University of Venda
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Using genotypic diversity to enhance climate resilience of peanut cropping in Limpopo Province

by

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DECLARATION

I, Mulaudzi Ntakadzeni Rose, student No:14001515, hereby declare that this research Dissertation for Master of Science (MSc.) in Agriculture (Soil Science) submitted to the Department of Plant and Soil Sciences, Faculty of Science, Engineering and Agriculture, University of Venda has not been submitted previously for any degree at this or any other University. Fundamentally, it is the result of my own original work, except for references to other people's work, which have been duly cited and referenced.

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Mulaudzi. N.R date

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DEDICATION

I dedicate this work to my precious daughter Orinea Thandolwethu Nyathi whom I gave birth during the course of this research study. She has been nothing but an inspiration for me to complete this work.

ABSTRACT

Groundnut or peanut (*Arachis hypogaea L.*) is mostly grown by small-holder farmers in semi-arid regions of sub-Saharan Africa, particularly South Africa. As with other crops, not all groundnut cultivars respond equally well to the various climatic conditions in the South African province of Limpopo due to different environmental factors. Abiotic stress factors such as drought, extremely high temperatures, unpredictable and insufficient rainfall with annual variation that cannot be accurately predicted are limiting groundnut production in South Africa. In order to increase groundnut production, it is necessary to design properly the management practices, such as season and site-specific exploitation of cultivar x location x management (C x L x M) interactions, which will minimize the impact of the low rainfall and high temperature that characterize the production, particularly in Limpopo Province. The objective of this study was to assess the effects of groundnut cultivar on groundnut performance, soil water use and mineral nitrogen levels under different climatic conditions in Limpopo Province. A further objective was to validate the performance of Agricultural Production Systems Simulators (APSIM) model to predict the observed yields of groundnut cultivar yields under variable environmental and climatic conditions in Limpopo Province.

Field experiments were conducted at two locations, the University of Limpopo (Syferkuil farm) and the University of Venda experimental farm during the 2018/2019 and 2019/2020 growing seasons. The experiments were laid out in randomized complete block design (RCBD) consisting of four treatments (groundnut cultivars: Kwarts, Sellie, Opal and Oleic) replicated four times to give a total of 16 plots each measuring 4 m × 3 m ($12\mathrm{m}^2$). Soil mineral nitrogen and dry biomass were determined at 50 % flowering and harvest maturity. Grain yield was collected at maturity and soil water content was determined every two weeks during the growing period using the gravimetric method. The APSIM-groundnut model (version 7.10) was used to simulate groundnut cultivars grain yield and biomass production to assess the risks associated with different climate conditions on the yield production of groundnut crops.

The results obtained from this study showed that the groundnut cultivar influenced measured parameters (grain, nodulation and yield components) at both locations, whereas the effect of cultivar on biomass, soil moisture and mineral nitrogen was significant only at Syferkuil site. There was a significant difference in the cultivar and cultivar x location interaction on pods and seeds yield, harvest index and shelling percentages. Sellie produced a higher seed yield at Univen, while at Syferkuil Oleic produced the highest seed yield. The cultivar Opal performed well while Kwarts produced low yield in both seasons and locations. Irrespective of cultivar performance, Syferkuil produced less biomass and grain yield compared to Univen due to prolonged dry conditions over the seasons. The results further showed significant variation in soil water content at different depths among the cultivars and soil water content increased with soil depth. Cultivars with high biomass had high soil water content than those with low biomass at all soil depths. It was notable that cultivars with higher biomass showed a higher level of NO_3^--N and NH_4^+-N at all depths. At Univen, the soil NO_3^--N and NH_4^+-N levels increased at harvest while at Syferkuil NO_3^--N and NH_4^+-N decreased at harvest. The results demonstrated the benefits of soil moisture content on groundnut growth and soil mineral nitrogen. APSIM-model showed some capabilities of simulating groundnut grain and biomass yield in response to groundnut cultivar and different environments over the two locations that were simulated in both seasons. Therefore, in these locations, the APSIM model might be a helpful tool for predicting groundnut productivity.

Keywords: *APSIM model, Cultivar, Groundnut, Simulate, Grain yield, Climatic conditions.*

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LIST OF ABBREVIATIONS.

°C	Degrees Celsius
ANOVA	Analysis of Variance
APSIM	Agricultural Production Systems Simulators
ARC	Agricultural Research Council
ARC-ISCW	Agricultural Research Council Institute for Soil, Climate and Water
BD	Bulk Density
BM	Biomass
BNF	Biological Nitrogen Fixation
C × L x M	Cultivar × Location × Management
C x L	Cultivar x Location
C	Cultivar
Ca	Calcium
CEC	Cation Exchange Capacity
CLL	Crop Lower Limit
Cm	Centimetre
CV	Coefficient of Variation
DAFF	Department of Agriculture, Forestry and Fisheries
DUL	Drain Upper Limit
FAO	Food and Agriculture Organization
FC	Field Capacity
GWC	Gravimetric Water Content
GY	Grain Yield

H	Harvested area
H_2O	Water
HI	Harvest Index
K	Potassium
L	Location
LAN	Limestone Ammonium Nitrate
LP	Limpopo Province
LSD	Least Significant Different
Mg	Magnesium
Mm	Millimetres
N	Nitrogen
Na	Sodium
NH_4^+	Ammonium ion
NO_3^{-1}	Nitrate ion
NRC	National Research Council
OC	Organic carbon
P	Phosphorus
Ph	Potential Hydrogen
PWP	Permanent Wilting Point
PY	Pod Yield
R^2	Coefficient of Determination
RCBD	Randomized Complete Block Design

SA	South Africa
SALLnet	South African Limpopo Landscape Network
SE	Standard Error for comparison
SH	Shelling
SMN	Soil Mineral Nitrogen
ST	Sampling Time
SWC	Soil Water Content
WAP	Week After Planting
WUE	Water Use Efficiency
XF	Root Exploration

CHAPTER1: INTRODUCTION.

1.1. Background information.

The groundnut or peanut (*Arachis hypogaea L.*) is an annual legume crop originated in Eastern Bolivia and native to South America. It is now cultivated in most subtropical, tropical, and temperate regions within 40 °C North and 40 °C South (Hammons *et al*., 2016). Around the world, including in South Africa (SA), groundnuts are a common source of food (Cilliers, 2015). Moreover, it contains approximately 25 % protein and 50 % oil, making it an important source of protein for human nutrition (Wang *et al*., 2016). Groundnuts are consumed in many countries as peanut butter, ground up into oil, or roasted, salted, or sweetened confectionery snacks. Other parts of the world boil them either with or without the shell (Cilliers, 2015) and as confectionary preparations and flour by human while fresh protein-rich fodder and hay by livestock (Pandey *et al*., 2014).

In addition, groundnut plays a crucial role in improving soil fertility of cropping systems due to the Nitrogen (N) it supplies through biological nitrogen fixation (Bodo *et al*., 2006). Furthermore, groundnut provides N to the succeeding crop through fallen senescent leaves or incorporation of green shoots into the soil (Bodo *et al*., 2006). This added N reduces the farmer's input of chemical fertilizer N which are expensive, especially to smallholder farmers with limited resources.

In the 1960s and 1970s, South Africa groundnut production averaged 300,000 tons annually, making it a major cash crop for small-scale and commercial farming systems (Hoffmann *et al*., 2018). However, groundnut production has since decreased to about 50 000 tons in 2010, with the lowest figure estimated at 20 000 tons in 2016. Due to this, SA now imports groundnuts to meet its demand (Hoffmann *et al*., 2018). Pandey *et al*. (2014) reported that the low productivity of groundnuts is due to its susceptibility to negative effects of drought and heat stress which is probably going to get even more damaging with unavoidable climate change, especially in Africa. Climate change refers to long-term alteration in the distribution of weather patterns over periods of time that range from decades to millions of years and is a main contributor to low-income generation for farmers with limited resources. Hoffmann *et al.* (2018) on the other hand reported that the decline in groundnut production is due to the lack of improved genetic material and high demand for labor. However, one of the biggest challenges is adapting to climate variability in many parts of SA particularly in Limpopo Province.

In order to meet food security goals, cropping systems will need to be managed in a new way that is flexible, adaptable, and tolerant to the occurrence of extreme events. However, considering adaptation to climate change, managing agricultural systems for resilience is proving to be a suitable strategy under such highly uncertain conditions (Webber *et al*., 2014). Therefore, to increase productivity, continue to provide steady support for millions of disadvantaged people's livelihoods, and fulfill the country's demand, nutrition-rich groundnut cultivars with improved oil quality and pod yield are needed (Pandey *et al*., 2014). According to Wang et al. (2016), the lack of genetic variation among the high-yielding cultivars selected as parents for hybridization in breeding programmes is the cause of the recent decline in groundnut production. Therefore, for a more productive and successful hybridization program, research on the genetic variety among cultivars is required (Wang *et al*., 2016).

However, efficient exploitation of season and site-specific cultivar x location x management (C x L x M) interactions to revitalize production growth are crucial for groundnut management to be well adaptable to fluctuating conditions (Hoffmann *et al*., 2018). This calls for conducting field trials to comprehend crop performance in a specific environment. Due to the high cost and resource demands, it is difficult to conduct such trials throughout a number of years and sites in order to generate season and site-specific recommendations for a wide range of C x L x M. Therefore, process-based crop modeling can be used as an additional strategy to determine production constraints and optimized cropping practices (Hoffmann *et al*., 2018). A well-tested model, Agricultural Production Systems Simulator (APSIM), offers reasonably accurate crop yield estimates based on climate, cultivar, soil, and management aspects while addressing concerns with long-term resource management challenges in farming systems, is considered as one of the most suitable modes for C x L x M interactions (Ncube *et al*.,2009). Researchers extensively use APSIM to access on-farm management methods and climate change adaption solutions under various conditions (Holzworth *et al*., 2014). In this study, the APSIM model was used to evaluate how genotypic diversity enhances climate resilience of groundnut cropping.

1.2. Problem statement.

Most of the small-holder farmers in SA, especially in Limpopo Province, experience low productivity of groundnut as compared to many parts of the world. One of the major factors attributed to low productivity of groundnut is climate change (such as extreme temperatures, low rainfall and climate variability) which is accelerating with time and thus will lead to food insecurity to the country as a whole. Therefore, the use of APSIM model to exploit season and site-specific cultivar x location x management interactions (C x E x M) will likely increase production because it will provide farmers with different management strategies for different climatic conditions, especially to smallholder farmers based on the APSIM model predictions.

1.3. Justification.

The use of genotypic diversity coupled with the use of APSIM model will improve the production of groundnut since these will help farmers to identify promising cultivars and their environment, thus fitting well to the local soil and climate conditions. The increase in groundnut production will improve food security while providing good nutrition in terms of proteins and vitamins to many people, especially those of rural areas, as well as better income to small-holder farmers growing groundnut as a cash crop. This study was necessary because there were minimal studies on the adaptation of groundnut cultivars in Limpopo region.

1.4. Study objectives

1.4.1. Overall objective

The overall objective of this study was to assess the effects of groundnut cultivars on groundnut performance, soil water use and mineral Nitrogen levels.

1.4.2. Specific objectives

i. To determine dry matter accumulation and grain yield.

ii. To assess nodulation.

iii. To evaluate soil water content and mineral N levels.

iv. To validate the performance of APSIM model to predict the observed biomass production and grain yield.

1.5. Hypotheses

i. Groundnut cultivars will affect biomass accumulation and grain yield.

ii. Groundnut cultivars will affect groundnut nodulation.

iii. Groundnut cultivars will affect soil water content and mineral N levels at every sampling time during plant growth.

iv. APSIM model accurately predicts the observed biomass production and grain yield.

CHAPTER 2: LITERATURE REVIEW

2.1. Groundnut origin and utilisation

Groundnut is a highly pollinated annual legume believed to have originated in South America and then spread to other regions of the world (Settaluri *et al*., 2012). Groundnut is extensively cultivated in most tropical and subtropical regions of the world, where average annual rainfall ranges between 500 and 1200 mm and the average daily temperatures exceed 20°C (Muruta, 2015; Variath and Janila, 2017). In most parts of the world, including SA, groundnuts are a common source of food (Cilliers, 2015). It is the world's fourth-most important oilseed crop and the thirteenth-most important food crop (Mandavia and Golakiya, 2015). Subsequently, it is greatly valued for the high-quality protein, vitamins, minerals, resveratrol, and other antioxidant compounds that are kept in its seed (Gantait and Mondal, 2018). Groundnut pods and kernels are the most valuable product of a groundnut plant, however all parts of the plant can be used in a variety of ways (Variath and Janila, 2017).

Seeds of groundnuts are consumed raw, roasted, boiled, and processed into confections, peanut butter, and groundnut flour, as well as crushed for edible oil (Cilliers, 2015). The oil it produces is the most important product used in both domestic and industrial purposes, including lubricants, fuel for diesel engines, and emulsions for insect control, and cooking oil, margarine, and salad dressings (Prasad, 2010). It can be used as a raw ingredient to make non-food products including cosmetics, pharmaceuticals, soaps, and medications (Murata, 1995). Groundnut shells can be used as blocks or hardboard in the building industry as well as for sweeping compounds (DAFF, 2010). After being harvested, dried groundnut plants (haulms) are fed to animals as fresh, high-protein fodder, especially during dry seasons (Pandey *et al*., 2014 and Sewordor et al., 2015). Since groundnut provides nutrient-rich fodder to livestock, groundnut farming helps mixed crop and livestock production systems remain sustainable, particularly in the semi-arid areas (Janila *et al*., 2013). Groundnuts typically include 48–50% fat, 26–28% protein, and vitamins A, thiamine, riboflavin, and other members of the vitamin B complex. It is therefore essential to the world's oilseed economy (Mahantesh et al., 2018 and Kokkanti et al., 2022).

Groundnuts contain nutrients that are beneficial to human health. The energy and growth supporting components found in groundnuts, such as carbohydrates (10–15%), lipids, protein (25–36%), vitamins (E, K, and B), minerals (phosphorus (P), calcium (Ca), and magnesium (Mg), as well as some organic acids, are what give them their nutritional importance. These nutrients can help prevent malnutrition in women and children who are resource-poor (Mbonwa, 2013 and

Settaluri *et al*., 2012). Because of its many uses, the groundnut plant is a great cash crop for both local markets and international trade in several developing and developed countries, especially for small-holder farmers in semi-arid regions (Mbonwa, 2013).

2.2. Groundnut production in SA.

According to DAFF (2010), groundnut is mostly produced in the following area in South Africa Northwest, Northern Cape, Free State, Limpopo, and Mpumalanga provinces, with the Northern Cape accounting for 48 percent of production, the North West for 28 %, and the Free State for 21 percent. The production of groundnuts is very low in the provinces of Limpopo and Mpumalanga., with production in Limpopo being only 6 %. The low production may be for the reason that it's produced mostly by small-scale farmers and in the other provinces it is produced by commercial farmers (Mbonwa, 2013).

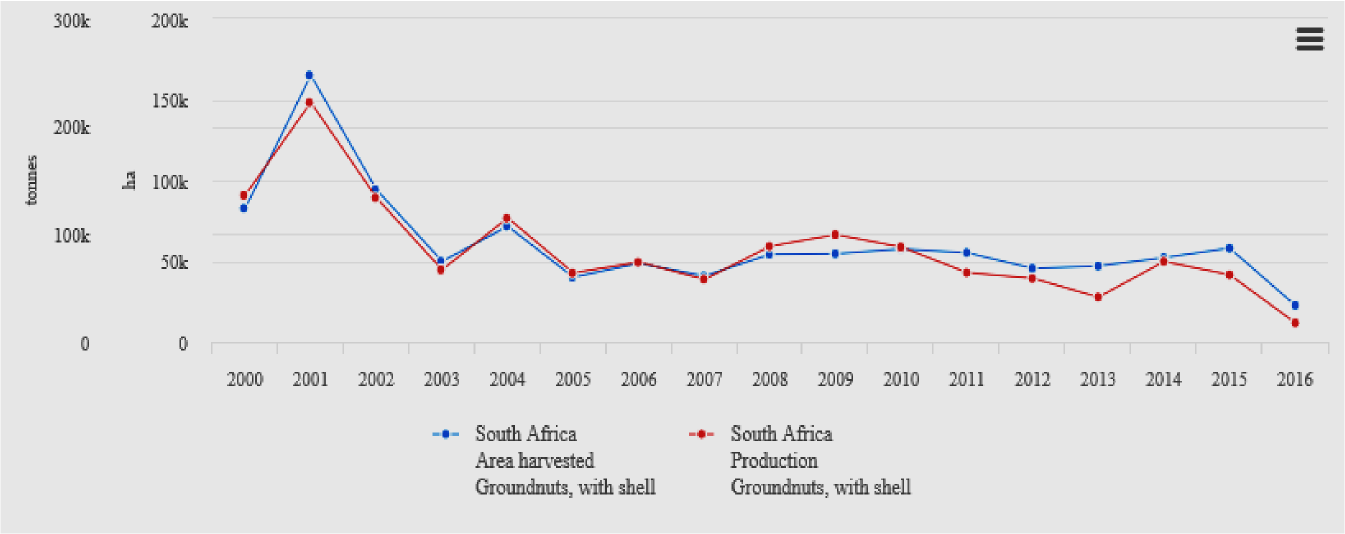

Figure 1. Production/yield quantities of groundnuts, with shell in South Africa (2000-2016) (AGBIZ, 2016).

