SYMBIOTIC ACTIVITIES IN SOYBEAN AND YIELD VALIDATION WITH APSIM UNDER TILLAGE AND MULCHING PRACTICES

by

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DECLARATION

I, Cyndi Mahloatjie Mante declare that **SYMBIOTIC ACTIVITIES IN SOYBEAN AND YIELD VALIDATION WITH APSIM UNDER TILLAGE AND MULCHING PRACTICES** is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other institution.

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Full names Date

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DEDICATION

This study is dedicated to my son Tumelo Mante and my parents Anna and Petrus Mante for their love, encouragement, support, and patience.

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LIST OF ABBREVIATIONS AND SYMBOLS

A	Photosynthetic rate (µmolm^{-2}s^{-1})
ANOVA	Analysis of variance
APSIM	Agricultural Production System Simulator
ARC	Agricultural Research Council
BD	Bulk Density (g/mL)
CA	Conservation Agriculture
Ca	Calcium
CCI	Chlorophyll Content Index
CLL	Crop Lower Limit
cm	Centimeter
Cu	Copper
°C	Degrees Celsius
DAE	Days after emergence
DST	Department of Science and Technology
DUL	Drained Upper Limit
E	Transpiration rate (mmol m^{-2} s^{-1})
GDD	Growing Degree Days
gs	Stomatal conductance (mol m^{-2} s^{-1})
K	Potassium
kg	Kilogram

kg ha^{-1}	Kilogram per hector
LSD	Least significant difference
m	Meter
mm	Millimeter
mg kg^{-1}	Milligram kilogram per hector
Mg	Magnesium
Mn	Manganese
NRF	National Research Foundation
P	Phosphorus
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SAT	Saturation
SWCon	Soil Water Component
T_{min}	Minimum temperature (˚C)
T_{max}	Maximum temperature (˚C)
tons ha^{-1}	Tonnes per hector
Zn	Zinc

ABSTRACT

Smallholder farmers are usually confronted with severe climatic conditions during summer growing seasons on production fields that are generally characterized by poor soil fertility and consequent low crop yields. Conservation agriculture could be a feasible local practice under such conditions to ensure a more sustainable and environmentally friendly system for cultivating crops. A rainfed field experiment was conducted at two diverse agroecological sites, Syferkuil and Ofcolaco during 2017 growing season in the Limpopo Province of South Africa to evaluate production, and symbiotic activities in soybean (*Glycine max* (L.) Merrill) and also to validate the performance of the Agricultural Production System Simulator (APSIM) model in simulating soybean biomass accumulation and grain yield under tillage and mulch practices. The experiment was established as a randomized complete block design in a split-plot arrangement with tillage (till and no-till) as the main plot treatment and four rates of grass mulch (0, 3, 6 and 9 tons ha^{-1}) as the sub-plots treatment. The APSIM-Soybean model was used to validate the result for simulated biomass and grain yield for the tillage practices at different mulching rates. A greenhouse experiment was also conducted during the 2017/2018 growing season to enhance the understanding of undulation potential in the selected soybean cultivar together with other cultivars. The greenhouse experiment was laid out in a randomized complete block design (RCBD) with four replications. Three soybean cultivars, commercial cultivar Donmario 8.6IRR (sourced from Agricol), Dundee commercial cultivar and Ibis 2000 (both sourced from Agricultural Research Council) were evaluated for their growth, phenological development, and symbiotic activities. Soybean growth was significantly ($p \leq 0.001$) affected by tillage at Syferkuil but not at Ofcolaco with the tilled soil having more pronounced growth than no-till at the former. Addition of mulch resulted in improved soybean growth relative to the control at both localities. Tillage and mulch as well as their interactive effects on soil moisture was significant at Syferkuil. Across tillage practices mulch application exhibited the highest moisture content than the control plots. At Ofcolaco tillage and mulch significantly ($p \leq 0.001$) affected soil water content but not the interaction effect, with more moisture recorded under the no-tilled condition and mulch application rate of 9 t ha^{-1}.

Soybean shoot and root nitrogen content was not influenced by tillage but was responsive ($p \leq 0.001$) to mulch application at both sites. The application of 9 t ha^{-1} mulch increased the shoot nitrogen content compared to the control plants at both locations. Soybean biomass and grain yield were also significantly influenced by tillage and mulch at Syferkuil but not at Ofcolaco ($p \leq 0.001$). A significant interaction effect of tillage and mulch ($p \leq 0.001$) on biomass and grain yield was also observed at Syferkuil but not Ofcolaco. At Syferkuil, higher biomass and grain yield was observed under the tilled condition when mulch at the rates of 6 and 9 tons were applied whereas, at Ofcolaco, soybean biomass and grain yield was higher under mulch application than the control with mulch application of 9 tons ha^{-1} at this location having the highest biomass and grain yield. The results of the APSIM model simulation showed the simulated biomass and grain yield to have a positive relationship. Hence, APSIM model can be used to guide alternate management practices to improve soybean production in the Limpopo Province. Findings from the greenhouse trial revealed that soybean cultivars significantly ($p \leq 0.001$) vary in symbiotic activities, growth, and physiological development. Across the cultivars, Ibis 2000 was superior in all studied parameters whereas Donmario, the cultivar used in the field trial was generally inferior among the three.

KEYWORDS: Cultivars, Grain yield, Soybean,

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background of the study

Conservation agriculture (CA) refers to a system that makes better use of agricultural resources through the integrated management of available soil, water, and biological resources, combined with limited external inputs (FAOSTAT, 2015). This system contributes to environmental conservation and to sustainable agricultural production through its three components which are; permanent or semi-permanent organic soil cover; zero or minimum tillage, and a varied crop rotation (FAOSTAT, 2015). Adoption of CA results in increased yields, reduced labor requirements, improved soil fertility and reduced erosion (Hobbs, 2007). CA is also recommended for climate variability adaptation in both high and low rainfall areas (Hobbs and Govaerts, 2010). Blanco and Lal (2010), stated that no-till farming and other conservation tillage practices eliminate drastic soil disturbance and enhance soil organic matter in the surface layers.

With regard to the three pillars of CA, tillage practices specifically no-tillage systems of cultivation potentially conserves water, reduces soil erosion, maintains more organic matter and may be economically and beneficial to farmers (Erenstein *et al.,* 2008). While the benefit of maintaining soil cover is widely recognized and there is a clear relationship between retention of mulch and reduction of runoff and soil losses by erosion. Mulches promote crop development, early harvest, and increase crop yields by conserving soil moisture which promotes plant growth (Lal, 2013). Additionally, crop rotation plays an important role in the maintenance of soil fertility and control of crop diseases and pests.

The success of crop production depends upon the amount of moisture available in the soil which is directly linked to improved growth and development. Moisture loss from the soil as a result of evapotranspiration and erratic rainfall distribution as well as changes in the temperature, due to droughty conditions that have increasingly become unpredictable and this is largely attributed to the changing climate. Hence, this leads to crop failure, thus reduced food production by smallholder farmers in South Africa

(Rankoana, 2016). Tillage and mulch practices have been reported to enhance soil moisture storage (Zhang *et al*., 2011).

