total	47	122.949				

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

block 1 *units* 11	51.0	s.e.	9.4
block 2 *units* 11	-26.3	s.e.	9.4
block 3 *units* 11	-24.7	s.e.	9.4

Tables of means

Variate: SH2

Grand mean 5.82

wheat	1	2	3	4
	6.34	6.67	4.32	5.96

GA	1	2	3	4
	5.62	6.02	6.29	5.35

wheat	GA	1	2	3	4
1		6.46	6.17	6.67	6.07
2		6.27	6.23	7.53	6.63
3		4.00	5.50	4.60	3.17
4		5.77	6.17	6.37	5.53

Standard errors of means

Table	wheat	GA	wheat
		GA	
rep.	12	12	3
d.f.	30	30	30
e.s.e.	0.393	0.393	0.785

Standard errors of differences of mean

Table	GA	wheat	GA
		wheat	
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.555	0.555	1.111

Least significant differences of means (5% level)

Table	wheat	GA	wheat
		GA	
rep.	12	12	3
d.f.	30	30	30
l.s.d.	1.134	1.134	2.268

Stratum standard errors and coefficients of variation

Variate: SH2

Stratum	d.f.	s.e.	cv%
block	2	0.668	11.5
block.*Units*	30	1.360	23.4

```

121 SET [IN=*]
127 "Two-way design in randomized blocks"
128 DELETE [REDEFINE=yes] _ibalance
129 A2WAY [PRINT=aovtable,information,means,%cv; TREATMENTS=GA,wheat;
BLOCKS=block; FACTORIAL=2;\
130 FPROB=yes; PSE=diff,lsd,means,alllsd; LSDLEVEL=5; PLOT=*;
COMBINATIONS=present; EXIT=_ibalance]\
131 SH3; SAVE=_a2save

```

Analysis of variance

Variate: SH3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	33.14	16.57	0.84	
block.*Units* stratum					
GA	3	22.81	7.60	0.38	0.765
wheat	3	153.69	51.23	2.59	0.072
GA.wheat	9	166.31	18.48	0.93	0.512
Residual	30	594.23	19.81		
Total	47	970.18			

Information summary

All terms orthogonal, none aliased.

Tables of means

Variate: SH3

Grand mean 12.79

GA	1	2	3	4	
	12.48	12.83	13.86	11.98	
wheat	1	2	3	4	
	14.28	14.60	10.18	12.09	
GA	wheat	1	2	3	4
1		18.07	14.23	8.07	9.57
2		12.77	13.13	13.03	12.37
3		15.13	14.50	11.37	14.43
4		11.13	16.53	8.23	12.00

Standard errors of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
e.s.e.	1.285	1.285	2.570

Standard errors of differences of means

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
s.e.d.	1.817	1.817	3.634

Least significant differences of means (5% level)

Table	GA	wheat	GA wheat
rep.	12	12	3
d.f.	30	30	30
l.s.d.	3.711	3.711	7.421

Stratum standard errors and coefficients of variation

Variate: SH3

Stratum	d.f.	s.e.	cv%
block	2	1.018	8.0
block.*Units*	30	4.451	34.8

132 SET [IN=*

Reference