Due to larger planting areas of about 140 000 hectares, groundnut production in SA increased significantly to 200 000 tons during the 2000/2001 growing season (DAFF, 2015). In 2010, SA experienced a decline in groundnut production when roughly 50 000 tons where produced. The lowest figure was reached in 2016 with the estimated production of 20 000 tons as shown in Figure 1 (Hoffmann *et al*., 2018). Since groundnut is a labour-intensive crop, high demand for labor, diseases, a lack of improved suitable varieties, a decrease in planted area, and a drought season brought on by El Nino are the major constraints to the decrease in groundnut production

(Hoffmann *et al*., 2018 and AGBIZ, 2016). Therefore, improving smallholder groundnut yields in the area is necessary to enhance food security (Mbonwa, 2013).

2.3. Impact of climate change on growth and yield of groundnut cropping.

Climate has an impact on agricultural practices, and it affects yields, which change from year to year. Therefore, the agricultural industry is highly susceptible to climate change (Pulvento *et al*., 2011). Climate change refers to long-term changes in the distribution of weather patterns over periods of time that range from decades to millions of years (Hurlimann *et al*., 2021). Climate change may be attributed to temperatures that are higher and more varied, fluctuations in precipitation and wind patterns, and a rise in the occurrence of severe events like droughts and floods, as well as climate variability (Ngcamu and Chari, 2020). These cause low adaptation of crops even in their native environments (Rotter *et al*., 2018). This will invariably result in a further decline in worldwide crop supply and production, a rise in food prices, and an increased chance of experiencing hunger, malnutrition, and food insecurity (Adazebra, 2013).

Smallholder farmers mainly grow groundnuts in semi-arid locations which are characterized by high temperatures and low rainfall (Wang *et al*., 2016 and Junjttakarn *et al*., 2013). Therefore, given that rainfall in these areas is generally unpredictable and insufficient, drought is a severe production restriction that contributes to a decrease in production (Songsri *et al*., 2008). Drought stress has detrimental effect on groundnut water interactions, metabolism, photosynthesis, mineral nutrition, development, and yield. However, the severity of the threat to crop yield varies on the growth stage, duration, and intensity of the stress (Mahantesh et al., 2018). Songsri et al. (2008) reported that, drought throughout the stages of pod and seed formation has been observed to decrease peanut pod production by 56–85 %. Given that germination is the most crucial and sensitive stage of a plant's life cycle, Mahantesh et al. (2018) reported that the occurrence of drought during this stage may compromise the sequence of seedling establishment. Long-term drought has been proved to decrease peanut yield and increase aflatoxin contamination, which can produce seeds that are unfit for human consumption (Junjttakarn *et a*l.,2013).

Temperature and sunlight have a greater impact on peanut productivity due to their direct involvement in several phenological occurrences (Ijaz *et al*., 2021). However, groundnut is temperature-sensitive, with an optimal range for most processes being between 20ºC and 30ºC (Hamidou *et al*., 2013). According to Ijaz *et al*. (2021), Immature pods may result from excessively low temperatures during the early or late stages of crop growth. Higher temperatures, on the other hand, encourage insects to work faster and more efficiently, limiting the rate of development of groundnuts (Ijaz et at., 2021 and Liu *et al*., 2013). Since drought stress and high temperatures are the major climatic conditions that limit groundnut yields, it is expected that climate change will further reduce productivity (Faye *et al*., 2018 and Kadiyala *et al*., 2021). Therefore, rather complex and well-tested modeling approaches that go beyond empirical description are needed to assess the implications of climate change and evaluate the alternatives for adaptation (Rotter *et al*., 2018).

2.4. Genotypic diversity and its impact on groundnut cropping.

Development of groundnut cultivars with tolerance to both abiotic and biotic stress is necessary because they have the potential to produce higher yields given that the reduction in groundnut yield is largely caused by abiotic (temperature, drought, and pests) and biotic (diseases, pests, and diseases) stress (Mandavia and Golakiya 2015). According to Songsri et al. (2008), drought is a major constraint to groundnut productivity and decreases pod yield, especially if it happens during the stages of seed and pod formation. Since most groundnut is cultivated in semi-arid tropical regions under rain-fed conditions, practically speaking, improving water access and management is challenging due to the scarcity of water. It is now generally accepted that a comprehensive approach is necessary to address the complexity of the drought syndrome. This approach should include analysis of resistance features from a physiological perspective, molecular genetic tools, as well as agronomic practices that improve soil moisture conservation and utilization and crop cultivar matching with the environment (Mahantesh et al., 2018).

According to Zongo et al. (2017), biotic factors, in particular foliar diseases such as rust and late leaf spot create a substantial yield-limiting problem in the production of groundnuts, with groundnut yield losses predicted to reach up to 50–70 percent and negatively impact the quality of the produce. Fungicides can be used to reduce the effects of these diseases. However, the majority of smallholder farmers are unable to utilize them because they lack the financial means and technical expertise needed, as well as because using fungicides has detrimental impacts on both the environment and human health. Therefore, using disease-resistant groundnut cultivars is thought to be both sustainable and economical in reducing the effects of these diseases (Zongo *et al*., 2017). Very few research has been done on genetic diversity. More genetic diversity research is therefore required since understanding genetic diversity is essential for its application in groundnut breeding for crop improvement (Ren *et al*., 2014 and Kokkanti *et al*., 2022).

2.5. Effects of groundnut cropping on mineral N- levels.

Many regions of South Africa's soils are low in fertility, especially nitrogen (Mokgehle *et al*., 2014). Low production, particularly of cereal crops, is caused by low soil fertility. Legumes like groundnut contribute to the health and fertility of the soil by releasing nitrogen into the soil through biological nitrogen fixation (Janila *et al*., 2013). Biological nitrogen fixation (BNF) is the process by which atmospheric nitrogen ($\mathrm{N_2}$) is transformed into to ammonia ($\mathrm{NH_4}$), catalyzed by enzyme nitrogenase (Nhamo *et al*., 2018). Biological nitrogen fixation, which is environmentally friendly and provides around 70% of the nitrogen needed by agricultural and natural ecosystems, is one of the most crucial processes for the sustainability of life on Earth (Adazebra, 2013). Grain legumes (like groundnut) can be incorporated into cereal-based cropping systems to assist in restoring soil fertility by fixing atmospheric nitrogen while also providing grains that are rich in protein for household food and nutrition. This is important because continuous cereal-based systems without adding enough nutrients to the soil have resulted in drastic reduction in soil fertility and low crop yields on smallholder farms (Kermah*,* 2020). Even though chemical fertilizers are now more widely accessible for crops in many locations, Mokgehle et al. (2014) found that their use in Africa is still constrained due to their high cost, inaccessibility to African farmers with limited resources, and risk of environmental degradation. The main option for smallholder farmers is organic fertilizers, which may be a more environmentally sustainable source of nutrients. However, organic fertilizers, such as compost or animal manure, are usually difficult for resource-limited farmers to obtain or use, especially in the recommended amounts.

Crop residues, which in addition to providing organic inputs, are widely used for other uses such as cooking fuel and livestock feed, and thus subject farmers with extra pressures and trade-offs (Witcombe and Tiemann, 2022). Therefore, intercropping of a cereal-based (groundnut and maize) cropping system will also increase production and farmers' income, especially for smallholder farmers who have few means to buy chemical fertilizer due to its high cost (Mokgehle *et al*., 2014). In addition to providing immediate and short-term nitrogen to succeeding crops, groundnut residues can enhance long-term nitrogen and soil fertility by promoting microbial biomass production, nutrient cycling, and soil organic matter stability and productivity (Witcombe and Tiemann, 2022). According to several studies, groundnuts have the ability to fix a significant quantity of nitrogen into the soil, up to 134 kg/ha (Mokgehle et al., 2014), and it has been reported that groundnut residues can supply up to 139 kg N/ha (Witcombe and Tiemann, 2022). Since existing trends for N fixed by groundnut are not considered to be sufficient for crop production, further study is still needed to produce more efficient fixed N that can replace mineral fertilizers.

This will minimize reliance on sources of mineral N fertilizer, which will assist to slow down the effects of climate change (Nhamo *et al*., 2018).

2.6. Groundnut cropping and soil water content.

Soil water content is the physical variable used to determine the amount of water accessible in the soil for plant usage. Soil water plays an important role in groundnut production. Mandal et al. (2019) reported that groundnut cultivation with insufficient soil water content results in decreased biomass and pod production as well as seed contamination that is unfit for human for consumption. Mahantesh et al. (2018) also observed that a decrease in soil moisture during the reproductive stage increases the percentage of peg sterility, which may lead to a reduction in yield under stress. Low yields have also been reported as a result of waterlogging because groundnut is sensitive to excessive soil moisture, which has resulted in pests and disease infestations, such as leaf-miners and leaf-spot disease (Mandal *et al*., 2019). However, Rowland *et al*. (2012) showed that some cultivars exhibit water use efficiency (WUE), where they have a potential of reducing stomatal conductance, leaf expansion and transpiration rate without decreasing photosynthetic rate (Devi *et al*., 2009). This trait enables them to conserve water in the soil, particularly when water supplies are limited.

2.7. APSIM model.

Modeling complex agricultural systems using APSIM is a common practice among agricultural researchers (Holzworth *et al*., 2018). It has linked management and biophysical models that can simulate systems involving the processes of soil, crops, trees, pastures, and livestock, and it is flexible enough to include non-biological farm resources like water storages and farm equipment (Holzworth *et al*., 2014). The APSIM model is used to advise farmers on yield gap analyses, educating them on plant breeding initiatives, climate change and adaptation analysis, and entire farm modeling techniques (Holzworth *et al*., 2018). It simulates crop growth and development on a daily basis according to weather, soil attributes, and management practices, such as planting density and date, cultivar traits, tillage, and the application of chemical fertilizer and organic matter (Corbeels *et al*., 2018 and Holzworth *et al*., 2018).

The model simulates crop growth and development based on weather conditions, soil characteristics, and management practices at a daily time step. Crop models, particularly the APSIM model, have great potential to evaluate crop genetic improvement to increase production and maximize adaptation to present and future target environments (Singh *et al*., 2012). Since APSIM includes a separate module called APSIM-peanut (APSIM-groundnut), which can simulate the growth of the leaf surface area, yield, and crop water use of groundnuts under various climatic conditions and cropping systems (Chauhan *et al*., 2007), It is an excellent model to increase groundnut yield in semi-arid areas. The APSIM model has undergone thorough testing and offers reasonably accurate crop production estimates in respect to climate, cultivar, soil, and management aspects, while addressing long-term resource management challenges in farming systems. Additionally, it is regarded as one of the best modes for cultivar x location x management interactions (Hoffmann *et al*., 2018 and Ncube *et al*., 2009).

Conducting yield trials in various environments is an important part of plant breeding practices because the findings of these trials have provided crucial information on cultivar performance, adaptation, and cultivar x location interactions that are necessary for cultivar selection, recommendation, and release (Makinde *et al*., 2013). Different groundnut cultivars produce different results in terms of performance both within and between environments. In most cases, this type of interaction can cause one cultivar to yield the highest in some environments while producing the lowest in others, while the second cultivar may succeed where the first cultivar may have failed (Ngirazi *et al*., 2017). For that reason, instead of just calculating the average performance of the cultivars under evaluation, it is important to know and understand the extent of interactions in the selection of cultivars across various environments. Adazebra (2013) discovered that until the development of molecular markers, morphological features, which are mostly phenotypical, have been predominantly used for genetic characterization. As a result, C x L x M interactions increase the possibilities for innovative crop development strategies. Therefore, it is important to understand and quantify the reasons of these interactions in order to construct C x M packages that maximize productivity under particular environmental conditions (Hajjarpoor et al., 2021).

CHAPTER 3: MATERIAL AND METHODS.

3.1. Study area.

3.1.1. Locations.

Field experiments were conducted at two locations in the Limpopo Province of South Africa namely, University of Venda (Univen) experimental farm, which is in Thohoyandou and University of Limpopo experimental farm at Syferkuil, during 2018/19 and 2019/20 growing seasons. Univen experimental farm is geographically located at latitude of 22° 35'14.0" S with longitude of 30° 15'50.3" E and Syferkuil is geographically located at latitude of 23°46' S with longitude of 29°42' E.

3.1.2. Climatic conditions.

The Univen site is a semi-arid environment, with daily temperatures ranging from around 25 °C to 40 °C in the summer and between 12 °C and 26 °C in the winter. The region receives an average annual rainfall of about 781 mm, which is very seasonal with 85% occurring between October and March (M'marete, 2003). Syferkuil is categorized as a semi-arid region, with daily temperatures ranging from 18°C to 35°C from October to March and 25°C or lower from April to September. The region receives an average of roughly 500 mm of rainfall annually (Shiringani, 2007 and Mpangane *et al*., 2004).

3.1.3. Soils.

Soil at the Univen site is predominantly deep (>1500 mm) red and yellow well-drained clays with apedal structure (Mzezewa *et al*., 2010). Clay content is generally high (60%) and soil reaction is acidic (pH 5.0). The soils are formed in situ and classified as Hutton form (Soil Classification Working Group, 1991), equivalent to Rhodic Ferralsol (WRB, 2006). While Syferkuil soil is sandy loam soil of the Hutton form, Glenrosa family (Soil Classification Working Group, 1991), with pH ranging from 6.0-6.2 (Moshia, 2005).

3.2. Field experiment design and management.

Plant materials.

The groundnut cultivars used for this study were obtained from the Agricultural Research Council (ARC) Grain Crop Institute, Potchefstroom in South Africa. Kwarts, Sellie, Opal and Oleic are Spanish Upright, bunch type with tan coloured round shape kernels. These cultivars are recommended for dryland and tolerance to high with grain yield potential between of 1.8-2.6 tons/ha and medium maturing dates between 150-155 days. Kwarts, Opal and Oleic are tolerant to early and late leaf sport while Sellie is susceptible to leaf sport. Sellie and Opal have higher fraction of large kernels.

The area was ploughed, horrowed mechanically using a disc plough followed by leveling using a hand hoe to make a seedbed with a fine tilth before planting. The experiment was arranged in a Randomized Complete Block Design (RCBD) with four treatments (groundnut cultivars), namely Kwarts, Oleic, Opal and Sellie. The groundnut cultivars used for this study were obtained from Agricultural Research Council (ARC) in South Africa. Each treatment was replicated 4 times to give a total of 16 plots each measuring 4 m × 3 m ($12\mathrm{m}^2$). A cleared 1 metre space was left between each plot to eliminate border effect and each plot comprised of five plant rows with 7 plants each. Planting (sowing) was done manually by placing three seeds per hole at spacing of 90 cm × 70 cm (inter and intra row) and thinned to one plant after emergence. Phosphorus (P) was applied using broadcasting method during planting time at a rate of 50 kg/ha on the rows in the form of superphosphate (10.5%P). Nitrogen (N) was applied at the rate of 30 kg N/ha in the form of Limestone Ammonium Nitrate (LAN) (28%N) as a starter N using broadcasting method in the rows at planting in all locations. The first rainfall event occurred in late November instead of September, therefore pushing the planting to be done on 30 November at Syferkuil and 02 December 2018 at Univen for the first cropping season. In the second cropping season, the experiment commences earlier due to early rain during November 2019. Planting date was 17 November 2019 at Univen and on the 19th of November at the Syferkuil location. The experiment was rainfed however irrigation was applied at Syferkuil only after planting for the seed germination and unfraternally amount of water applied was not recorded. After planting, all the plots were kept weed free by hand hoe for both seasons to avoid competition for light, water, and nutrients with the main crop.