Furthermore, low yields are associated with declining soil fertility due to continuous cropping without soil replenishment as well as non-leguminous monoculture practices which restricts the benefit of biological nitrogen fixation (BNF) in agroecosystems (Jonas *et al*., 2011). Biological nitrogen fixation is a key source of N for farmers who use little or no fertilizer. Resource-poor smallholder farmers in Limpopo rarely use chemical fertilizers (Odhiambo and Magandini, 2008) even though their soils are inherently infertile and hugely deficient in N. Such farmers need to incorporate legumes in their farming system for yield enhancement.

One of the world's most valuable grain legume crops is soybean (*Glycine max* (L.) Merrill) which is also an oilseed crop and feed for livestock in many parts of Africa (DAFF, 2010). According to Garg and Geetanjali (2007), soybean has the potential to improve soil fertility and fulfill the nitrogen requirement of crops on farmers' fields due to its unique ability to fix N biologically from the atmosphere. Soybean has the potential of adding approximately 200 kg N/ha per year, which is capable of benefiting an intercropped or subsequent crop. The fixed nitrogen enhances crop production and reduces production cost in terms of nitrogen fertilizer for smallholder farmers (Smaling *et al*., 2008). Harnessing the combined benefits of minimum tillage, soil cover and crop rotation for soybean production could be beneficial for smallholder farmers.

Crop models also serve as a research tool to evaluate optimum management or cultural practices, fertilizer use and water use (Stephens and Middleton, 2002). Agricultural Production Systems Simulator (APSIM) is a detailed mechanistic crop growth model used to generate parameters and variables that can be introduced as descriptive functions (Chikowo *et al*., 2008). APSIM is widely used in a broad range of applications such as support for on-farm decision making, farming systems design for production or resource management, assessment of the value of seasonal climate forecasting (Whitbread *et al*., 2010). The model uses a whole system approach of soil, plant and atmospheric influence on crop production and is a useful tool to accurately predict soybean growth and yield under tillage and mulching practices in the province and provide valuable recommendations for smallholder farmers under dryland conditions (Keating *et al*., 2003).

1.2 Research problem

In the Limpopo Province, smallholder farmers’ are usually confronted with severe climatic conditions during the summer growing seasons. These include variable weather particularly low and poorly distributed rainfall and high temperature. Their production fields are also generally characterized by low nutrient ion concentration and low organic matter content leading to low crop yields. Continuous ploughing and disking prior to sowing are also widespread among smallholder farmers in the province and this can lead to a general reduction in soil moisture and soil fertility (Ramoroka, 2008; Mkhari, 2016). Proper correction and management of soil nutrient deficiencies are thus, critical if productivity on farmers’ fields are to be improved. The inclusion of legume crops such as soybean has the potential to improve soil fertility through nitrogen fixation as has been reported in other studies (Ayisi *et al*., 2000; Giller, 2001; Rondon *et al*., 2007). However, information on the benefits of soybean BNF under the no-till system and soil cover under diverse agro-ecological conditions is limited. Experiments to study the effects of conservation agriculture options are lacking because they are expensive and cannot be easily managed.

1.3 Motivation of the study

Adoption of tillage and mulching practices that result in improved soil fertility and moisture retention on smallholder farmers’ fields has the potential to improve crop yields and alleviate food insecurity and malnutrition (Erenstein, 2002; Ramoroka, 2008). Soybean, as a legume crop, has the ability to contribute significant amounts of biologically fixed nitrogen in a cropping system. Its potential contribution in this regard has, however, not been exploited by farmers in the Limpopo province. The crop is generally regarded as drought tolerant, but its productivity is still governed by moisture availability during critical growth stages and hence the need to monitor and manage local soil resources on its growth, BNF and grain yield (Giller, 2001). Understanding the relationship between weather variables and soil factors under tillage and mulching systems that influence soybean production, will be an important climate change adaptation strategy for the smallholder farmers in the Limpopo province. However, crop simulation models, such as Agricultural Production Systems Simulator (APSIM), have the ability to use weather data and the local soil parameters to assess the potential effects of conservation agriculture practices (Mkoga *et al*., 2010).

1.4 Hypotheses

i. Tillage and mulch influence soybean growth, soil moisture, soil temperature, nitrogen yield, biomass and grain yield under varying agro-ecological zones.
ii. APSIM-model validates soybean biomass accumulation and grain yield as influenced by tillage and mulching practices under different agro-ecological zones.
iii. Cultivars influence soybean symbiotic activities, growth, and physiological development under greenhouse conditions.

1.5 Aim and objectives of the study

1.5.1 Aim

The aim of the study was to assess symbiotic activities in soybean, and validate its growth and yield under tillage and mulching systems with APSIM model in two diverse agro-ecological conditions of the Limpopo Province, South Africa.

1.5.2 Objectives

The objectives of this study were to:

i. Assess the impact of tillage and mulching on soybean growth, nitrogen yield, biomass, and grain yield as well as soil moisture and soil temperature under two distinct agro-ecological zones.
ii. Validate the performance of the APSIM model in simulating soybean biomass accumulation and grain yield under tillage and mulching practices.
iii. Assess the symbiotic activities, growth, and physiological development of three soybean cultivars under greenhouse conditions.

1.5.3 Expected Outcomes are as follows:

i. Growth characteristics and yield of soybean crop are expected to improve under tillage and mulching practices
ii. Findings from this study should help to improve the use of tillage and mulch in soybean production which is useful for both small and large scale soybean growers.
iii. To generate information that is publishable in scientific journals.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of pertinent studies conducted on soybean crop and conservation agriculture (CA). The overview focused on the background information and the importance of the crop, symbiotic activities of the crop, effect of tillage and mulch on growth and yield of soybean crop and crop simulation.

2.2. Background information and description of a soybean crop

Soybean (*Glycine max* (L) Merr.) is a native crop to Manchuria, China. It is a highly nutritious annual grain legume crop belonging to the *Fabaceae* family. The crop is believed to have been introduced to Africa in the 19th century by Chinese traders along the east coast of Africa (IITA, 2007). The major soybean producing countries in Africa include; Kenya, Zimbabwe, Egypt, South Africa, Zambia, Malawi, and Uganda (Nassiuma and Wassike, 2002).

2.2.1 Description and importance of soybean crop

The crop is said to be widely adaptable to warm temperatures and it is a short-day plant, which normally has bushy or upright growth habit. The height of the plant ranges from 40 to 100 cm and is much branched with a well-developed root system. Each plant produces a number of small pods containing one to four seeds/pod (DAFF, 2010).

Soybean is rich in proteins (38-44%), carbohydrates (35%) in the form of starch and lipids, together with some vitamins and minerals. Soybean also contains all the essential amino acids except methionine (FAO, 2010). Soy protein products can be good substitutes for animal products because, unlike some other beans, soybean offers a "complete" protein profile. Furthermore, the oil content of soybean is relatively low in harmful saturated fats and high in poly and monounsaturated fats. Its oil is the major source of Omega-3 fatty acids in the United States diet and the primary commercial source of vitamin E whose industrial uses also include the production of biodiesel (USB, 2008). The crop can be consumed as fresh green vegetable or dried beans; and its products include soy flour, soy milk, and soy sauce (DAFF, 2010).