(a) Syferkuil **(b) Univen**

Figure 2: Pictures (a) and (b) showing field experiments from the current study that indicate variation in groundnut cultivar performance in two different locations.

3.3. Soil sampling and determination of the initial soil physical and chemical properties.

Characterization of the soil at the experimental site was done by randomly collecting soil samples at both locations at 0-30 cm and bulking them together. A representative soil sample was then obtained from the bulk sample and subsample was obtained from the composite and stored in a freezer for the determination of soil mineral nitrogen. The remaining sample was air-dried and passed through a 2 mm sieve for the determination of selected physical and chemical soil properties. These included pH, CEC, texture, organic carbon, total P, Ca, Mg, K and Na. Soil mineral nitrogen was determined using colorimetric method following the procedure outlined by Sattolo *et al*. (2016), pH (H_2O) was measured using pH meter using 1:2.5 soil to water ratio, Ammonium acetate extraction procedure was used to determine CEC and exchangeable cations (Mg, Ca, Na, and K) as described by Peech (1965). Soil organic carbon was measured using the Walkley-Black method (Nelson and Sommers, 1982). Available P was determined using Bray-1 method (Bray and Kurtz, 1945). Soil texture was determined using hydrometer method following a procedure described by Bouyoucous (1962). Additional soil samples were collected at similar soil depths to determine soil bulk density and initial soil water content following the gravimetric method as described by Black *et al*. (1965).

3.4. Data collection.

3.4.1. Soil moisture content.

Soil water content (SWC) was determined every two weeks during the growing season. Soil samples were collected from a depth of 0-15, 15-30 and 30-60 cm using soil auger at both experimental sites. The samples were collected between rows of plants in the middle of each plot. Collected soil samples were placed into plastic bags and stored in a cooler box while in the field to minimize moisture losses through evaporation. SWC was determined using the gravimetric water content method (GWC) (Black *et al*., 1965). Samples were transferred into tins that were weighed and labelled before adding soil. The samples were oven dried at a temperature of 105°C for 24-48 hours, until there was no difference between any two consecutive measurements of the weight of the dry soil sample and soil water content was calculated using the following formula:

$$GWC = \frac{weight\ of\ wet\ soil - weight\ of\ dry\ soil}{weight\ of\ dry\ soil}$$ (Black *et al*., 1965)

3.4.2. Soil mineral nitrogen (NH_4^+ and NO_3^-).

Soil mineral nitrogen (SMN) was determined by the colorimetric method following the procedure by Sattolo *et al*. (2016). Soil samples for the determination of SMN were collected at groundnut flowering and harvest maturity sages. The samples were collected across the soil profile from 0-30 and 30-60 cm depth in both seasons. All the samples were collected from the middle of each plot. Collected samples were transferred into plastic bags and placed into a cooler box with ice to keep the samples cool while in the field. The samples were stored in a freezer at a temperature of 4°C until they were ready for analysis.

3.4.3. Nodulation.

During flowering (six weeks after planting), four plants were randomly selected from each plot and carefully dug out for determination of dry nodule weight. The procedure consists of delicately removing the soil around the plants without disturbing the roots. The plants were then taken to the laboratory where roots were carefully washed under running water to eliminate all soil particles from the plants. The nodules were then removed and kept in brown envelopes and oven-dried at 65℃ for 72 hours and then weighed at the end of the drying period to determine the nodule dry weight per plot.

3.4.4. Dry matter (biomass).

Dry matter was determined at flowering where four (4) plants were sampled and at harvest where ten (10) plants were sampled from the middle rows of each plot to avoid border effects. Samples were kept in sampling bag and transported to the laboratory and oven dried to a constant weight for 48 h at a temperature of 70°C. The oven-dried samples were then weighed using electronic scale and the value were recorded from each plot and converted into kg ha^{-1} basis over harvested area.

3.4.5. Grain yield.

At harvest, ten (10) plants harvested for biomass were also used for grain yield. matured pods were separated from the harvested plant samples. The harvested pods were sun dried in open air space for a period of 2 weeks. The pods were weighed to determine dry weight of the pods per plot and later threshed to obtain the seeds. The threshed seeds were then weighed to obtain the total grain yield per plot and finally, the grain yield was converted into kg ha^{-1} basis using the following formula.

$$\text{GY (kg/ha)} = \frac{\text{GYW (g)}}{\text{H (m}^2\text{)}} \times \frac{10000\ (\text{m}^2\ /\text{ha})}{1000(\text{g/kg})}$$ (Adazebra, 2013).

Where:

GY is the final grain yield.

GYW is the grain yield weight per plot

H is the area from which plant sample was harvested.

3.4.6. Harvest Index (HI).

The HI was calculated as the ratio of final grain yield weight to the final biomass at harvest using the following formula:

$$\text{HI \%} = \frac{\text{Grain yield}}{\text{Total above ground biomass}} \times 100$$ (Yeshiwas, 2019)

3.4.7. Shelling percentage.

The shelling percentage was calculated as the ratio of grain yield (unshelled grain) to the total pod yield (shelled grain) and multiplied by hundred.

Shelling percentage was determined using the formula:

$$\text{Shelling \%} = \frac{\text{unshelled grain weight}}{\text{shelled grain weight}} \times 100$$ (Tekulu et al., 2020)

3.4.8. Weather data.

The climate data used in this study was obtained from University of Limpopo experimental farm (Syferkuil) weather station and University of Venda on-site weather station. However, additional stations close to the sites were used to complete and compare the meteorological data because the stations on both sites occasionally malfunctioned. at Univen weather data from Makwarela station (six kilometers from a site) was used and at Syferkuil Agricultural Research Council (ARC) Institute of Soil Climate and Water database was used. This database includes daily hydro-climatological data for the period of 15 years (2005 to 2020), including rainfall, solar radiation, reference evapotranspiration, minimum and maximum temperatures. These parameters are meteorological parameters required to run the APSIM model. Temperature, radiation, and rainfall were recorded during the 2018/19 and 2019/2020 growing seasons at Syferkuil and Univen by means of automatic weather stations on daily record basis.

3.5. Model setup.

3.5.1. APSIM evaluation.

Crop (APSIM-groundnut), SoilWat (soil water) and residue modules were linked with APSIM 7.10 for simulations. weather (met) and manager and modules were also included. The manager folder deals with crop management module information such as planting date, type of cultivar to use, type and amount of fertiliser applied. The met module contains inputs of daily weather data for the study area. Weather data is a key input parameter, along with soil characteristics as all processes are heavily driven by these variables. Weather data includes rainfall, maximum temperature, minimum temperature, and solar radiation.

Soil modules were also input mainly with measured data from experimental sites. Drained upper limit (DUL) also referred as Field capacity (FC), Crop lower limit (CLL) also referred as permanent wilting point (PWP), Bulk density (BD) and saturation (SAT) for the sites were estimated. The results for soil water parameters are indicated in Tables 1 and 2.

Table 1: Soil chemical and physical properties and initial values at Univen by soil depth.

Depth (cm)	**0-15**	**15-30**	**30-60**	**60-90**
Bulk density (g cm ^{3})	1.220	1.250	1.340	1.340
SAT (mm)	0.490	0.490	0.490	0.490
DUL (mm)	0.260	0.290	0.290	0.320
Air-Dry weight (mm/mm)	0.060	0.080	0.130	0.130
LL (mm/mm)	0.120	0.130	0.150	0.150
XF (0-1)	1.0	1.0	1.0	1.0
KL (0-1)	0.06	0.06	0.06	0.04
FBiom (0-1)	0.030	0.020	0.020	0.010
FInert (0-1)	0.500	0.700	0.700	0.900
OC (%)	2.420	1.000	0.400	0.400
pH (water)	5.920	5.920	5.820	5.720

SAT= Saturated volumetric water content, DUL= Drained upper limit, LL= Lower limit, KL= Water extraction coefficient, OC= initial organic carbon, and XF= Root exploration factor.

Table 2: Soil chemical and physical properties and initial values at Syferkuil by soil depth.

Depth (cm)	**0-15**	**15-30**	**30-60**	**60-90**
Bulk density (g cm ^{3})	1.450	1.450	1.450	1.450
SAT (mm)	0.403	0.403	0.403	0.403
DUL (mm)	0.150	0.156	0.157	0.157
Air-Dry weight (mm/mm)	0.060	0.080	0.130	0.130
LL (mm/mm)	0.054	0.072	0.110	0.110
XF (0-1)	1.0	1.0	1.0	1.0
KL (0-1)	0.06	0.06	0.06	0.04
FBiom (0-1)	0.030	0.020	0.020	0.010
FInert (0-1)	0.500	0.700	0.700	0.900
OC (%)	0.870	0.870	0.700	0.600
pH (water)	6.760	6.760	6.660	6.560

SAT= Saturated volumetric water content, DUL= Drained upper limit, LL= Lower limit, KL= Water extraction coefficient, OC= initial organic carbon, and XF= Root exploration factor.

3.5.2. Calibration of the APSIM-Peanut model.

The APSIM model contains a description of early, medium, and late maturity groundnut cultivars which are commonly used by most smallholder farmers in Southern Africa. The groundnut cultivars (Kwarts, Sellie, Opal, and Oleic) were planted in all experimental sites and are not available in the library of APSIM's crop models. However, the genetic coefficients of other similar cultivars such as drought tolerant and early maturing (which are recommended for dry areas of South Africa) are available in the APSIM-Peanut model. The crop parameters from the cultivars Foruner, Viginia bunch, Mccubbin and Chico (available in APSIM), were used for the calibration of the cultivars planted in the field experiments. Crop phenology, biomass and yield were calibrated for each cultivar. Utilising observed flowering and maturity dates from the season 2018/2019, phenology was calibrated, which involved changes in the parameters describing the thermal times between the flowering stage and maturity stages (i.e., y_tt_floral initiation: thermal time from floral initiation to flowering, and y_tt_start_grain_fill: thermal time from flowering to start grain fill) (see, Tables 3 and 4). Biomass and grain yield was calibrated by modifying the crop parameter y_rue (Radiation use efficiency at different stages, from emergence to grain filling) until a point was reached that optimized model agreement with observed values. Yield was calibrated by adjusting harvest index (y_hi_incr) were applicable.

Table 3: Genetic coefficients fitted for APSIM-peanut cultivars at Univen site.

	cultivar			
Model parameter	**Virginia bunch**	**Florunner**	**Mccubin**	**Chico**
y_tt_floral initiation	240	280	300	230
y_tt_start_grain_fill	300	400	370	340
y_hi_incr	0.55	0.60	0.70	0.35
y_rue	1.25, 1.25, 1.15, 1.00, 0.50, 0.50, 0.50, 0.20, 0.20	1.20, 1.20, 1.20, 1.30, 1.30, 0.60 0.60, 0.20, 0.20	1.20, 1.20, 1.20 1.30, 1.30, 0.55 0.55, 0.20, 0.20	1.20, 1.20, 1.20, 1.30, 1.30, 0.60 0.60, 0.20, 0.20

Table 4: Genetic coefficients fitted for APSIM-peanut cultivars at Syferkuil site.

	cultivar			
Model parameter	**Virginia bunch**	**Florunner**	**Mccubin**	**Chico**
y_tt_floral initiation	280	280	300	300
y_tt_start_grain_fill	240	100	300	300
y_hi_incr	0.62	0.42	0.63	0.62
y_rue	1.25, 1.25, 1.15, 1.00, 0.50, 0.50, 0.50, 0.20, 0.20	1.20, 1.20, 1.20, 1.30, 1.30, 0.60 0.60, 0.20, 0.20	1.20, 1.20, 1.20 1.30, 1.30, 0.55 0.55, 0.20, 0.20	1.20, 1.20, 1.20, 1.30, 1.30, 0.60 0.60, 0.20, 0.20

The APSIM model was validated using data on soil water, crop biomass, and grain yield from field experiments during the 2019/2020 growing season. Statistical methods were used to evaluate the performance of the crop simulation model in relation to the observed, measured data. The degree to which crop biomass and grain yield were closely correlated between observed (Obs) and simulated (Sim) data was calculated using:

Root mean square error (RMSE)

$\text{RMSE} = [n^{-1}\ \Sigma\ (yield_{\ sim} - yield_{\ obs})^{2}]^{0.5}$

Where:

n is the number of replications of each planting date experiment

sim and obs denote simulation and observed biomass and yield parameters compared for each replicate. The coefficient of determination, (R^2), which can be interpreted as the proportion of the variance in the simulated data that is attributable to the variance in the observed data.

3.5.3. Simulation set-up for APSIM model.

The climatic records obtained from Syferkuil and Univen weather stations from 2018 to 2020 were used together with the soil data, management data such as sowing date, sowing depth, fertilizer application rates, fertilizer application methods, and weather data. All these data were entered in the manager window in the APSIM-model. However, there missing rainfall data in the records which made it difficult during simulation and time was lost in the process of finding weather records from the nearest weather station to fill the in missing data. Weather data form Makwarela weather station which is 6 km away from the Univen site was used to fill missing data for Univen site. For the Syferkuil site, Agricultural Research Council-Institute for Soil, Climate and Water (ARC-ISCW) has a weather station at Syferkuil farm and its database was used. The initial water content and initial mineral nitrogen measured (see, table 5) from both sites were entered in the soil window data in the APSIM model. Simulation runs were made, and model-predicted data were generated.

Table 5: Initial soil mineral nitrogen and soil water content at both sites.

	Initial soil mineral nitrogen and soil water content			
Site	**Depth (cm)**	**NO_3^- (mg kg^{-1})**	**NH_4^+ (mg kg^{-1})**	**SWC (g g^{-1})**
Univen	0-15	21.85	13.10	0.16
	15-30	37.90	15.8	0.18
	30-60	34.05	14.47	0.21
Syferkuil	0-15	12.52	9.92	0.10
	15-30	11.15	16.44	0.11
	30-60	11.15	12.29	0.15

3.6. Data analysis.

Data obtained from the trials were analyzed as a Randomized Complete Block Design using Statistix software version 10.0. Analysis of variance (ANOVA) was used to assess the effect of cultivar on growth and yield of groundnut. The Least Significant Difference (LSD) test was used to compare treatment means at 5% level of significance ($p \leq 0.05$).

CHAPTER 4: RESULTS.

4.1. Physico-chemical properties of the soil at experimental sites.

The initial physico-chemical properties of the soil at Univen and Syferkuil experimental sites are presented in Table 6 below. Soil analysis indicated that soil at Univen was clay while at Syferkuil was sandy clay loam. The soil pH was moderately acidic at Univen (5.92) and slightly acidic at Syferkuil (6.76). The observed pH can promote the growth of groundnut since they are within the range of pH 5.5 to 7.0 recommended for groundnut production (Cilliers, 2015). Available Phosphorus concentration at Univen was 11.23 mg/kg and at Syferkuil was 15.47 mg/kg which was little above than the Landon (1984) ratings who reported that soil P concentration of 0-9 mg/kg is considered low. Therefore, Superphosphate was applied at planting at both locations at a rate of 60 kg P ha^{-1} to improve available phosphorus concentration in the soil. Both sites had adequate exchangeable cations and adequate CEC. Univen had adequate soil organic carbon (SOC) of 2.42% and Syferkuil had low SOC content of 0.82%. An indication of the amount of organic matter in a soil is provided by its soil organic carbon, and high SOC may be due to previous organic material added to the soil. The total nitrogen concentration at Univen was 0.09% and at Syferkuil was 0.04%. These N contents are extremely low and much below the 2.0 % value needed for sufficient crop production (Kermah *et al*., 2017). Therefore, supplementary nitrogen as Limestone Ammonium Nitrate (LAN 28%) was applied as starter nitrogen at a rate of 30 kg/ha at planting to support germination.

Table 6: Chemical and physical properties of the soils at both experimental sites.