2.2.2 Soybean production levels in South Africa

Soybean production in South Africa ranges from 450 000 to 500 000 tons per annum at an average yield of 2.5 to 3.0 t/ha under dryland conditions (DAFF, 2010). In terms of all provinces in South Africa, Mpumalanga produces the largest quantity of soybeans (42%), followed by the Free State (22%), KwaZulu-Natal (15%), Limpopo 8%, the North West produce (5%) and Gauteng (2%). The Western and Eastern Cape provinces of South Africa have been the lowest producers of soybeans. In the Limpopo Province, Waterberg and Sekhukhune districts are the major producing areas (DAFF, 2011). In the Limpopo province, soybean is becoming a popular crop for biodiesel production. For example, the establishment of Mapfura-Makhura Incubation (MMI) Company in Limpopo Province to train small-scale black farmers (incubatees) in business management skills to optimize the yield of soybean for biodiesel production. Generally, very few smallholder farmers are involved in soybean production in the country.

2.3 Conservation Agriculture and its benefits in the agricultural sector

Conservation agriculture (CA), is an agricultural management system that is gaining popularity in many parts of the world as a more sustainable cultivation and environmentally friendly system for cultivating crops for the future (Giller *et al*., 2009). Its main function is to protect the soil physically from sunlight, rain, and wind and to feed soil biota (FAO, 2012).

The three main pillars of CA are no-till, soil cover (mulch) and rotations (FAO, 2012). Soil tillage is considered to be one of the fundamental agro-technical operations in agriculture due to its influence on soil properties, environment and crop growth (Altieri, 2018). Since continuous soil tillage strongly influences the soil properties, it is important to apply appropriate tillage practices to avoid degradation of the soil structure, maintain crop yield as well as ecosystem stability (Karunakaran and Behera, 2015). Conventional tillage has attributed to land degradation (Morris *et al*., 2010). This is due to farming practices such as; ploughing that destroys the soil structure and degrades organic matter, burning or removing crop residues, monocropping, which contributes towards erosion resulting in poor soil fertility (Rusinamhodzi *et al*., 2011). According to Lal *et al.* (2007), conventional tillage loosens the soil and buries crop residue which leaves the soil vulnerable to pounding rain and strong winds, which are both contributing factors to soil erosion, resulting in poor soil quality. Thus, no-tillage was born out of a necessity to combat soil degradation and has been widely adopted by farmers at different scales (Kassam and Friedrich*,* 2009). The practice has been reported to improve soil moisture availability in recent years (Horowitz *et al*., 2010).

2.3.1 No-till as CA component

With regards to the no-till system, the crop is planted either without tillage or with just sufficient tillage to allow placement and coverage of the seed with soil to allow it to germinate and emerge (Horowitz *et al*., 2010). Therefore, the no-till system involves soil management practices that minimize the disruption of the soil's structure, composition, and natural biodiversity, thereby minimizing erosion and nutrient ion degradation (Araya *et al*., 2012*;* Karunakaran and Behera, 2015). In addition, it has been reported that application of no-tillage practice under dryland smallholder farming for five years markedly improved soil organic matter content, nitrogen concentration and moisture content which result in improved crop yields (Worku *et al.,* 2006; Karunakaran and Behera, 2015).

2.3.2 Mulch as CA component

Mulch refers to any material spread left on the soil surface to protect it from erosion and soil moisture evaporation (Kassam and Friedrich, 2009). Different types of materials such as wheat straw, rice straw, plastic film, grass, wood, and sand are used as mulch. Mulch has great potential in soil moisture conservation through modification of microclimatic soil conditions. It also helps to reduce evaporation, and increase infiltration of rainwater during the growing season for increased crop yields (Steinmetz *et al*., 2016; Kader *et al*., 2017a).

2.3.3 Crop rotation as CA component

Rotation is also one of the conservation agriculture practices used to explore different soil layers for nutrients absorption including leached nutrient ions into deeper profiles.

Thus, the rotation is useful in recycling leached nutrients thereby making them available for rotational crops. Furthermore, a diversity of crops in rotation leads to a diverse soil flora and fauna (Kassam and Friedrich, 2009). Cropping sequence and rotations involving legumes reduce the rates of build-up of pest species, through life cycle, biological nitrogen fixation, control of off-site pollution and enhanced biodiversity (Dumanski *et al*., 2006; Kassam and Friedrich, 2009). Hence, not allowing insects or weeds to establish a pattern helps to eliminate problems with yield reduction and infestations within fields (FAO, 2007).

2.4 Effect of tillage and mulch on soil moisture

Tillage is widely known to affect crop available moisture. According to Deosthali *et al*. (2005), water availability is a primary limiting factor and a very important management concern in soybean production. Hence, any chosen tillage and mulching practices method should aim at maximizing the rainwater resource for the crop. Powlson *et al*. (2014), stated that, soil water storage is greater where there is no-till compared to where there is conventional tillage system. Conventional tillage is reported to promote surface runoff due to soil disturbance, but under the no-till system, where crop residues are left on the soil surface reduces the risk of water and wind erosion (Hazarika *et al*., 2009).

In soil and moisture conservation practice, no-till system and surface residue or soil cover can be managed to better conserve soil water for greater use efficiency by the plant (Reicosky, 2008). The surface residue, mainly mulch, has the potential to increase infiltration of water into the soil by 25 to 50% under no-till compared to the conventional tillage system. Under conventional tillage, the soil surface is unprotected against loss of moisture through evaporation from the beginning of the growing season until the end (Reicosky, 2008). However, it has been hypothesized that the combination of no-till or conventional till with mulch modifies the soil surface and may have a much greater impact on the soil water balance and evapotranspiration; and so would ultimately affect how efficiently crops use the rainwater input (Arsyid *et al*. 2009; Hatfield *et al*., 2001).

2.5 Effect of tillage and mulch on soil temperature

Soil temperature determines the rates of physical, chemical, and biological reactions in soils and has a strong influence on plant growth (Brooks *et al*., 2004). Low crop yields are generally caused by high soil temperature earlier during the growing season (Sekhon *et al*., 2005). A study conducted by Romero *et al*. (2015), on the effect of tillage system on soil temperature in a rainfed Mediterranean vertisol, reported that soil temperature was higher in conventional tillage than with no-tillage the differences ranged between 0.7 and 2.6°C for different periods of the year, which result in the degree of tillage and presence of crop residues influencing soil temperatures. Singh (2006), also stated that soils under zero tillage management resulted in Iow daily maximum temperatures than tilled soils. Furthermore, the presence of a crop residue mulch on the soil surface is an integral factor in minimizing the negative impacts of high soil temperature (Lamont, 2005; Kader *et al*., 2017a). Mulching provides a thermostatic effect in the soil by reducing soil temperature in summer and raising it in winter (Lamont, 2005). The effect of crop residues on soil temperature increases with higher rates of residue and decrease with increasing soil depth. Blanco-Canqui and Lal (2009), reported that removal of the previous crop residues from the soil surface led to an increase in the mean weekly maximum soil temperatures over fields where the residues had been left. The difference was attributed to the presence of crop residues which protects the soil against direct solar radiation effect.