	Location	
Soil properties	**UNIVEN**	**Syferkuil**
Physical Properties		
Clay (%)	61	20
Silt (%)	18	21
Sand (%)	21	59
Textural class	*clay*	*Sand Clay Loam*
Chemical properties		
pH (H_2O)	5.92	6.76
P(mg/kg)	11.23	15.47
EC (mS m^{-1})	28.83	65.12
OC (%)	2.42	0.82
Total N%	0.92	0.04
CEC ($cmol_{(+)}$ kg^{-1})	24.21	19.03
Exchangeable Cations(mg/kg)		
Na	140	130
K	65	72
Ca	724	633
Mg	271	389

4.2. Climatic data.

4.2.1. Temperature.

Figures 3 and 4 present the summary of weather variables during the growing season at both Syferkuil and Univen. The mean seasonal temperature during the 2018/2019 ranged from a minimum of 19.03 ^{o}C to a maximum of 32.09 ^{o}C (Figures 3 and 4). However, 6 days during the growing season, maximum daily temperature was above 40 ^{o}C during 2019/2020 growing season, and 2 days had maximum temperature of 40 ^{o}C. Mean seasonal minimum and average temperature ranged from 18.81 ^{o}C to 31.34 ^{o}C. Cropping seasonal average daily solar radiation was 22.2 MJ m^{-2} in 2018/2019 and 121.2 MJ m^{-2} in 2019/2020. Syferkuil had cooler seasons compared to Univen. During 2018/2019 cropping season, 4 days had maximum temperature of more than 35°C while 2019/2020 had only 3 days. Season mean temperature during 2018/2019 ranged from minimum of 16.07 °C to a maximum of 29.03 °C, while in 2019/2020 season, it ranged from 16.16 °C to 28.85 °C, respectively. Solar radiation was high at both sites with a daily average of 22.6 MJ m^{-2} in 2018/2019 and 21.4 MJ m^{-2} in 2019/2020 at Syferkuil.

4.2.2. Rainfall.

Rainfall pattern during the duration of the experiment is indicated in Figures 3 and 4. At Univen, the cropping season 2018/2019 was characterized by low rainfall of 795.9 mm from 01 November 2018 to 31 April 2019 (Figure 3) compared to 2019/2020 cropping season. Total monthly rainfall ranged from 31.1 mm to 320.1 mm with highest monthly total recorded during February (320.1 mm) whereas the lowest was recorded in March (31.1 mm). The 2019/2020 cropping season was a wetter season recording an amount of 1066.33 mm of rainfall. The highest rainfall was received in February (407.92) and in general, there were 7 occasions with more than 40 mm of rainfall in the 2019/2020 crop season and five occasions in the 2018/2019 cropping season. At Syferkuil, in general, rainfall was low in 2018/2019 (341.3 mm) and 2019/2020 (403.7 mm) for the period between November to April (Figure 4). In contrast to Univen, both seasons were drier in Syferkuil. Highest rainfall was received in January (156.5 mm) during 2018/2019; however, during 2019/2020 season, the highest rainfall was received in November (121.8 mm) and February (105.5 mm). Both seasons received low rainfall of 41 mm and 18 mm in March, respectively. The number of rain days was the same for both seasons (36 rainy days). During the 2018/2019 season, there was no heavy rainfall occasions with more than 40 mm of rain. However, during the 2019/2020 growing season, heavy rainfall occasion of more than 40 mm occurred only in one day.

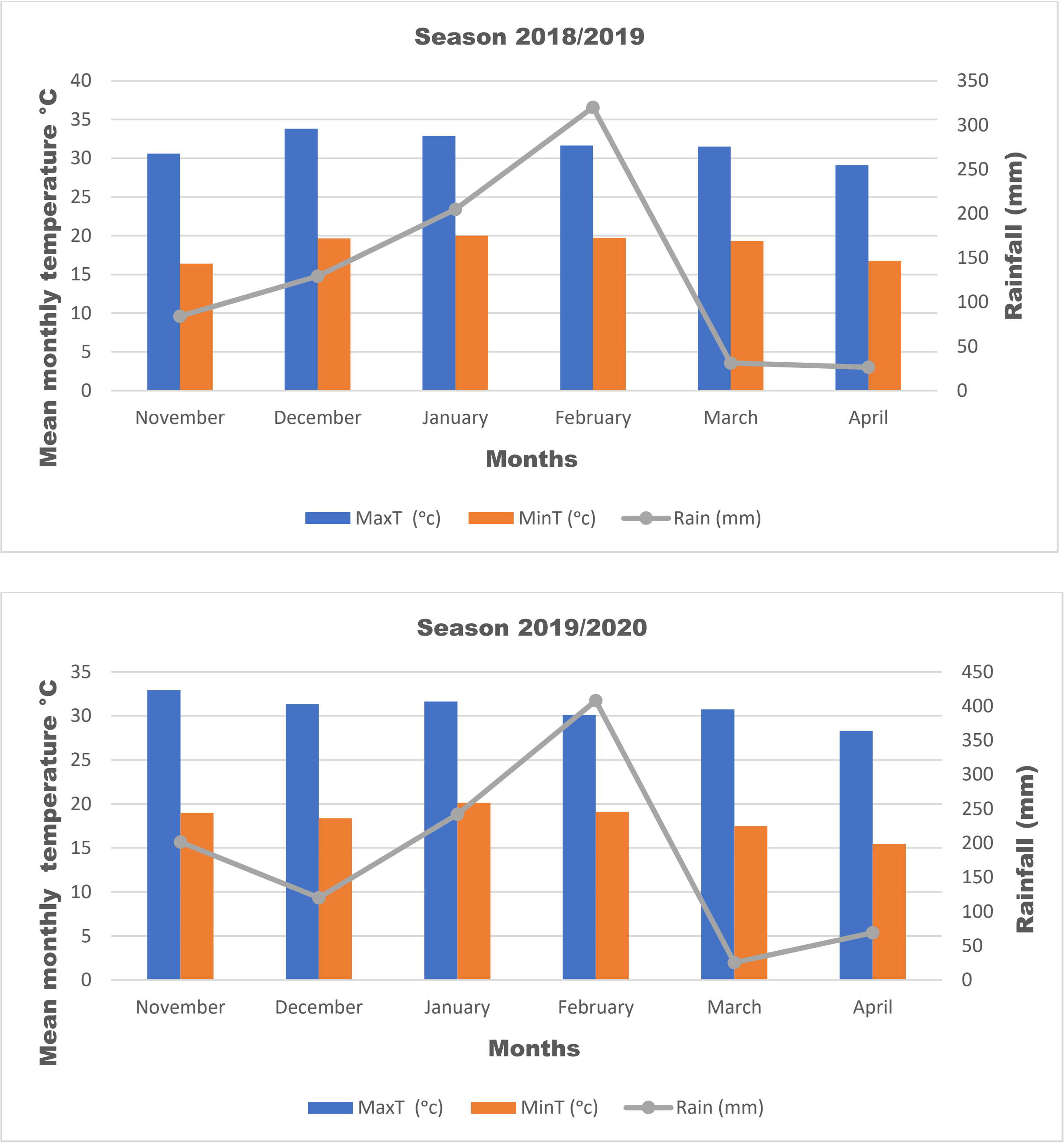

Figure 3: Maximum and minimum monthly average temperatures and total monthly rainfall experienced at Univen during both growing seasons.

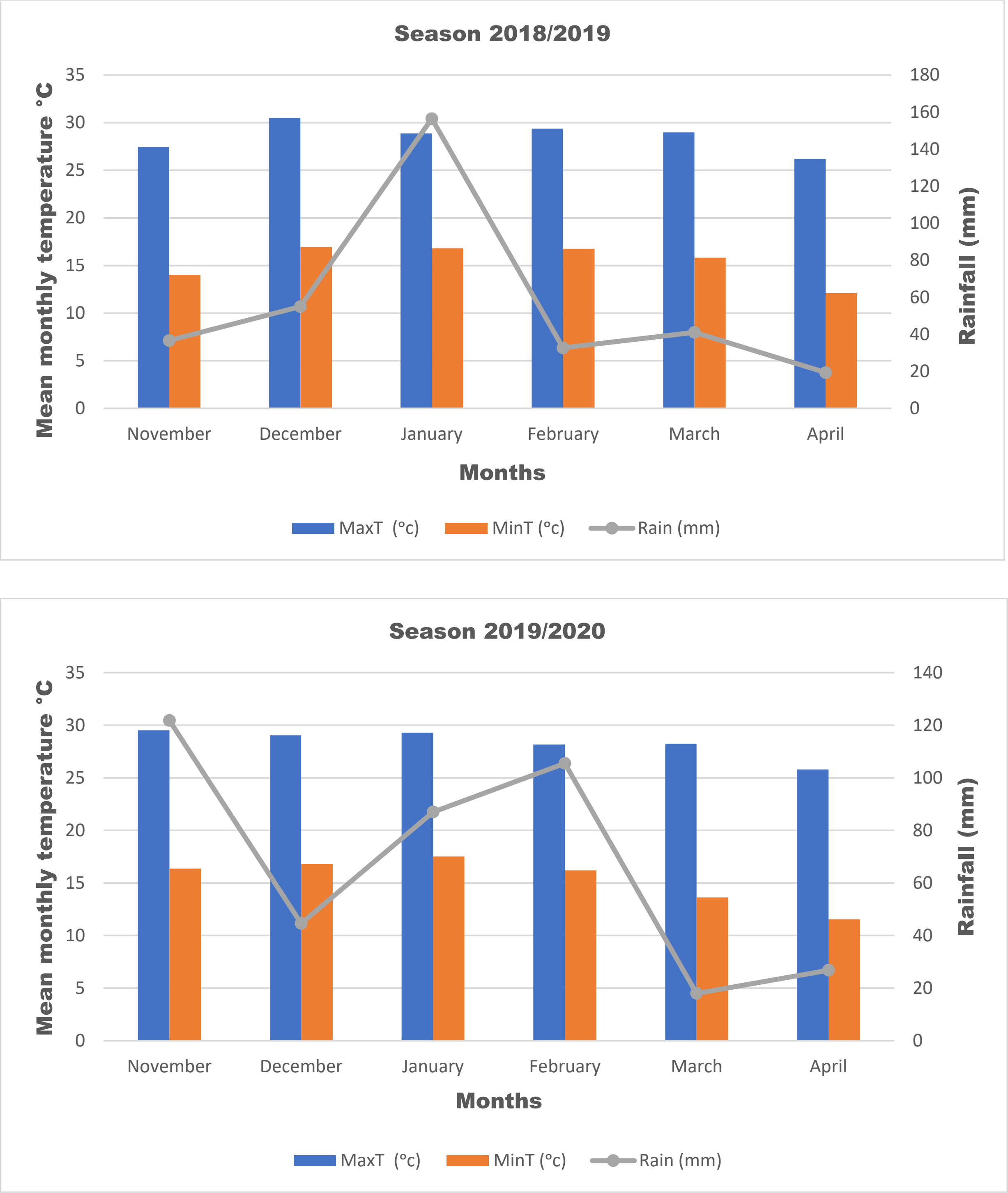

Figure 4: Maximum and minimum monthly average temperatures and total monthly rainfall experienced at Syferkuil during both growing seasons.

4.3. Effect of groundnut cultivar on dry matter at flowering and harvest at both locations and seasons.

4.3.1. Biomass yield at flowering and Harvest.

Groundnut cultivar had significant effect ($P \leq 0.05$) on biomass at harvest whereas biomass at flowering did not show significant difference during first season 2018/2019 at Syferkuil (Table 7). Cultivar Oleic produced significantly higher (1878.7 kg/ha) biomass at harvest compared to Kwarts (1181.7 kg/ha) and Sellie (1271.1 kg/ha) but was similar to cultivar Opal (1648.1 kg/ha). Cultivars Sellie and Opal produce similar biomass at harvest, at Syferkuil. During second season (2019/2020) at Syferkuil, groundnut cultivars had significant effect ($p \leq 0.05$) on biomass yield at flowering (Table 7). Cultivar Oleic produced significantly higher biomass (224.56 kg/ha) than Opal (180.38 kg/ha) but was similar to Kwarts (199.68 kg/ha) and Sellie (208.95 kg/ha). However, at Univen groundnut cultivar had no significant effect ($P \geq 0.05$) on plant biomass at both flowering and harvest stages in both seasons (Table 7).

4.4. Effect of groundnut cultivar on grain and pod yield, shelling percentages, and harvest index at both locations and seasons.

4.4.1. Grain and pod yield at Univen site.

There was a significant effect ($p \leq 0.05$) of groundnut cultivar on grain yield during both 2018/2019 and 2019/2020 seasons (Table 8). Sellie produced significantly higher grain yield of 1363.3 kg/ha and 1867.2 kg/ha while Oleic produced lowest grain yield of 931.2 kg/ha and 883.5 kg/ha in both seasons, respectively. However, grain yield of Opal (1225.7 kg/ha) was not significantly different from Sellie, Kwarts and Oleic, while Kwarts (986.3 kg/ha) produced significantly lower grain yield compared to Sellie but not significantly different from both Oleic and Opal during 2018/2019 season. During 2019/2020 season, Opal grain yield (1752.9 kg/ha) was not significantly different from Sellie and Kwarts (1357.6 kg/ha) but significantly different from Oleic which produced the lowest grain yield. Kwarts and Oleic produced statistically similar means of grain yield during 2019/2020 growing season.

Groundnut cultivars had significant effect ($p \leq 0.05$) on pod yield during 2019/2020 growing season (Table 8). Sellie produced significantly higher (2850.1 kg/ha) pod yield compared to Oleic (1616.5 kg/ha) with lowest pod yield. However, Sellie pod yield was not significantly different from both Opal (2747.1 kg/ha) and Kwarts (2343.8 kg/ha), respectively. Furthermore, Kwarts and Oleic produced statistically similar means of grain yield. Groundnut cultivar did not have a significant effect ($P \geq 0.05$) on pod yield in the 2018/2019 season (Table 8).

Table 7: Effect of groundnut cultivars on biomass at flowering and harvest in both locations and seasons.

Treatment	**UNIVEN**		**Syferkuil**	
Cultivars	**BM at flowering Kg/ha**	**BM at harvest Kg/ha**	**BM at flowering Kg/ha**	**BM at harvest Kg/ha**
		2018/1019 season		
Kwarts	541.71	3063.3	309.62	1181.7 b
Sellie	558.65	2979.5	333.49	1271.1 b
Opal	588.55	3172.5	255.30	1648.1 ab
Oleic	514.71	3499.1	347.02	1878.7 a
SE	53.41	357.80	37.26	201.94
F-test probability	ns	ns	ns	*
CV%	13.71	15.92	16.92	19.10
		2019/2020 season		
Kwarts	489.48	3816.0	199.68 ab	1032.4
Sellie	569.11	4355.4	208.95 ab	1101.5
Opal	481.21	4112.0	180.38 b	1179.9
Oleic	586.53	4993.3	224.56 a	1265.5
SE	53.88	396.92	100.34	1596.2
F-test probability	ns	ns	**	ns
CV%	14.36	13.00	6.83	19.72

*Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level, *Significant at p≤0.05, **significant at p≤0.01, ns= Not significant, CV=Coefficient variation, SE= Standard Error for Comparison, BM= Biomass.*

4.4.2. Grain and pod yield at Syferkuil site.

Groundnut cultivar had significant difference (p≤0.05) on grain yield during both seasons at Syferkuil (Table 8). During 2018/2019 growing season Oleic produced highest grain yield (1040.6 kg/ha) followed by Opal (802.8 kg/ha) while Kwarts (534.7 kg/ha) produced the lowest grain yield followed by Sellie (690.5 kg/ha). However, grain yield of Sellie was not significantly different from Opal and Kwarts. During 2019/2020 growing season, Oleic produced significantly higher grain yield of 691.07kg/ha compared to all cultivars. However, Kwarts (475.30 kg/ha) produced lowest grain yield though it was not significant different from Sellie (531.25 kg/ha) and Opal (571.13 kg/ha), respectively. Therefore, in both seasons Oleic produced highest grain yield and Kwarts produced lowest grain yield.

Groundnut cultivar had significant effect ($p \leq 0.05$) on pod yield during 2018/2019 growing season (Table 8). Oleic produced highest pod yield (1510.4 kg/ha) followed by Opal (1212.6 kg/ha) while Kwarts (800.1 kg/ha) produced lowest grain yield followed by Sellie (980.9 kg/ha). However, Opal pod yield was not statistically different from Oleic and Sellie. During 2019/2020 growing season, groundnut cultivar had no significant effect on pod yield (Table 8).