2.6 Effect of tillage and mulch on soybean growth and yield production

The effect of tillage systems is widely recognized on crop growth and yield (Pretty *et al*., 2006). However, they are typically inconsistent in their agronomic effects, as it is reported to depend on crop species, climate, site and time of tillage (Martinez *et al*., 2008). With regards to soybean, inconsistent or variable yields within and between tillage practices are generally attributed to the effect of tillage methods (Singer *et al*., 2008); Thus, crop yield might be higher with no-till (Pederson and Lauer, 2003; Temperly and Borges, 2006) or sometimes be higher with conventional till (Lasisi and Aluko, 2009; Fecak *et al*., 2010). Application of mulch, on the other hand, is reported to offer a viable opportunity to increase crop productivity in a long-term sustainable manner (Hobbs, 2007). The effect of surface mulch is almost always predictable.

Surface mulch has been reported to have a positive effect on crop yield and increased soybean yield was reported under wheat straw mulch (Arora *et al*., 2011).

2.7 Biological nitrogen fixation

Poor soil fertility has been recognized as a major hindrance to high crop yield (Giller *et al*., 2009). However, researchers have devised ways of alleviating this problem, some of which comprise the application of organic and inorganic fertilizers, but most smallholder farmers are unable to afford inorganic fertilizers. Therefore, relying on the biological nitrogen fixation (BNF) of grain legumes is a strategy to ease the burden that commercial fertilizers exert on resource-poor farmers. BNF is defined as the process whereby atmospheric nitrogen (N_2) is reduced to ammonia by living microorganisms e.g. rhizobia in the presence of the enzyme nitrogenase (Lindemann and Glover, 2003). The most important economic benefit of BNF includes the reduced input of inorganic nitrogen fertilizer, higher crop productivity, reduced costs of production. The environmental advantage of BNF includes reduced contamination of water resources from runoff and leaching of excess chemical fertilizers (Silva and Uchida, 2000).

2.7.1 Factors affecting biological nitrogen fixation

The amount of nitrogen fixed by grain legume crops such as soybean is primarily controlled by factors such as the effectiveness of rhizobia-legume symbiosis; the ability of the host plant to accumulate N; the amount of available soil N and environmental constraints (Mabrouk and Belhadj, 2012).

2.7.1.1 Rhizobia-legume symbiosis

Rhizobium-legume symbiosis strongly depends on the physiological state of the host plant, therefore an active and persistent rhizobial strain is not expected to express its full N_2 fixation activity if there are factors that impose limitations on the growth and vigor of the host legume (Mabrouk and Belhadj, 2012).

2.7.1.2 Environmental constraints

In terms of environmental constraints, soil acidity can limit the survival and growth of Rhizobia in the soil and can also affect the process of nodulation and N_2 fixation (Havlin *et al*., 2005). Hence, soil pH, generally at values less than 5.5 to 6.0, can drastically affect rhizobial infection, root growth and legume productivity (Havlin *et al*., 2005). The pH ranges between 6.0 and 7.0 is considered to be suitable for rhizobial growth (Hungria and Vargas, 2000). High temperature also affects both free-living and symbiotic life of rhizobia in arid regions and critical temperatures ranging from 35 to 40°C for soybean and peanuts have been reported to be conducive for nitrogen fixation (Havlin *et al*., 2005).

2.7.2 Effect of tillage and mulch on BNF

Tillage and surface crop residues are among the major practices that influence physical, biological and chemical properties of the soil environment and subsequently affects nitrogen fixation (Kihara *et al*., 2012). The sustainability of tillage has been questioned over time because of a decrease in the natural resources and climate change issues (Hobbs and Gupta, 2003). However, through improved microbial activities in no-tillage and crop residue management, decomposition of the residue improves resulting in increased N-release to the soil pool, thus affecting nitrogen fixation (Shipitalo *et al*., 2000).

2.8 Impact of climate change on crop production

According to Seinfeld and Pandis (2012), climate change is referred to as any significant change in measures of climate that occurs over a number of decades and such changes in climate could result from natural phenomena or from human activities. The changing climate threatens agriculture in South Africa which makes cultivation of crops challenging, leading to decreased crop yield which adversely affects food security (Boko *et al*., 2007). Durand (2006), reported that current climate prediction models show that, rainfall is likely to be reduced by 5 to 10%, accompanied by a projected increase in temperature of 1℃ to 3℃ drastically which affect global agricultural systems. Hence, in South Africa, there has been an increase in mean annual temperatures by approximately 0.65°C over the past five decades, which is about 1.5 times the global average (Ziervogel *et al*., 2014).

Temperature is one of the climatic factors that have an effect on crop production. It controls the rate of plant metabolic processes which ultimately influence the production of biomass, fruits, and grains. Very high temperature leads to delayed flower and pod set, lower pods per plant, reduced seed per plant resulting with low crop yields (Young *et al*., 2004). According to Liu *et al*. (2008), temperature influences the distribution, growth, yield, and quality in soybean as it is sensitive to temperature change. The suitable temperature for soybean is 15-22 °C at emergence, 20-25 °C at flowering, and 15-22 °C at maturity stages.

According to Łabędzki and Leśny, (2008) climate change brings about more and more frequently long drought conditions during spring and summer months. Moreover, shortage of rainfall or unevenly distributed rainfall is one of the major factors that tend to restrict the yields of legumes. Rainfall shortage during legumes critical period thus, flowering and pod setting stages result in substantial reduction in yield and yield components (Barrios *et al*., 2005). The rainfall requirement of soybean in SA is 500 to 900 mm per annum for better yields and better seed quality (DAFF, 2010).

2.9 Crop models utilization

Crop simulation models are mathematical descriptions that use quantitative descriptions of eco-physiological processes to predict plant growth and development as influenced by environmental conditions and crop management (Hodson and White, 2010). Crop modeling is becoming a valuable tool to understand and mimic climatic constraints and yield gaps, it is primarily used as a decision-making tool for crop management (Slafer, 2003). The use of computer models to predict crop production over long periods in South Africa has matured over the years (Kgonyane *et al*., 2010). Agricultural Production Systems Simulator APSIM is amongst the long used models that have been widely incorporated in the climate change research (Keating *et al*., 2003).

2.10 APSIM Model description

The Agricultural Production Systems Simulator model (APSIM) is a software system that provides a flexible structure for the simulation of climatic and soil management effects on the growth of crops and changes in soil resources which was developed in Australia (McCown *et al.*, 1996 and Keating *et al.*, 2003). The APSIM modeling framework is made up of the following components: biophysical modules that simulate biological and physical processes in farming systems; management modules that allow the user to specify the intended desired cultural practices in their crop production systems; input and output data modules and a simulation engine which drives the simulation process and facilitates information between the modules (Keating *et al*., 2003). Figure 2.1 illustrates the modeling framework of APSIM.

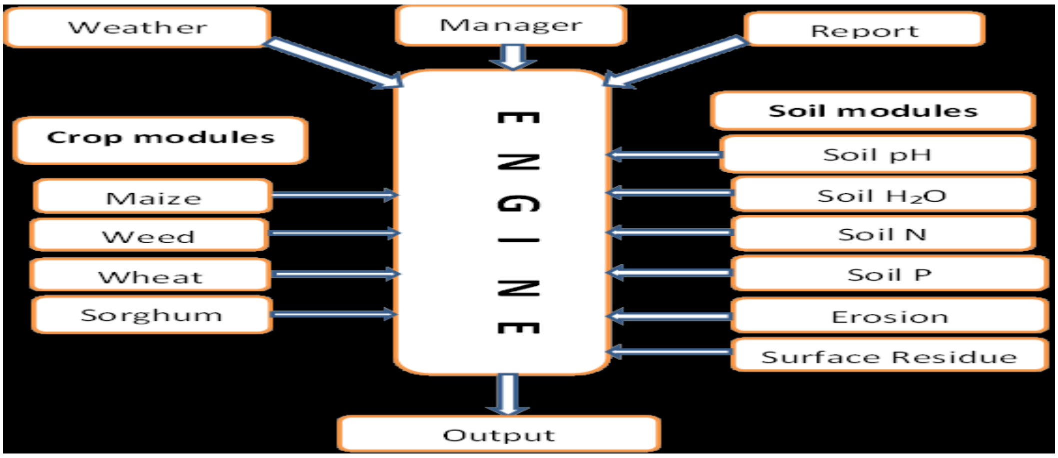

Figure 2.1: APSIM-modelling framework (adopted from McCown *et al*., 1996).

APSIM model is a predictive and deterministic model that provides a reasonably accurate prediction of crop production in relation to plant, soil, and climate and management modules whilst simultaneously addressing long-term resource management issues in farming systems (Whitbread *et al*., 2010). Crop modules that are currently available in APSIM model include barley, canola, chickpea, cotton, cowpea, hemp, fababean, lupin, maize, millet, mucuna, mungbean, navy bean, peanut, pigeon pea, sorghum, soya bean, sunflower, wheat and sugarcane (Keating *et al*., 2003). These crop modules simulate the physiological process using weather data, soil characteristics and crop management practices on a daily time-step (Nape, 2011).

2.11 Previous studies on soybean modeling using APSIM

The modeling study conducted by Mabapa *et al*. (2010), on the effect of phosphorus fertilizer rates on growth and yield of three soybean (*Glycine max*) cultivars in Limpopo Province, demonstrated that APSIM may be capable of stimulating crop growth and grain yield of soybean in one area of Limpopo Province. The study also conducted by Mohanty *et al*. (2012), revealed that, the use of APSIM model parameterization and validation in simulating soybean grain yield and N uptake in both inorganic and organic treatments was satisfactory.

2.12 Limitations of crop modeling

Crop models may be very good in predicting or estimating risks as a result of climate change. However, there are some limitations associated with modeling. These include inadequate understanding of computers by users, shortage of capable modelers and unavailability of reliable input data (Shewmake, 2008 and Masere, 2011). Shewmake. (2008), further reported that most crop simulation models are not able to provide reliable projections of changes in climate variability on a local scale or in the frequency of exceptional events such as storms and droughts as these events significantly affect crop yield (Oteng-Darko *et al*., 2005). Another limitation according to Holzworth *et al*. (2006) and Masere *et al*. (2011) is that, crop models do not include the incidence of pest and diseases infestation in its framework and this result in simulated yields being higher than the actually observed yields. Also the quality of the input data, and the large input data requirements for some models.

Based on these attributes and capabilities, APSIM which incorporate whole system approach as much as possible will be used in this study to simulate soybean yield response to different tillage and mulching practices under varying agro-ecological zones in Limpopo Province.

CHAPTER 3

GROWTH IN SOYBEAN AND YIELD VALIDATION WITH APSIM UNDER TILLAGE AND MULCHING PRACTICES

3.1 Introduction

Smallholder farmers are usually confronted with severe climatic conditions during summer growing seasons on production fields that are generally characterized by poor soil fertility leading to low crop yields. Conservation agriculture could be a feasible practice under such conditions to ensure a more sustainable and environmentally friendly system for cultivating crops (Giller *et al*., 2009). Conventional tillage has been practiced for many years. However, its sustainability is in question as a result of depletion of natural resources such as soil and water (Hobbs *et al*., 2007). As a result, conservation tillage has been adopted to address the problems associated with soil degradation resulting from poor agricultural practices (Giller *et al*., 2009). Furthermore, Giller *et al*. (2009), reported the decreased crop yields, observed in early years of conservation agriculture could be associated with weeds management constraints and the lack of mulching material, especially where priority on the utilization of the material is given to livestock feeding. However, mulching is amongst the management practices for increasing rainfall-use efficiency. Mulch increases water infiltration and decreases evaporation from the soil surface (Thierfelder and Wall, 2009). Various studies have shown the effect of mulching to vary with climate, soil conditions and amount of mulch applied. For example, Döring *et al*. (2005) and Vanlauwe *et al*. (2010), reported that increased mulch quantity reduces soil degradation, hence influencing crop growth, soil moisture retention, temperature, and crop yield. Tillage methods and mulching can also be applied to soybean to improve water availability in the soil and enhance crop yield and also the practices are easy to apply by smallholder farmers. Most of the research emphasis is on optimizing symbiotic nitrogen fixation and to increase the use of legumes in crops systems due to increasing fertilizer prices and environmental concerns (Sanginga *et al*., 2001). Quantifying the contribution of soybean to the nitrogen balance under different tillage and mulching practices is important for optimizing symbiotic activities. APSIM is a dynamic crop growth model that combines biophysical and management modules within a central engine to simulate cropping systems. It can be applied in agronomic practices to support decision making for improved production and environmental benefits (MacCarthy *et al*., 2010). Hence, the present study accomplished objective 1 and 2 in assessing the impact of tillage and mulch on soybean growth, nitrogen yield, biomass, and grain yield, as well as soil moisture and soil temperature also validating the performance of the APSIM model in simulating soybean biomass accumulation and grain yield under two distinct agro-ecological zones.

3.2 Materials and methods

3. 2.1 Study locations

This field study was conducted under dryland conditions during the 2017 growing season at two distinct agro-ecological zones in the Limpopo Province of South Africa. The sites were University of Limpopo experimental farm (Syferkuil 23° 49’ S, 29° 41’E) and a smallholder cooperative farmers’ field at Ofcolaco (24° 08’ S, 30° 39’E), located approximately 140 km southeast of Syferkuil (Figure 3.1).