4.4.3. Harvest Index and Shelling percentage at both locations and seasons.

At Univen, groundnut cultivar had significant effect ($p \leq 0.05$) on harvest index over both seasons (Table 8). The highest harvest index was obtained with Sellie (46.0% and 44.9%) followed by Opal (38.7% and 42.7%), whereas Oleic (28.1% and17.8) produced the least harvest index in both 2018/2019 and 2019/2020 growing seasons, respectively. However, Kwarts harvest index (32.1%) was not significantly different from all cultivars in 2018/2019 and not significant different from Opal and Oleic during 2019/2020 season. In general, Sellie produced highest HI while oleic produced lowest HI in both seasons. At Syferkuil, groundnut cultivar had no significant effect ($P \geq 0.05$) on harvest index during both growing seasons (Table 8).

At Univen, groundnut cultivar showed significant difference ($p \leq 0.05$) on shelling percentage during the first season 2018/2019 (Table 8). Sellie produced highest shelling percentage (75.6%) while oleic produced least (54.3%) shelling percentage. However, Kwarts (70.9%) and Opal (70.9%) produced statistically similar shelling percentage with Sellie and Oleic. During 2019/2020 growing season, groundnut cultivar had no significant effect on shelling percentage. At Syferkuil, groundnut cultivar did not have significant effect on shelling percentage in both growing seasons (Table 8).

Table 8: Grain yield, Pod yield, Harvest Index and shelling percentage as influenced by groundnut cultivars at the two locations during the two seasons.

				2018/2019 season				
Treatment		**UNIVEN**				**Syferkuil**		
cultivars	GY kg/ha	PY kg/ha	HI %	Shelling %	GY kg/ha	PY kg/ha	HI %	Shelling %
Kwarts	986.3 b	1391.7	32.1 ab	70.9 ab	534.7 c	800.1 c	47.0	67.0
Sellie	1363.3 a	1808.5	46.0 a	75.6 a	690.5 bc	980.9 bc	54.31	69.3
Opal	1225.7 ab	1741.1	38.7 ab	70.9 ab	802.8 ab	1212.6 ab	48.9	66.2
Oleic	931.2 b	1794.7	28.1 b	54.3 b	1040.6 a	1510.4 a	56.5	70.5
SE	113.38	224.19	4.78	6.74	75.37	125.78	4.77	1.76
F-test probability	**	Ns	**	*	**	**	ns	ns
CV%	14.23	18.66	18.66	14.02	13.89	15.80	13.05	3.63
				2019/2020 season				
Kwarts	1357.6 ab	2343.8 ab	35.6 b	58.6	475.30 b	826.1	47.8	58.8
Sellie	1867.2 a	2850.1 a	44.9 a	65.7	531.25 b	844.4	48.8	62.9
Opal	1752.9 a	2747.1 a	42.7 ab	64.6	571.13 b	936.5	51.3	61.3
Oleic	883.5 b	1616.5 b	17.8 b	54.8	691.07 a	1100.1	55.2	63.9
SE	205.41	346.55	6.07	5.72	29.65	100.34	7.46	5.44
F-test probability	**	*	**	ns	**	ns	ns	ns
CV%	18.38	19.70	26.43	13.29	7.40	15.31	20.84	5.44

*Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level, *Significant at p≤0.05, **significant at p≤0.01, ns= Not significant, CV=Coefficient variation, SE= Standard Error for Comparison= Grain Yield, PY= Pod Yield, HI= Harvest.*

4.5. Effect of cultivar, location, and cultivar x location interaction.

4.5.1. Grain and pod yield.

Effect of cultivar, location, and cultivar x location interaction (CLI) combined analysis of variance (ANOVA), are presented in Table 9. In the second season 2019/2020, the effect of cultivar x location (C x L) interaction was significant ($p \leq 0.05$) for both grain and pod yields, whereas in the first season 2018/2019, C x L interaction had significant effect only for grain yield (Table 9). In this study, the C x L interaction effect was observed in the cultivars Sellie and Oleic. Sellie produced highest pod and grain yields at Univen and produced lowest yields at Syferkuil while Oleic produced highest pod and grain yields at Syferkuil and produced lowest yields at Univen (Figures 5 and 6). In general, the highest grain yield was recorded from Sellie (1862.8 kg/ha) followed by Opal (1752.1 kg/ha) during the second season at Univen while the lowest grain yield was recorded at Syferkuil site from Kwarts (534.7 kg/ha) during the first season (Figure 5). Highest pod yield was recorded by Sellie and Opal (2852.0 and 2703.0 kg/ha) at Univen while Kwarts recorded least pod yield (826.1 kg/ha) at Syferkuil in second season (Figure 7). Location had significant effect ($p \leq 0.05$) on grain and pod yields among groundnut cultivars during both growing seasons (Table 9). Univen produced 46.86% and 62.69% more grain yield than Syferkuil during both 2018/2019 and 2019/2020 growing seasons, respectively (Table 9).

4.5.2. Harvest index and shelling percentages.

Results from this study showed that cultivar by location interaction had significant effect ($p \leq 0.05$) on harvest index during both 2018/2019 and 2019/2020 growing seasons (Table 9). Sellie recorded highest harvest index at Univen and lowest HI at Syferkuil. Oleic recorded highest HI at Syferkuil and produced lower HI at Univen during both growing seasons. In general, cultivar Oleic (56.47%) recorded highest HI in 2018/2019 at Syferkuil and lowest HI was also recorded by Oleic (17.58%) at Univen in 2019/2020 season (Figure 7). Location had significant effect ($p \leq 0.05$) on harvest index among groundnut cultivars. Syferkuil produced 42.59% and 44.83% more HI than Univen during both 2018/2019 and 2019/2020 growing seasons, respectively (Table 9).

Cultivar x location interaction had significant effect showed significant ($p \leq 0.05$) on shelling percentage during 2018/2018 season (Table 9). Sellie recorded the highest shelling percentage at Univen while at Syferkuil highest shelling percentage by Oleic. In general, highest shelling percentage was recorded by Sellie (75.64%) whereas lowest shelling percentage was recorded by Oleic (54.29%) at Univen site in 2018/2019 season (Figure 8). Location had no significant effect on the shelling percentage among cultivars.

Table 9: Effect of cultivar, location, and cultivar x location interaction on groundnut performance traits during both growing seasons.

Season	**2018/2019**					**2019/2020**				
Cultivars	GY kg/ha	PY kg/ha	BM kg/ha	HI%	SH%	GY kg/ha	PY kg/ha	BM kg/ha	HI%	SH%
Kwarts	760.5 b	1095.9 b	2122.5 b	39.56 a	68.98 ab	932.2 ab	1616.4	2424.3 b	41.72	58.77
Sellie	1026.9 a	1394.7 ab	2125.3 b	50.17 a	73.07 a	1197.0 a	1848.2	2728.4 ab	46.70	64.51
Opal	1014 a	1476.8 a	2410.3 ab	43.84 ab	68.60 ab	1161.6 a	1819.7	2645.9 ab	46.87	63.22
Oleic	760.5 b	1652.6 a	2688.9 a	42.31 ab	61.77 b	787.3 b	1375.9	3129.4 a	36.42	58.95
SE	64.67	135.78	212.05	3.24	3.54	96.76	191.34	224.84	5.11	4.82
Location										
Univen	1126.6 a	1684.0 a	3178.6 a	36.25 b	67.96	1471.9 a	2403.3 a	4319.2 a	35.07 b	60.98
Syferkuil	767.1 b	1126.0 b	1494.9 b	51.69 a	68.26	567.2 b	926.8 b	1144.8 b	50.79 a	61.77
SE	45.73	96.01	149.94	2.29	2.51	68.41	135.30	158.98	3.61	3.41
F-test probability										
C	**	**	*	*	*	**	ns	*	ns	ns
L	**	**	**	**	ns	**	**	**	**	ns
C x L	**	ns	ns	*	*	**	**	ns	**	ns
CV%	13.66	19.33	18.15	14.72	10.41	18.98	22.98	16.46	23.82	15.72

*Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level, *Significant at p≤0.05, **significant at p≤0.01, ns= Not significant, CV=Coefficient variation, SE= Standard Error for Comparison, GY= Grain Yield, PY= Pod Yield, BM= Biomass, HI= Harvest, SH=Shelling%, C=Cultivar, L=Location.*

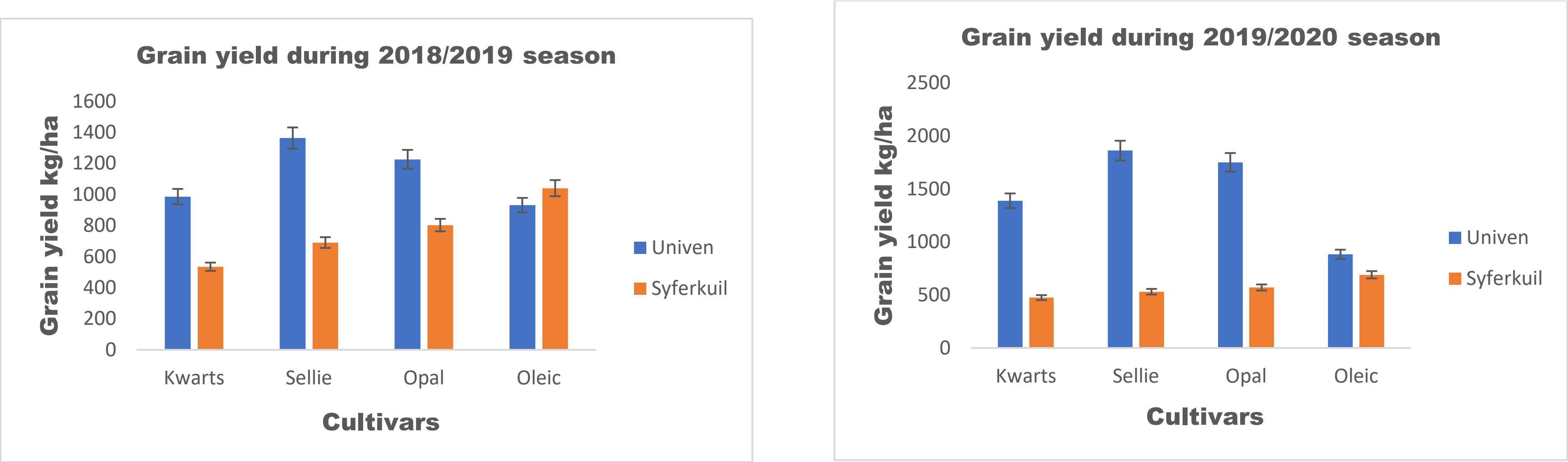

Figure 5: Effects of cultivar x location interaction on grain yield in both seasons.

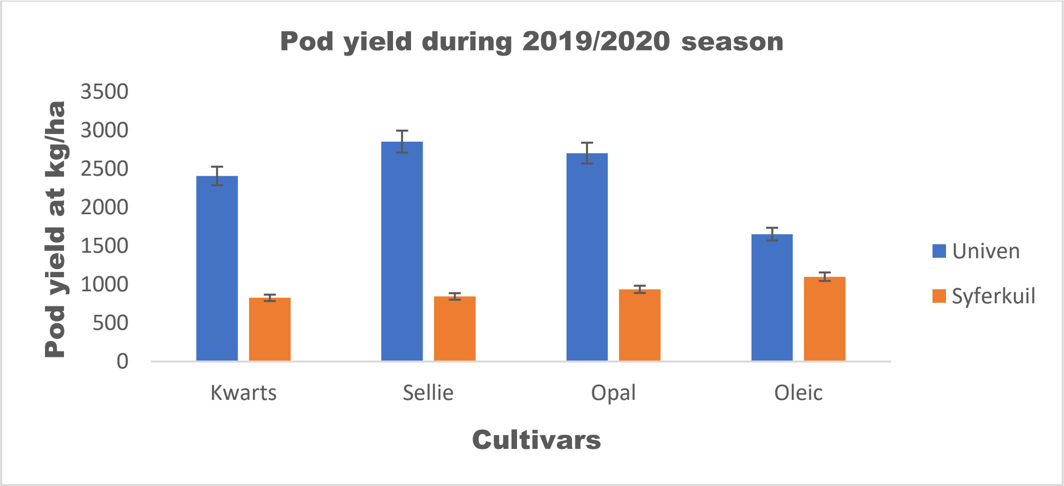

Figure 6: Effects cultivars x location interaction on pod yield in 2019/2020 season.

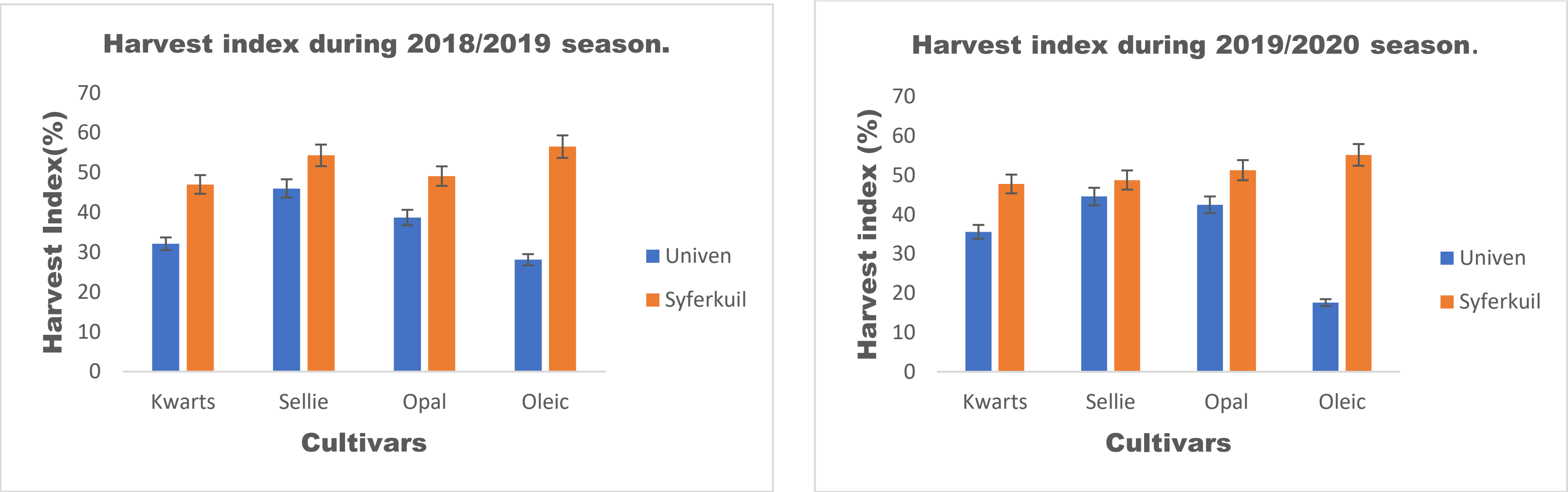

Figure 7: Effects of cultivar x location interaction on harvest index in both seasons.

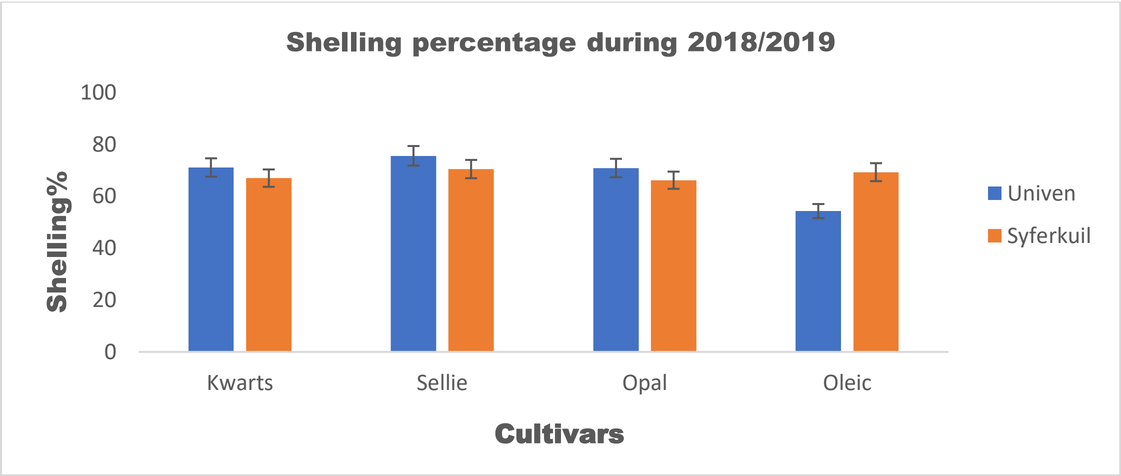

Figure 8: Effects of cultivar x location interaction on shelling percentage in 2018/2019 season.

4.6. Nodule weight per plot.

At Univen, groundnut cultivar had significant effect (p≤0.05) on mean dry nodule weight during both seasons (Figure 9). Cultivar Sellie had the highest mean dry nodule weight per plot (0.183g and 0.173g) in both 2018/2019 and 2019/2020 seasons, respectively. The lowest mean nodule weight was observed in Kwarts (0.115g and 0.120g). However, mean dry nodule weight of Opal was not statistically different from Kwarts, Sellie and Oleic cultivars during both growing seasons (Figure 9). At Syferkuil, groundnut cultivar had significant effect on the dry nodule weight per plot during both seasons. Highest dry nodule weight was also recorded by Sellie (0.182g and 0.170g) while lowest dry nodule weight per plot was recorded by Opal (0.108g and 0.107g) in both seasons (Figure 10). However, Kwarts dry nodule weight per plot was not significant from all cultivars.

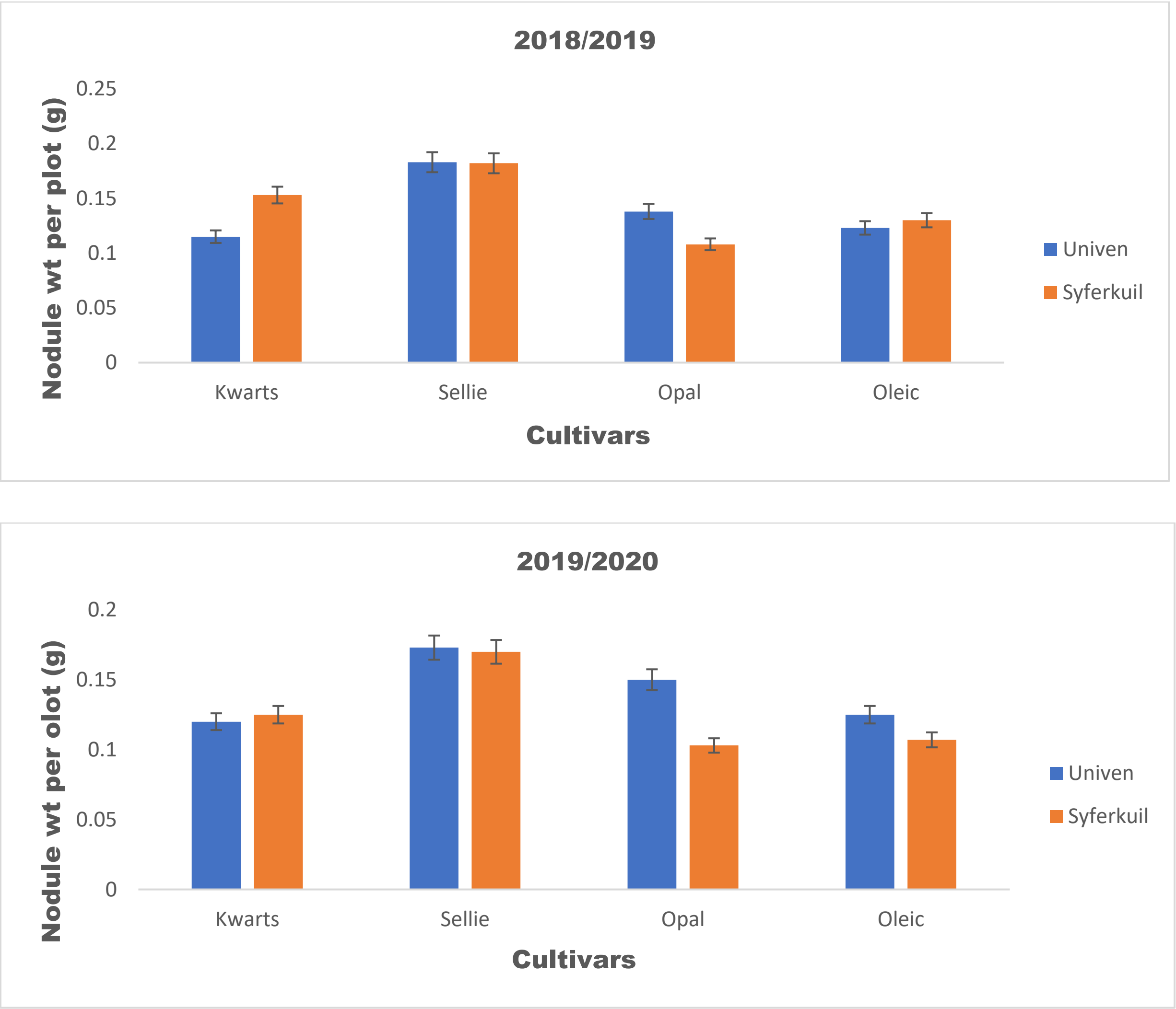

Figure 9: Effect of groundnut cultivar on nodulation during both seasons.

4.7. Effect of groundnut cultivars on Soil moisture content.

4.7.1. Soil moisture content at Univen.

The effect of groundnut cultivar, sampling time and cultivar x sampling time (C x ST) interaction are shown in Table 10 below. Results from this study indicated that the effect of both cultivar and C x ST interactions on soil moisture content were not statistically significant during both growing seasons. Sampling time had significant different ($p \leq 0.05$) on soil moisture content at all soil depths; 0-15 cm, 15-30 cm, and 30-60 cm during 2019/2020 season while in 2018/2019 season, sampling time at 15-30 cm soil depth was not statistically significant (Table 10). Sampling time 10WAP recorded highest soil moisture content at all soil depths (27.99%, 28.24% and 38.11%) as compared to other sampling times, though soil moisture content was not statistically different at 15-30 cm soil depth in 2018/2019 season. During 2019/2020 season, sampling time 8WAP (34.78%, 39.27% and 45.31%) recorded significantly higher soil moisture content at all soil depths compared to other sampling times. Sampling time 6WAP recorded the lowest soil moisture content at all depths during both seasons. In general, 2019/2020 season recorded higher soil moisture content compared to 2018/2020 season. Soil moisture content increased with soil depths at all sampling times among groundnut cultivars. Even though there was no statistically significant difference on soil moisture content among groundnut cultivars, Sellie recorded the highest soil moisture content at all depths in both season (Table 10).

4.7.2. Soil moisture content at Syferkuil.

The effect of groundnut cultivar and sampling time showed significant difference ($p \leq 0.05$) on soil moisture content during both 2018/2019 and 2019/2020 seasons (Table 11). Cultivar Opal recorded the highest soil moisture at all depths in both 2018/2019 (14.09%, 16.34% and 20.17%) and 2019/2020 (14.19%, 16.44% and 21.01%) seasons. However, cultivar effect was only significant at 15-30 cm depth while at 0-15 and 30-60 cm, moisture content was not significantly different among the cultivars during 2018/2019 season. During 2019/2020 growing season, soil moisture content was significant at 15-30 cm and 30-60 cm among groundnut cultivars while at 0-15 cm soil depth, soil moisture content was not statistically different among the cultivars (Table 11). Sampling time 10WAP recorded significantly higher soil moisture at all soil depths in both 2018/2019 (16.91%, 18.01% and 23.06%) and 2019/2020 (20.76%, 22.84% and 27.18%) seasons. In general, soil moisture content increased with soil depth at all sampling time among groundnut cultivars. Furthermore, 2019/2020 recorded higher soil moisture content compared to 2018/2019 season. Cultivar x sampling time interaction had no significant effect on soil moisture content in both 2018/2019 and 2019/2020 seasons (Table 11).

Table 10: Soil moisture content as influenced by cultivar and sampling time at Univen in both growing seasons.

	Soil moisture content (%)					
Season	**2018/2019**			**2019/2020**		
Depth	**0-15 cm**	**15-30 cm**	**30-60 cm**	**0-15 cm**	**15-30 cm**	**30-60 cm**
Cultivars (C)						
Kwarts	22.79	25.62	30.37	26.52	30.12	37.22
Sellie	24.59	27.37	32.62	27.57	29.84	34.40
Opal	24.18	25.02	31.94	27.84	28.99	35.44
Oleic	23.45	26.56	30.55	26.86	29.87	34.38
SE	0.94	1.34	1.91	0.92	0.80	1.35
Sampling Time (ST)						
6WAP	20.40 c	24.61	26.37 b	23.32 c	25.41 d	30.02 c
8WAP	23.92 b	27.04	32.27 ab	34.78 a	39.27 a	45.31 a
10WAP	27.99 a	28.24	38.11 a	31.72 a	32.08 b	40.39 b
12WAP	23.76 bc	25.67	31.21 b	26.69 b	28.65 c	34.36 c
14WAP	21.83 bc	25.86	30.27 b	24.89 b	26.47 cd	30.94 c
16WAP	24.59 b	25.43	29.98 b	25.72 b	27.18 cd	31.19 c
SE	1.15	1.64	2.34	1.13	0.98	1.65
F-test probability						
C	ns	ns	ns	ns	ns	ns
ST	**	ns	**	**	**	**
C x ST	ns	ns	ns	ns	ns	ns
CV %	13.72	17.79	21.07	11.70	9.32	13.21

*Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level, *Significant at p≤0.05, ** highly significant at p≤0.01, ns= Not significant, CV=Coefficient variation, SE= Standard Error for Comparison, WAP=weeks after planting, C=Cultivar, ST=sampling time.*

Table 11: Soil moisture content as influenced by groundnut cultivars and sampling time at Syferkuil in both growing seasons.

	Soil moisture content (%)					
Season	**2018/2019**			**2019/2020**		
Depth	**0-15 cm**	**15-30 cm**	**30-60 cm**	**0-15 cm**	**15-30 cm**	**30-60 cm**
Cultivars (C)						
Kwarts	13.57	14.57 b	19.30	13.79	15.61 b	19.22 b
Sellie	13.80	14.80 ab	19.13	14.08	15.54 ab	19.85 b
Opal	14.09	16.34 a	20.17	14.19	17.20 a	21.05 a
Oleic	14.02	15.71 ab	20.25	14.10	16.44 ab	20.01 a
SE	0.43	0.59	1.06	0.40	0.41	0.79
Sampling Time (ST)						
6WAP	11.57	13.52 c	16.99 b	15.34 c	18.27 b	22.16 bc
8WAP	13.85 bc	16.23 ab	19.98 ab	13.40 d	16.16 c	19.95 c
10WAP	16.91 a	18.01 a	23.06 a	20.76 a	22.84 a	27.18 a
12WAP	13.12 c	13.48 c	17.99 b	8. 60 e	19.82 b	14.10 d
14WAP	13.11 c	14.22 bc	20.48 ab	8.88 e	11.02 d	15.11 d
16WAP	14.67 b	16.66 a	19.76 ab	17.25 b	19.55 b	23.21 b
SE	0.52	0.73	1.30	0.50	0.51	0.96
F-test probability						
C	ns	**	ns	ns	**	*
ST	**	**	**	**	**	**
C x ST	ns	ns	ns	ns	ns	ns
CV %	10.62	13.37	18.63	10.11	8.83	13.41

*Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level, *Significant at p≤0.05, ** highly significant at p≤0.01, ns= Not significant, CV=Coefficient variation, SE= Standard Error for Comparison, WAP=weeks after planting, C=Cultivar, ST=sampling time.*

4.8. Effect of groundnut cultivars on soil mineral Nitrogen.

4.8.1. Soil Nitrate (NO_3^--N) and Ammonium (NH_4^+-N) levels at Univen during both seasons.

Groundnut cultivar, sampling time and cultivar x sampling time (C x ST) interaction effect on soil mineral nitrogen are shown in Table 12 below. Results from this study showed that both cultivar and C x ST interaction had no significant effect on NO_3^--N and NH_4^+-N levels at all soil depths during both 2018/2019 and 2019/2020 growing seasons. Sampling time had significant effect ($p \leq 0.05$) on NH_4^+-N levels in both 2018/2019 and 2019/2020 seasons. NH_4^+-N levels were significantly higher at harvest (89.47 and 94.15 mg/kg) compared to flowering (80.66 mg/kg and 82.87 mg/kg) at both 0-30 cm and 30-60 cm soil depths in 2018/2019, respectively. During 2019/2020 season, NH_4^+-N levels were significantly higher at harvest (90.90 mg/kg) than at flowering (85.30 mg/kg) at 0-30 cm soil depth (Table 12). In general, soil mineral nitrogen (NO_3^--N and NH_4^+-N levels) increased with sampling time at all soil depths in both seasons (Table 12).

4.8.2. Soil Nitrate (NO_3^- -N) and Ammonium (NH_4^+-N) levels at Syferkuil during both seasons.

Results from this study showed that groundnut cultivar and sampling time had significant effect ($p \leq 0.05$) on NO_3^--N and NH_4^+-N levels in 2019/2020 season while in 20218/2019 season, the effect was not significant (Table 13). During second season 2019/2020, Oleic recorded significantly higher level of NO_3^--N (34.39 mg/kg) compared to Sellie (26.47 mg/kg) and Kwarts (25.88 mg/kg) at 30-60 cm. However, Oleic NO_3^--N level was not statistically different from Opal (32.72 mg/kg). During 2019/2020 season, Oleic recorded highest levels of NH_4^+-N at both 0-30 cm (70.66 mg/kg) and 30-60 cm (90.37 mg/kg) soil depths. However, Oleic NH_4^+-N was not statistically different from that of Opal (69.77 mg/kg) and Sellie (66.77 kg/ha) at 0-30 cm depth. In general, Oleic recorded highest levels of NO_3^--N and NH_4^+-N while Kwarts recorded least levels at all depths during both growing seasons (Table 13). Furthermore, NO_3^--N and NH_4^+-N levels increased with sampling time at all soil depth during 2019/2020 season. In 2019/2020 season, Harvest produced 26.78% and 20.69% more NO_3^--N level compared to Flowering at both 0-30 cm and 30-60 cm soil depths, respectively. At 0-30 cm soil depth, harvest also produced 5.48% more NH_4^+-N level compared to flowering in 2019/2020 season. During 2018/2019 season, high levels of NO_3^--N and NH_4^+-N was recorded at harvest compared to flowering stage though the difference was not statistically different. Cultivar by sampling time interactions had no significant effect ($P \geq 0.05$) on NO_3^--N and NH_4^+-N levels in both seasons (Table 13).

Table 12: Soil mineral Nitrogen as influenced by groundnut cultivars and sampling time at Univen during both growing seasons.

	Soil mineral Nitrogen (mg/kg)							
	NO_3^--N				NH_4^+-N			
Season	**2018/2019**		**2019/2020**		**2018/2019**		**2019/2020**	
Depth	**0-30 cm**	**30-60 cm**	**0-30 cm**	**30-60 cm**	**15-30 cm**	**30-60 cm**	**0-30 cm**	**30-60 cm**
Cultivars (C)								
Kwarts	40.60	41.46	36.10	23.89	83.50	86.39	89.48	92.02
Sellie	51.44	47.38	46.05	47.93	87.23	90.12	90.61	91.04
Opal	41.65	42.65	37.44	38.11	83.90	89.59	86.02	96.47
Oleic	45.60	39.94	30.32	32.75	85.67	87.94	86.27	90.94
SE	8.10	9.52	7.70	9.97	2.56	3.59	2.11	4.21
Sampling Time (ST)								
F	42.46	42.53	34.68	32.87	80.66 b	82.87 b	85.30 b	89.82
H	43.19	47.38	40.28	38.47	89.47 a	94.15 a	90.90 a	95.52
SE	5.86	6.89	5.44	7.05	1.81	2.97	1.50	2.98
F-test probability								
C	ns	ns	ns	ns	ns	ns	ns	ns
ST	ns	ns	ns	ns	**	**	**	ns
C x ST	ns	ns	ns	ns	ns	ns	ns	ns
CV%	36.08	44.42	41.09	55.89	6.03	8.10	4.80	9.09

*Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level, *Significant at p≤0.05, ** highly significant at p≤0.01, ns= Not significant, CV=Coefficient variation, SE= Standard Error for Comparison, F- flowering, H- harvest, C=Cultivar, ST=sampling time.*

Table 13: Soil mineral Nitrogen as influenced by cultivars and sampling time at Syferkuil during both locations and seasons.