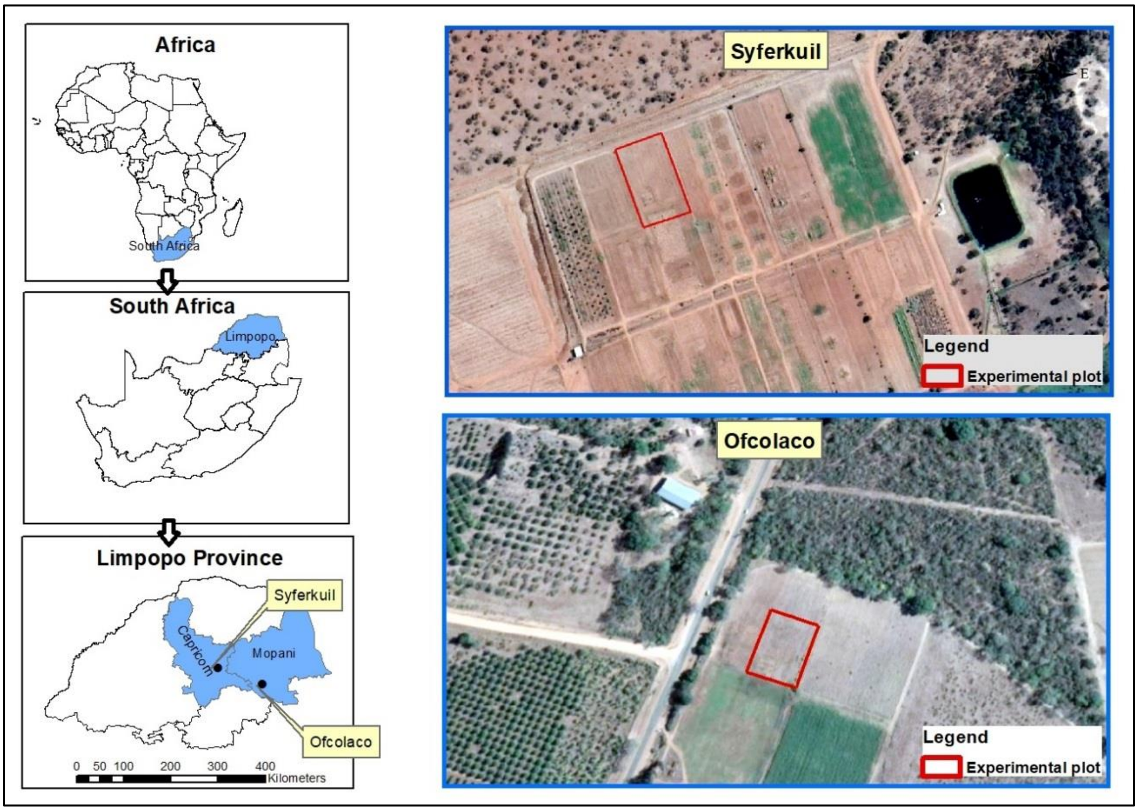

Figure 3.1: Locality map of the study locations

3.2.2 Weather at the study sites

Syferkuil is classified as semi-arid with mean annual precipitation ranging from 400-500 mm and an average daily temperature range of 16℃ to 30℃ (Moshia *et al*., 2008). Ofcolaco on the other hand receives mean annual rainfall of about 700 mm with average daily minimum and maximum temperatures of 18℃ and 35℃, respectively.

3.2.3 Experimental design and treatments

The experiment was laid out as a randomized complete block design in a split-plot arrangement with four replications at both locations. The main plot treatment was tillage, comprising conventional tillage and no-till. The subplot treatment was Eragrostis tef grass mulching applied at rates of 0, 3, 6 and 9 t ha^{-1}. Making a total treatments of 8 per rep with 32 plots per unit area. A commercial soybean cultivar Donmario 8.6IRR, inoculated with a commercial *Bradyrhizobium* was used in the experiment. Each experimental unit under the subplot measured 5m x 6m, consisting of 6 rows at inter-row and intra-row spacing of 60 cm and 15 cm respectively.

3.2.4 Soil sampling

Prior to the study and at harvest maturity, soil samples at the two selected sites were randomly collected at the depth of 0-30 cm and used to determine soil chemical and physical properties at pre-plant and harvest maturity. The bulk of the roots activity of soybean is within the top 30 cm depth

3.2.5 Land preparation and management practices

Under the conventional tillage, the experimental units were ploughed according to the treatments, followed by disking to provide a fine seedbed. Herbicide was applied to the no-till plots and was left unploughed but a hand hoe was used to open the rows for placing the seeds. At planting, phosphorus was applied using the row banding method in the form of Super-phosphate (10%) at the rate of 50 kg per hectare at both locations. No pesticide was used in the study and Irrigation was applied only at planting using a sprinkler irrigation system to encourage good stand establishment of at least 80 plants per sampling area after which the study was allowed to run under rainfed conditions. At Syferkuil, the selected site was fallowed from 2014 until 2016 growing seasons, whereas at Ofcolaco, the site had been fallowed for more than 5 years. Subsequent weeds infestation were controlled manually throughout the growing season.

3.2.6 Data collection

Days to flowering was scored when 50% of the plants within an experimental unit had flowered, whereas, days to physiological maturity was scored when 90% of the pods had changed color from green to golden brown (Elias and Copeland, 2001).

Plant height was determined at 45, 60 and 80 days after emergence (DAE) at both locations. Measurements were taken from the ground surface to the tip of the youngest fully expanded leaf on five plants within each plot. The five plants were randomly selected and measured using a measuring tape.

Leaf chlorophyll content was determined on fully expanded young leaves at 45, 60 and 80 DAE. Five individual plants were randomly selected from an area of 0.75 m^2 for the readings on each plot using the CCM-200 plus chlorophyll content meter.

Soil samples were collected at two different stages of growth, namely flowering and at harvest maturity to assess gravimetric soil water content. The samples were collected from 0-30 cm and 30-60 cm depths using an auger at both locations and placed in labeled zip log plastic bags to conserve moisture. The samples were quickly weighed after sampling and placed in labeled brown bags for oven drying (oven model and capacity). They were allowed to dry at a temperature of 103 ˚C until a constant weight was attained. Gravimetric moisture content was determined using the following formula:

Gravimetric water content (%) = [(Wet weight – Dry weight)/ Dry weight] x 100
(Scott, 2000).

Soil temperature was measured at 45, 60 and 80 DAE during the growing season using 370 PH meter (JENWAY). During sampling, the probe was inserted in the soil up to 15 cm depth making sure it is firmly touching the soil, sample was taken on the center-row positions of each plot in the morning (Van Wijk, 1959).

Soybean shoots and roots samples were dried at room temperature (24°C) for 72 hours and ground to pass through a 2 mm sieve. Ten grams of the fine fraction was used to determine nitrogen content, using the Kjeldahl method (Helric, 1990).

Shoot biomass within each experimental unit was collected from 0.09 m^2 area in all plots for biomass analysis when 50% of the plants had reached flowering. The samples were oven dried at a temperature of 65 °C to a constant weight. The electronic weighing balance was used to weigh the dried samples.

Grain yield of soybean was determined by harvesting plants from a 3 m x 3 m area within each experimental unit at harvest maturity. Pods from the harvested plants were threshed to retrieve the seeds and weighed.