	Soil mineral Nitrogen (mg/kg)							
	NO_3^--N				NH_4^+-N			
Season	**2018/2019**		**2019/2020**		**2018/2019**		**2019/2020**	
Depths	**0-30 cm**	**30-60 cm**	**0-30 cm**	**30-60 cm**	**15-30 cm**	**30-60 cm**	**0-30 cm**	**30-60 cm**
Cultivars (C)								
Kwarts	26.87	34.00	24.53	25.88 b	78.78	77.76	63.38 b	68.50 b
Sellie	29.18	31.80	21.89	26.47 b	81.14	81.65	66.32 ab	69.65 b
Opal	32.78	35.81	22.53	32.72 a	79.60	82.41	69.77 ab	71.34 b
Oleic	34.78	41.85	25.88	34.39 a	82.02	82.45	70.66 a	90.37 a
SE	4.05	4.44	3.38	2.01	4.51	4.07	2.43	6.78
Sampling Time (ST)								
F	31.17	35.97	20.91 b	27.06 b	82.83	83.86	65.74 b	73.16
H	30.64	35.76	26. 51 a	32.66 a	77.93	78.27	69.34 a	76.76
SE	2.86	3.14	2.39	1.41	3.19	2.88	1.72	2.97
F-test probability								
C	ns	ns	ns	**	ns	ns	*	**
ST	ns	ns	*	**	ns	ns	*	ns
C x ST	ns	ns	ns	ns	ns	ns	ns	ns
CV%	26.20	24.74	28.55	13.43	11.23	10.04	7.18	18.10

*Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level, *Significant at p≤0.05, ** highly significant at p≤0.01, ns= Not significant, CV=Coefficient variation, SE= Standard Error for Comparison, F- flowering, H- harvest, C=Cultivar, ST=sampling time.*

4.9. Crop simulation.

The performance of groundnut cultivars and the accuracy of the APSIM-peanut model simulations were evaluated by running the independent data sets collected during 2018/2019 and 2019/2020 growing seasons at two locations (Univen and Syferkuil) in Limpopo Province.

4.9.1. observed and simulated biomass yield at Univen and Syferkuil.

Observed and simulated dry matter biomass and yield at Univen and Syferkuil sites during both seasons are presented in Table 14. At Univen, APSIM simulated above-ground dry matter biomass for all cultivars for the 2019/2020 season with higher accuracy, when compared to the model performance for the 2018/2019 season (Table 14). The model overestimated dry matter biomass for most cultivars (except for Kwarts) in both seasons. The differences between observed and simulated were higher in 2018/2019 (26.29%) compared to 2019/2020 with the average of difference of 6.90% season. Overall RMSE of 914.89 kg/ha and coefficient of efficacy (R^2) of 0.37 was recorded representing both seasons.

At Syferkuil, the calibration of the model improved its ability to simulate dry matter biomass during both 2018/2019 and 2019/2020 growing seasons (Table 14). However, APSIM was better for the 2019/2020 season. Similarly, as observed at Univen site, the model calibration tends to overestimate dry matter biomass, especially 2019/2020 season. The average difference (error) among simulated and observed dry matter yield values was 8.52% and 27.25% for both 2018/2019 and 2019/2020 growing season. Overall, RMSE of 286.63 kg/ha and coefficient of efficiency of 0.55 was recorded for both seasons.

4.9.2. Observed and simulated grain yield at Univen and Syferkuil.

Comparison between the observed and simulated grain of both sites during 2018/2019 and 2019/2020 are presented in Table 15. In general, the model accurately predicted grain yield at Univen during both growing seasons with the overall coefficient of efficiency (R^2) of 0.86 for both seasons. At Univen, APSIM also overestimated simulated grain of most cultivars (exception of Kwarts), especially with 2018/2019 season. Overall RMSE value of 271.65 kg/ha was recorded for both seasons with also a good range of average difference (error) among simulated and observed grain yield values of 4.98% and 7.69%.

Table 14: Comparison of simulated and observed biomass during 2018/2019 and 2019/2020 growing period at both Univen and Syferkuil sites.

		Univen			**Syferkuil**		
Seasons	**Cultivar(s)**	**Sim (kg/ha)**	**Obs (kg/ha)**	**Diff (%)**	**Sim (kg/ha)**	**Obs (kg/ha)**	**Diff (%)**
2018/2019	Kwarts	2525.3	3063.3	-17.56	1195.5	1181.7	1.16
	Sellie	4081.8	2979.5	36.99	1652.0	1271.1	30.0
	Opal	4430.8	3172.5	39.66	1660.5	1648.1	0.75
	Oleic	5111.4	3499.1	46.07	1919.3	1878.7	2.16
2019/2020	Kwarts	3752.0	3816	-1.67	1323.8	1032.4	28.23
	Sellie	5319.9	4355.4	22.14	1323.1	1101.5	20.12
	Opal	4191.8	4112	1.94	1345	1179.9	13.99
	Oleic	5254.4	4993.3	5.22	1856.2	1265.5	46.68
	RMSE	914.89 kg/ha			286.63 kg/ha		
	R^2	0.37			0.67		

Obs=observed, Sim=simulated, R^2*=coefficient of determination, Diff = difference. RMSE= root mean square error.*

At Syferkuil, the model better performed at simulating grain yield, with overall coefficient of efficiency (R^2) of 0.95 for both 2018/2019 and 2019/2020 growing season (Table 15). For the 2018/2019 season, APSIM slightly overestimated grain yields for Kwarts and Sellie, but underestimated grain yield for Opal and Oleic. The groundnut grain yield was consistently overestimated by the model during the 2019/2020 season. An overall RMSE of 88.17 kg/ha with average differences (errors) of -3.30% and 12.06% between simulated and observed biomass yield were obtained for both the 2018/2019 and 2019/2020 growing seasons. The results from this study showed that APSIM has the capability to capture the C x L interactions of groundnut.

Table 15: Comparison of simulated and observed grain yield during 2018/2019 and 2019/2020 growing period at both Univen and Syferkuil sites.

Seasons	Cultivar(s)	Univen			Syferkuil		
		Sim (kg/ha)	**Obs (kg/ha)**	**Diff (%)**	**Sim (kg/ha)**	**Obs (kg/ha)**	**Diff (%)**
2018/2019	Kwarts	755.3	986.3	-23.42	548.5	534.7	2.58
	Sellie	1836.8	1363.3	34.73	746.5	690.5	8.11
	Opal	1270.3	1225.7	3.63	747.2	802.8	-6.93
	Oleic	1091.3	931.2	17.19	863.9	1040.6	-16.98
2019/2020	Kwarts	1305.7	1357.6	-3.82	533.5	475.30	12.24
	Sellie	2389.9	1867.2	27.99	597.3	531.25	12.43
	Opal	1848.9	1752.9	5.46	601.6	571.13	5.34
	Oleic	893.8	883.5	1.17	817.1	691.07	18.24
	RMSE	271.65 kg/ha			88.17 kg/ha		
	R^2	0.85			0.80		

Obs=observed, Sim=simulated, R^2=coefficient of determination, Diff = difference. RMSE= root mean square error.

CHAPTER 5: DISCUSSION.

5.1. Effect of groundnut cultivars on the groundnut performance.

5.1.1. Dry matter biomass.

Results from this study showed that groundnut genotypes had no significant effect ($p \geq 0.05$) on dry matter biomass during both flowering and harvest at the Univen site in both growing seasons. Cultivars exhibited similar vegetative growth and resulted in the similar biomass, this could be due to the fact that both cultivars planted are high yielding and tolerant to high temperatures. Similar findings were reported by Adu-Gyamfi *et al*. (2012) and Adezebra (2013) after evaluating 8 groundnut cultivars and finding no significant differences in their biomass at both flowering and physical maturity stages. At Syferkuil, groundnut cultivar had significant effect ($p \leq 0.05$) on biomass at physical maturity in 2018/2019 and at the flowering stage in 2019/2020 season. Oleic recorded the highest biomass while Kwarts recorded the lowest biomass at both stages. High biomass observed in Oleic could be due to more plant density per plot than the other cultivars, resulting in efficient use of intercepted solar radiation for higher biomass production. This observation agrees with the findings of Adezebra (2013) who reported that biomass yield in soybeans increase with plant density. The findings are inconsistent with those made by Mbowa (2013), who found a significant effect on biomass among four groundnut cultivars examined in two locations in Eastern Cape province. Mokgehle et al. (2014) also observed a significant effect on biomass among 25 genotypes evaluated in Mpumalanga Province South Africa.

Results from this study indicated that the interaction effect of genotype by location had no significant effect ($P \geq 0.05$) on biomass. The Opal cultivar that produced high biomass at Univen also produced high biomass at Syferkuil. Location had a significant effect ($p \leq 0.05$) on biomass in both seasons. However, the magnitude of the location effect was greater than the cultivar effect, indicating that location effects (different environments) accounted for most of the variation in biomass among cultivars. In general, Univen produced more biomass compared to Syferkuil during both the 2018/2019 and 2019/2020 seasons. Since rainfall and daily maximum temperatures varied between the two study locations, the difference in biomass could be attributed to environmental conditions like temperature and rainfall. Groundnut is a warm season crop requiring abundant sunshine and enough soil moisture from the beginning of flowering up to two weeks before harvest for normal development. On the other hand, extremely high temperatures and low rainfall are detrimental to groundnut growth and development, resulting in reduced dry matter production, partitioning of dry matter to pods, and pod yields due to severe decrease in the amount of water available for transpiration and photosynthesis (Ijaz *et al*., 2021).Therefore, high biomass observed in Univen could be attributed to the adequate temperatures and solar radiation, while inadequate soil moisture (or drought) from low rainfall at Syferkuil could have impaired groundnut growth and biomass. The soil pH at Univen was optimum for groundnut production. Furthermore, the higher SOC could have contributed to the improved aboveground biomass. These results corroborate with those of Mokgehle *et al.* (2014) who found a significantly positive correlation between groundnut biomass and maximum temperature and Hamidou *et al*. (2013) who observed higher biomass in seasons with high temperatures than those with moderate temperatures.

5.1.2. Grain and pod yield.

The features that groundnut improvement programs target the most globally are yield and yield contributing parameters. Grain (seeds) and pod yield were the important yield-contributing parameters that were measured in this study. At Univen, results demonstrated that groundnut cultivar had significant effect ($p \leq 0.05$) on both pods and grain yield in the 2019/2020 season whereas in the 2018/2019 only grain yield was significant (Table 8). At Syferkuil, groundnut cultivar showed a significant effect on grain and pod yield during the 2018/2019 season while in 2019/2020 season, significant difference was only observed in grain yield (Table 8). Cultivars performed differently in the growing environments, and thus typically indicated large variation among them. Large variations among cultivars for grain yield in this study can be attributed to traits like as seed size, production potential, and disease tolerance. For example, Sellie and Opal have a higher fraction of seeds, a higher yield potential, and are resistant to early and late leaf spot, when compared to other cultivars (ARC,2017). Results from this study agree with the findings of Yol and Uzun (2018) and Mokgehle *et al*. (2014) who obtained differences in grain and pod yield among cultivars but is in contrast with the findings of Adezebra (2013) in that, no significant differences were found to exist among cultivars on pod and grain yield.

At Univen, the Cultivar Sellie produced significantly higher grain and pod yield, whereas Oleic produced significantly higher grain and pod yield at Syferkuil in both seasons (Table 8). Similar observations were made by Mbonwa (2013) who reported that there are variations in cultivars responses to environmental changes and different locations. High grain yield recorded by Sellie and Oleic at both locations could be attributed to the high number of pods per plant that translated to the extensive grain filling leading to larger and heavily matured seeds and that the cultivars are more effective in partitioning production and assimilate it to produce more seeds (Mbowa, 2013). Cultivar Kwarts was recorded to produce low grain and pod yield in both seasons and locations.

The poor performance of Kwarts at both locations could be due to poor adaptation to either environment. Results for Kwarts in this study contradict the findings of Mbowa (2013) who found that Kwarts had a high grain yield and was recommended by South African ARC, Grain Crop Institute as the best yielding cultivar in arid conditions. Therefore, poor performance of Kwarts in both sites could well have been as a result of contrasting soil and temperature conditions under which the studies were conducted. Results from this study also revealed that cultivar's ability to produce grain and pod yield does not always depend on the biomass produced but also on its genetic make-up ability. For example, Sellie produced low biomass at Univen compared to Oleic at the same location, but Sellie had the highest grain yield (Table 8). These findings confirm the results obtained by Mbonwa (2013) who reported that cultivar ICGVSM-90087 produced less seeds compared to other cultivars despite its highest dry matter biomass in Mpumalanga province. In general, cultivars that produced the highest pods also produced the highest grain yield. This disagrees with the finding of Adezebra (2013) who found that cultivar T3 recorded high pod yield and low grain yield. However, the genotypes used in the studies were different, also, the environments and soil fertility varied. This provides evidence to suggest that crop plants react differently to environmental stresses and adopt different strategies to overcome the stress events occurring at a particular location (Yol and Uzun.,2018).

Results from this study showed that the effects of cultivar by location interaction were highly significant on grain and pod yield (Table 9). Similar results where results were reported by Jahanzaib *et al*. (2019) and Temesgen *et al*. (2015) who evaluated 8 genotypes at six different locations and observed high significant effect of C x L interaction on grain and pod yield. The results are in conformity with the findings of Santos *et al*. (2012) who also found C x L interaction effect for grain yield of 7 groundnut cultivars at 6 different locations but contradicts the findings of Yol and Uzun (2018) who reported that C x L interaction yield had no significant on grain and pod yield. In this study behavior of tested cultivars was not consistent with different environments, indicating that some cultivars performed better than others and their yield potential differed from location to another. Dolinassou *et al.* (2016) indicated that groundnuts are sensitive to changes under growing conditions and their yields are very much affected by the environment. Therefore, in this study, pod and grain yields were influenced by varied environmental factors like soil types, rainfall pattern and temperature which induce C x L interaction. During both seasons, the magnitude of the C x L interaction effect was similar or greater than the magnitude of the cultivar effect for both traits (pods and grain) indicating that, when all other conditions are favorable, grain and pod yield production depends on cultivar planted in that location. These results supported by the findings of Hoffman *et al*. (2018) and Makinde *et al*. (2013) who reported that when C x L interaction is highly significant for a specific trait such as grain and pod yield in this study, no valid comparison of cultivar performance across all environments can be made. Therefore, comparisons can only be made in each location separately. This may be helpful in breeding programs because a significant C × L interaction for grain and pod yield promote selection effectiveness for a particular location (Yol and Uzun, 2018). Therefore, the most suitable cultivars with respect to grain and pod yield, were Sellie at Univen and Oleic at Syferkuil environment.

Location had a significant effect ($p \leq 0.05$) on grain and pod yield in both seasons (Table 9). In this study, location contributed most to overall yield performance of groundnut cultivars. For example, Univen produced more grain and pod yield compared to Syferkuil and this could be due to the varying amounts of rainfall received at the study sites. Ijaz et al. (2021) reported that Optimal rainfall amount and distribution ensures proper development of the groundnut plant in subsequent stages (pegging and pod development stages), whereas Insufficient rainfall during flowering and pegging stage reduces groundnut pod and grain yield. High yields at Univen might be attributed to the moderately good rainfall of 795.9mm and 1066.3 mm and low yields at Syferkuil could be due to low rainfall received of 341.3 mm and 403.7 mm in both seasons (Figures 3 and 4). At Syferkuil, low rainfall of 44.6 mm and 87 mm during the flowering, pegging, and pod formation stages of groundnut at the end of December and beginning of January may have affected the plant's ability to absorb nutrients, resulting in low grain and pod yield. Similar findings were made by Semalulu *et al.* (2014) who reported the effect of drought stress on plant nutrient uptake, particularly during the pod filling reproductive stage. Low yields at Syferkuil could also be due to poor weed control of the plots compared to Univen sites due to a shortage of funds during the trials. Ngirazi et al. (2017) reported that weeds are a significant limiting factor to the production of legumes and are also a significant depressant due to competition with the main crop for resources including nutrients, moisture, light, and space resulting in decreased crop growth and yield. This was confirmed by Adu-Gyamfi *et al*. (2012) who reported lower yields of 192 kg/ha and 688 kg/ha (lowest and highest) obtained from the practice of weeding once during cultivation. Low grain yield could also be attributed to animal pests (squirrel and monkey) which were eating the pods and burrowing next to the roots exposing pods to high temperatures which resulted in empty and immature pods.