Yield components were determined at harvest maturity as: number of pods $plant^{-1}$, number of seeds pod^{-1} and hundred seed dry weight. The hundred seed weight was determined by weighing 100 randomly picked seeds from the grain yield samples.

3.2.7 Crop simulation

Agricultural Production System Simulator (APSIM) 7.4 Model was used under the different tillage and mulching practices to simulate soybean biomass accumulation and grain yield relative to the observed field data. Crop (APSIM-Soybean), SoilWat (soil water), tillage and residue modules (grass) were linked with the Agricultural Production System Simulator (APSIM) 7.4 for simulations. Other inputs in the model included management and weather (met) modules. The manager folder deals with crop management module information such as when to plant and the type of cultivar to use. The met module includes inputs of daily weather data for both experimental locations. It is a key input parameter as it controls all the weather variables. The met module data used in this study was obtained from South African Weather Service, Institute of Climate Information. This database contains 2016/2017 daily hydro-climatological data such as daily rainfall, minimum and maximum temperatures, solar radiation and reference evapotranspiration. Furthermore, site information (latitude, longitude, altitude) was also used to run the model.

Soil modules were incorporated mainly with measured data from experimental sites. The measured water characteristics included Drained Upper Limit (DUL), Crop Lower Limit (CLL), Bulk Density (BD) and Saturated volumetric water (SAT) at the depth intervals of (0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm) at each site. The soil water parameters collected from both locations are presented in Tables 3.1 and 3.2.

3.2.8 Crop parameters and management

The APSIM model 7.4 was used to simulate crop biomass and grain yield of soybean within the two locations. The APSIM model does not have the cultivars used in the experiment, however, the cultivar Magoye available in the APSIM was found to best represent the growth of the Donmario 8.6IRR cultivar used in this study. Some of the major inputs to the model included: tillage practice (till or no-till), mulching rates (grass mulch) 0, 3, 6 and 9 t ha^{-1}. The number of days between emergence and end of the juvenile stage, end of the juvenile stage and flowering, flowering and grain filling, flowering to physiological maturity and maturity and ripe stages are indicated in Table 3.3. With the use of soil data, management data and weather data, simulation runs were made and model predicted data was generated. Actually reported and simulated data were generated and tested for their statistical differences.

Table 3.1: Soil chemical and physical properties and initial values at Syferkuil by soil depths.

Depths (cm)	0-15	15-30	30-60	60-90
Bulk density (g cm^{-3})	1.26	1.21	1.17	1.13
Saturation (mm)	0.403	0.404	0.406	0.409
Drain Upper Limit (mm)	0.275	0.283	0.287	0.306
Air-Dry weight (mm/mm)	0.030	0.030	0.110	0.110
Lower Limit (mm/mm)	0.184	0.189	0.188	0.205
SWCon (0-1)	0.700	0.700	0.700	0.700
FBiom (0-1)	0.035	0.02	0.015	0.015
Finert (0-1)	0.4	0.5	0.7	0.95

Table 3.2: Soil chemical and physical properties and initial values at Ofcolaco by soil depths.

Depths (cm)	0-15	15-30	30-60	60-90
Bulk density (gm^{-3})	1.19	1.17	1.17	1.15
Saturation (mm)	0.402	0.402	0.406	0.409
Drain upper limit (mm)	0.233	0.270	0.274	0.283
Air-Dry weight (mm/mm)	0.040	0.080	0.130	0.130
Lower Limit (mm/mm)	0.150	0.177	0.178	0.184
SWCon (0-1)	0.500	0.500	0.500	0.500
FBiom (0-1)	0.035	0.02	0.015	0.015
Finert (0-1)	0.4	0.5	0.7	0.95

Table 3.3: Genetic coefficients used for modeling soybean in APSIM (Fosu-Mensah *et al.,* 2012)

Coefficient	Definition
tt_emerg_to_endjuv	Thermal time accumulation from seeding emergence to end of juvenile phase (°C days)
tt_endjuv_to_init	Thermal time accumulation from end juvenile to floral initiation (°C days)
x_pp_hi_incr	Photoperiod (hours)
tt_flower_to_start_grain	Thermal time accumulation from flowering to grain filling (°C days)
tt_end_grain_to_maturity	Thermal time accumulation end grain fill to maturity (°C days)
tt_flower_to_maturity	Thermal time accumulation from flowering to maturity (°C days)
tt_maturity_to_ripe	Thermal time accumulation from maturity to ripe (°C days)

3.2.9 Reporting frequency

The model was set to report the selected variables at harvest stage of the soybean crop. Biomass and grain yield were reported at two locations which were subsequently compared with observed data.

3.2.10 Statistical analysis

Significance among the treatments at each site was determined through standard analysis of variance (ANOVA) using Statistix version 10 software. Where significant differences among the treatment means were observed at the probability level of 5%, differences between the treatments were compared using Duncan Multiple Range (Gomez and Gomez, 1984). Linear regression analysis was used to determine the relationship between the mulching and the measured dependent variables.

Data on soil water, crop biomass and grain yield from the field experiments were used to validate the APSIM model. In order to assess the performance of the crop simulation model in comparison with the observed measured data, statistical methods were used.

The closeness of the relationship between observed (Obs) and Simulated (Sim) crop biomass and grain yield were estimated using:

1. Root mean square error (RMSE)

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 measured biomass and yield parameters.

2. The coefficient of determination, (R^2), which is interpreted as the proportion of the variance in the observed data that is attributable to the variance in the simulated data.

3.3 Results

3.3.1 Weather data

3.3.1.1 Temperature

The ambient temperature during the 2016/2017 growing seasons was lower at Syferkuil relative to Ofcolaco (Figure 3.2). The maximum temperatures ranged from 19.7 to 27.5 ˚C at Syferkuil and from 25.0 to 31.4 ˚C at Ofcolaco. The minimum temperature ranged from 3.4 to 16.6 ˚C at Syferkuil and 12.6 to 21.6 ˚C at Ofcolaco. The mean seasonal temperature ranged from 12.10 to 22.0˚C at Syferkuil and 18.8 to 26.4 ˚C at Ofcolaco.