5.1.3. Harvest index and Shelling percentages.

Harvest index (HI) represents the portion of total biomass partitioned into seeds and has been identified as a mechanism for drought tolerance in groundnut (Banavath *et al*., 2018). Results from this study showed that groundnut cultivars had significant effect on HI at Univen while at Syferkuil the effect was not statistically different (Table 8). Location and C x L interaction showed a significant effect during both growing seasons (Table 9). Similar results were reported by Hamidou *et al*. (2012) who observed significant effect of cultivar, location, and C x L interaction on Harvest Index. Yeshiwas (2019) also reported a significant of cultivar, location, and C x L interaction on harvest index when 15 cultivars were evaluated in 6 locations. At Univen, Sellie recorded the highest HI while at Syferkuil Oleic recorded the highest HI during both growing seasons (Table 8). In general, all cultivars recorded high HI at Syferkuil compared to Univen site, however, Sellie recorded high HI in both locations. The low harvest index observed at Univen may have contributed to high moisture content which promoted biomass production. Adezebra (2013) showed higher biomass production, low harvest indices at soil moisture contents below 70%, and higher harvest indices at soil moisture contents between 30 and 40%. Low HI at Univen, could be due to high temperatures which favored biomass growth. Previous studies revealed that groundnut's HI decreased in high temperature conditions, indicating that the high temperature had an impact on the reproductive processes, but not on plant growth (Hamidou *et al*., 2013). High HI in Syferkuil, could be due to drought stress combined with high temperature during flowering, pegging and pod filling stages resulted in low grain yield (Figure 8). Hamidou *et al*. (2013) reported that groundnut reproductive processes are susceptible to high temperature. Raising soil and air temperatures caused groundnut seeds and the number of pods to be produced to decrease. Luo *et al*. (2020) reported that grain yield declined by up to 56–85% when peanut was exposed to drought at seed-filling stage. High temperature with limited water availability at Syferkuil, decrease groundnut ability to partition biomass into harvestable yields, which led to a reduced grain yield and greater HI. Harvest indices range from this study was similar to that reported by Yeshiwas (2019) of 29.4% and 57.84% representing lowest and highest.

The shelling percentage showed significant variation among cultivars only at Univen during 2018/2019 growing season while at Syferkuil the effect was not significant (Table 8). Cultivar x location interaction effect was significant on shelling percentage (Table 9). Results from this study agree with the findings of Yeshiwas (2019) and Yol and Uzun (2018) who found significant effect of cultivar, location and C x L interaction on shelling percentage when 15 cultivars were evaluated in 6 different locations. In this study, shelling percentage was strongly influenced by cultivar and environmental factors, and positively related to pod yield in groundnuts. cultivars that recorded highest shelling percentage also recorded highest pod and seed yield (Table 8 and 9). Shelling percentage and seed yield obtained in this study confirmed the results of Mbowa (2013) who reported a correlation between the quantity of filled pods and shelling percentage. In general, Univen recorded highest shelling percentage compared to Syferkuil. More shelling percentage recorded at Univen could be that cultivars recorded more seed and pod weight during both seasons. Low shelling percentage recorded by cultivars at Syferkuil could be attributed to the level of immaturity of pods and some which were empty and shrieked kernels. This confirmed the findings of Yeshiwas *et al*. (2019) who found out that kernel yield was directly related to shelling percentage, so the higher the shelling percentage the higher the kernel yield of that cultivar. In this study, high shelling percentages indicated greater seed weight, therefore, cultivars with high shelling percentages are preferable.

5.1.4. Nodulation.

The result on nodule dry weight differed significantly ($p \leq 0.05$) among the cultivars and across the locations with Sellie recording a significantly higher nodule dry weight at Univen during both growing season while at Syferkuil, Oleic recorded highest nodule dry weight. However, in both locations, Kwarts recorded significantly lower nodule dry weight. These results corroborate the work of Lal *et al*. (2021) and Moji *et al*. (2020) who both evaluated groundnut cultivars under two different environmental conditions and found significant difference on nodule dry weight among groundnut cultivars. The nodule dry weight ranges of this study were above that reported by Adazebra (2013) and Lal *et al*. (2021) with the ranges of 0.029 g to 0.07 g and 0.01 to 0.14 g, and below those reported by Moji *et al*. (2020) of 0.13 g and 0.27 g representing lowest and highest, respectively. The higher nodule weight observed in Sellie and Oleic could be attributed to the higher percentage of effective nodules, greater number of nodules and mostly the morphological variations existing among groundnut cultivars. Since cultivars performed differently in both locations, this was evidence that the environmental factors including rainfall, temperature, and the soil properties of the growing area have a significant impact on how groundnut cultivars respond to nodulation. Similar trends were reported by Lal *et al*. (2019) and Ajay *et al*. (2020), who found higher contribution of environment against cultivar for nodule weight, suggesting that cultivar selection based on multi environments rather than single environment is the best strategy to achieve selection gain.

5.2. Effect of groundnut cultivars on soil moisture content.

Results from this study showed that groundnut cultivar significantly affected soil moisture content at Syferkuil while at Univen, the cultivar effect was not significant. High soil moisture recorded by Opal (Table 10) could be due to its reduced leaf area and deep roots, which boasted water usage efficiency during growing period since it also recorded high grain yield and HI. Banavath *et al*. (2018) reported that groundnut reduce leaf area to improve transpiration efficiency and increase root length to extract water from lower depths, which results in lesser biomass and more seeds. At both locations, soil moisture content was significantly affected by sampling time (Tables 10 and 11). High soil moisture content on sampling times 8 and 10 WAP could be attributed to the high amount of rain received during February at both locations (Figures 3 and 4), which resulted to adequate soil moisture during both growing seasons. Comparing sites, Univen recorded high moisture content during both growing seasons than Syferkuil. High rainfall received at Univen compared to Syferkuil attributed to high soil moisture content in Univen. In 2018/2019 and 219/2020, Univen received higher rainfall by 454.6 mm and 662.63 mm, respectively, resulting in higher water supply compared to Syferkuil. Furthermore, high soil moisture content at Univen may be due to rapid growth of groundnut cultivars observed during field trials which resulted in greater vegetation cover when compared to Syferkuil which had lower biomass accumulation with less vegetation cover (Figure 2). Groundnut vegetation may have contributed to lower daytime soil temperatures, which in turn reduced moisture loss through evaporation (Luo *et al*., 2020). In addition, Univen is characterized by high clay content (Table 1) which contributed to high soil water holding capacity compared to sandy soil at Syferkuil with low soil water holding capacity.

5.3. Effect of groundnut genotypes on soil mineral nitrogen.

Effect of groundnut cultivar on soil mineral nitrogen varied widely across locations and seasons. Groundnut cultivars showed significant effect on soil mineral nitrogen (SMN) at Syferkuil during 2019/2020 growing season (Table 13). Oleic and Opal resulted in high soil mineral nitrogen compared to other cultivars at Syferkuil. High soil mineral nitrogen recorded by Oleic, and Opal could be due to high biological nitrogen fixation by groundnut cultivars while Kwart's low SMN may have been caused by the plant obtaining more nitrogen from the soil to meet its N requirements during growing period. Additionally, Kwarts might have produced ineffective nodules which led to reduced BNF and increased plant reliance on soil N throughout the reproduction phases (Mokgehle *et al,* 2014). Results from this study showed that the cultivar Oleic which obtained the most biomass recorded the highest amount of SMN, while Kwarts recorded the lowest amounts of SMN and biomass production. This could suggest that Kwarts fixed less N due to lesser biomass resulted in low SMN. These findings are corroborated by Mokgehle *et al*. (2014) observation, which indicated that high nitrogen fixing cultivars contributed the most symbiotic N and promoted plant growth and grain yield while low nitrogen fixing cultivars showed reduced plant growth and decreased grain yield. Studies by Awadalla and Abbas (2017) have indicated that pod yield and biomass produced by groundnuts were strongly correlated with nitrogen fixation. The 4 groundnut cultivars studied in this study varied in their plant growth, which is consistent with the findings of Mokgehle *et al*. (2014) for 25 groundnut cultivars in three locations at Mpumalanga Province, South Africa.

Sampling time (flowering and harvest) showed significant difference on soil mineral nitrogen at both locations (Tables 12 and 13). However, interaction effect of cultivar x sampling time was not significant. At Univen, NO_3^--N and NH_4^+-N levels significantly increased with sampling time (Table 12). The increased soil mineral nitrogen at harvest may be due to mineralization of nitrogen rich groundnut residues (leaves) and possibly high nitrogen fixation by groundnut cultivars (Mokgehle *et al*., 2014). Furthermore, application of starter nitrogen combined with phosphorus fertilizers applied at planting could have promoted BNF and attributed to increased soil mineral nitrogen at harvest. These results are consistent with those of Tekulo *et al*. (2020) who found that applying 46 P kg/ha and 15 N kg/ha as a starter at planting resulted in higher soil N content at harvest. Previous studies indicated that under poor soil conditions, it is advisable to apply starter N and P fertilizers at low rates in order to promote BNF efficiency and plant root growth and development (Argaw, 2017 and Pourranjbari Saghaiesh *et al*., 2019). However, Large N fertilizer applications restrict BNF by causing the growth of ineffective nodules, which lowers the nitrogen content of the soil at harvest (Aslani and Souri, 2018; Naiji and Souri, 2018). This could be the reason why soil mineral nitrogen at flowering was lower. Cultivars could have used soil N and fix less to save nitrogen for pod filling since nodulation may be suppressed by large pools of available soil nitrogen during flowering stage. This study indicated that application of starter N (30 kg/ha) and P (50 kg/ha) fertilizers enhanced soil mineral nitrogen at harvest. These results are contradicted with those of Tekulo *et al*. (2020) who observed lowest soil mineral nitrogen when 30 N kg/ha and 49 P kg/ha applied as a starter. This study indicated that groundnut crop is crucial for BNF and increases the nitrogen level of the soil after harvest, benefiting succeeding crops.

At Syferkuil, soil mineral nitrogen decreased with sampling time, as a result, flowering recorded high soil mineral nitrogen levels than harvest. This could be due to loss of soil N through ammonia volatilization and denitrification facilitated by high temperatures combined with drought. Ullah *et al*. (2020) found that BNF reduction in groundnut was proportional to the levels of drought stress. Therefore, low rainfall and high temperature could in part, account for the observed decreased SMN at harvest. For example, there was a rainfall differential of 454.6 and 662.63 mm between Univen and Syferkuil during both seasons. Therefore, the lack of soil moisture (or drought) caused by low rainfall Syferkuil may have hindered nodulation and reduced nitrogen fixation in the groundnut nodules that had existed, increasing the legume's dependence on soil N for its N nutrition. This might be as a result of a plant's inability to utilize soil nitrogen efficiently, which arises from roots finding it challenging to mine soil nitrogen in dried soil. Low SMN could also be attributed to by nitrogen leaching coupled with nutrient uptake. The Syferkuil soils sandy loam texture may have made it easier for mineral nitrogen, particularly NO_3, to leach outside the top part of the profile and into the lower portions of the soil profile (Tekulu *et al*., 2020).

5.4. Simulated dry matter above-ground biomass and grain yield.

APSIM has shown capabilities in simulating groundnut cultivars in response to two different locations with an acceptable degree of accuracy, given the growing conditions for the two seasons considered in this study. There was a significant correlation between the observed and simulated dry matter biomass in the 2019/2020 planting season at both locations. However, at Syferkuil, APSIM tend to overestimate dry matter biomass, a smaller gap (between observed and simulated) which are within the acceptable range shown by a reasonable coefficient of efficiency (R^2) of 0.67. At Univen, the model overestimated dry matter biomass, but there was a lower gap, and despite the low coefficient of efficiency (R^2) of 0.37 the predicted dry matter was within the acceptable values resulting in a reasonable accuracy with RMSE of 286.63 kg/ha and differences between observed and simulated of less than 26.29% which are within fair dry matter predicted by the model. Comparable findings were made by Palmero *et al*. (2022) who found very low coefficient of efficiency (R^2) of 0.02 for dry matter biomass while the error difference between simulated and observed was 21.20%.

Overestimation of the dry matter biomass at both locations could be attributed to the shortage of weather data since weather stations at Syferkuil and Univen were sometimes not operating and unable to record data for extensive periods during growing seasons. Additionally, there were multiple pests observed during the experiment such as monkey, squirrels, termites, and late leaf sports that the APSIM model did not take into consideration which could have affected groundnut biomass and grain yield. When comparing grain yields at the field scale between observed and predicted, simulations of groundnut grain production was reasonable over the two sites; with overall R^2 of 0.80 and 0.86 for both sites and seasons indicated good agreement between model predictions and field trials observations (Hoffman et al, 2018). However, at Syferkuil, model underestimated grain yield during 2018/2019 with a lower error difference of -3.30%, and since the predicted and observed resulted in good R^2 of 0.80 and low RMSE of 88.17kg/ha, therefore, the error was within the acceptable range. Underestimated grain yield could be due to a lack of irrigation data which might have introduced the large biases in simulated and observed grain yield since the field was irrigated after planting for the germination of seeds. However, the results showed that the APSIM-groundnut model performed well during evaluation and validation under the specified set of conditions and was able to reasonably represent the overall impact of management on the productivity of groundnuts across different locations and seasons. This can be used to design precise agronomic practices for the sustainable yield of groundnut crop in semi-arid climatic conditions (Holzworth *et al.,* 2018).

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS.

The main goal of the study was to identity suitable cultivars for different agroecological zones of Limpopo Province of South Africa. In this study, cultivar showed significant differences in seed and pod yield across locations. This demonstrated the existence of performance variation for yield among the cultivars studied, allowing for the identification of high yielder cultivars for possible use in those locations. This generally means that the cultivars respond to different environment differently across locations, resulting in the identification of a specific cultivar for a specific location. This study's highly significant effects of location, cultivar, and C x L interaction on grain yield indicate a major impact of the environment on the biological performance of groundnut cultivars in both locations. Therefore, selection for best cultivar must be specific to the screening environment. In this study, Sellie was found to be suitable in the climatic conditions of the Thohoyandou region (Univen) since it produced the highest seed yield in both seasons while Oleic was found to be suitable in the climatic conditions of Syferkuil. Opal also was one of the high-yielding cultivars at both locations and, therefore, farmers in both locations can use this cultivar since it showed good seed yield in both environments and produced consistently from year to year. This study's highly significant effect of location revealed that groundnut cultivars performed best at Univen regardless of their genotypic variability. Therefore, Univen was found to be a better location for groundnut production while at Syferkuil, mitigation measures like irrigation and soil nutrient management should be implemented by farmers in order to obtain higher yields. High biomass, pod yield, HI, and shelling percentage were also produced by the superior cultivars in addition to high seed yield. confirming that superior cultivars chosen for each location will be reliable to smallholder farmers in Limpopo Province when unreliable rainfall is delayed. However, Oleic showed greater biomass at both locations, therefore farmers can use this cultivar for fodder production. Superior cultivars also influenced soil moisture retention, nodulation, and soil mineral nitrogen. Therefore, identified cultivars at each location will result in adequate soil moisture and soil nutrients and can make a significant N contribution to cropping systems of the studied locations resulting in reduced costs and higher yields.

The APSIM-peanut model was able to accurately simulate grain and biomass yield for four cultivars grown at various locations of Limpopo Province. The model generally produced acceptable results for grain yield across both seasons and locations. The results suggest that APSIM has the capability to capture the C x L interactions of groundnut in order to simulate grain yield and biomass at both locations. The model can be used to direct other strategies for increasing groundnut production in Limpopo Province. However, there is a need for more research to be conducted to make sure that the optimal conditions for groundnut growth are guaranteed in order to conduct calibration and validation of the APSIM-peanut model with high-quality biological and environmental data. The genetic coefficients of several groundnut cultivars as well as the minimal data sets for the province's soils and weather need to be identified. It is essential to initiate further research on modelling the growth and yield of groundnut cultivars and other field crops produced in dryland environments in the province of Limpopo. From this study, it was observed that cultivar and location are the important determinants of final grain yield. Subsequently, to find the best groundnut cultivars in Limpopo Province that would produce the highest grain yield given the region's diverse climatic conditions, more research involving a variety of cultivars, more growing seasons, and more sites is necessary. Such information will also assist in the accurate simulation of groundnut yield using the APSIM model.

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