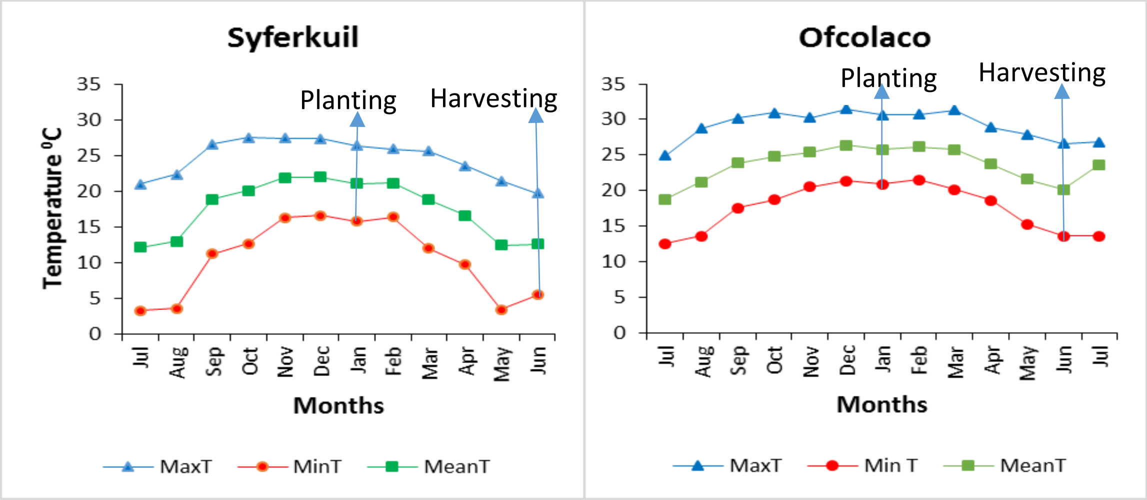

Figure 3.2: Monthly averaged temperature experienced at Syferkuil and Ofcolaco during 2016/2017.

3.3.1.2 Rainfall

According to the recorded seasonal rainfall at both localities, Syferkuil received an annual rainfall of 398.5 mm and 454.7 mm at Ofcolaco (Figure 3.3). The highest rainfall during the growing season (from January to June) was experienced at Syferkuil was 200.2 mm whereas Ofcolaco received 171.0 mm.

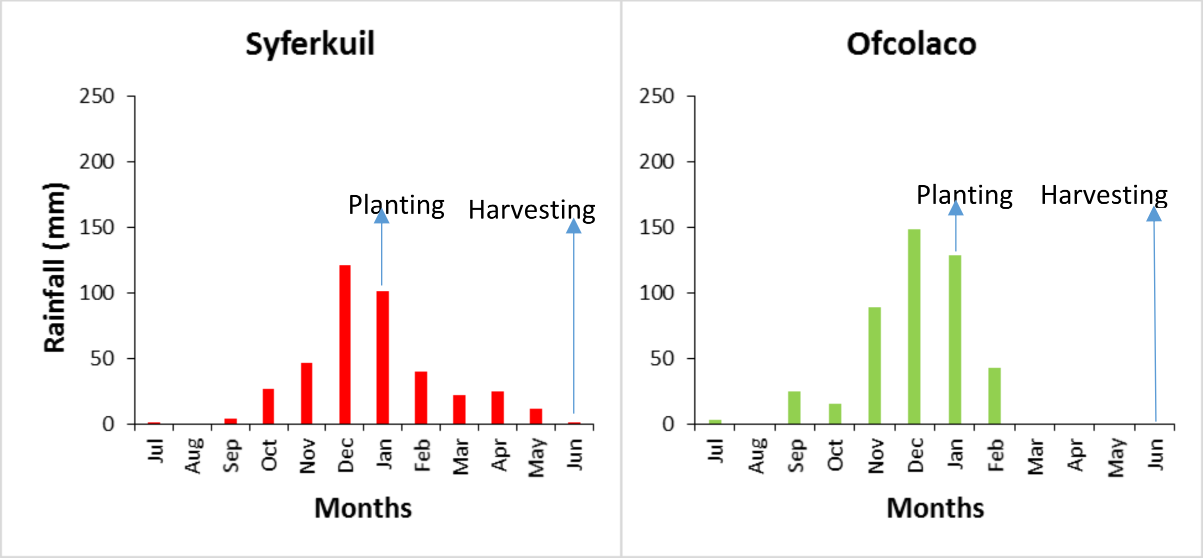

Figure 3.3: Total monthly rainfall experienced at Syferkuil and Ofcolaco during the 2016-2017 growing season.

3.3.1.3 Evapotranspiration

As indicated by figure 3.4 reference evapotranspiration ranged from 2.56 mm to 4.39 mm at Syferkuil whereas at Ofcolaco it ranged from 2.76 mm to 4.19. On average the seasonal atmospheric evaporative demand was lower at Syferkuil with 3.29 mm than at Ofcolaco 3.52 mm.

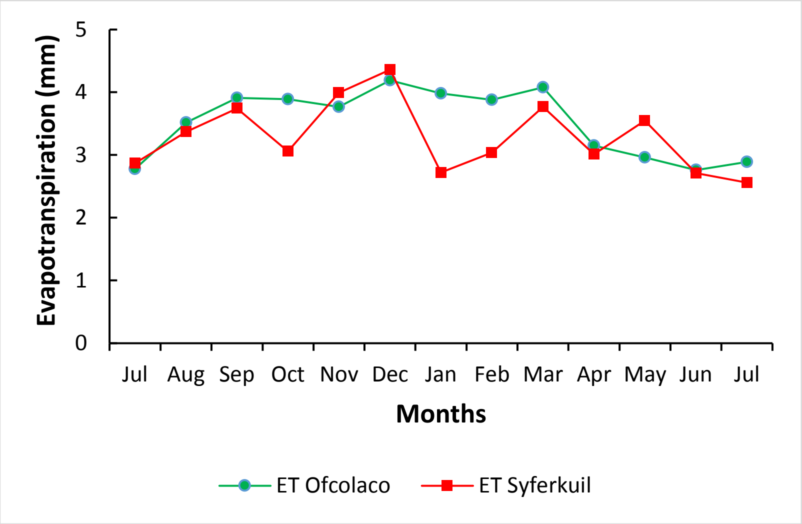

Figure 3.4: Monthly total reference evapotranspiration at Syferkuil and Ofcolaco

3.3.2 Selected nutrient analysis of grass mulch

Results of the analysis of the grass mulch used in the experiment are presented in Table 3.4. The grass sample indicated available soil N, P, K of 2.80, 0.02 and 0.04%, respectively. The exchangeable basic cations: Ca and Mg were 0.16 and 0.05, respectively and the concentration of Zn, Cu and Mn were 11, 2.1 and 103 Mg kg^{-1} respectively.

Table 3.4: Nutrients composition of the grass mulch

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Zn (Mg kg^{-1})	Cu (Mg kg^{-1})	Mn (Mg kg^{-1})
Grass mulch	2.80	0.02	0.04	0.16	0.05	11	2.1	103

N=Nitrogen, P=Phosphorus, K=Potassium, Ca=Calcium, Mg=Magnesium, Zn=Zinc, Cu=Copper, Mn=Manganese

3.3.3 Soil analysis

Pre-plant and harvest maturity soil chemical properties analyses results at Syferkuil and Ofcolaco are presented in Tables 3.5 and 3.6.

Pre-plant soil analysis

The initial soil analysis results from the two locations were generally higher at Syferkuil as compared to Ofcolaco, with the exception of pH, Phosphorus, and Zinc. According to the standards reported by Peverill *et al*. (1999), the nutrients content of the topsoil at both Syferkuil and Ofcolaco is within the normal range. Hence, they were adequate to support the growth and yield of soybean crop at the two locations.

Soil analysis at maturity

Generally, the effect of tillage was not significant on most nutrients at both locations, except for OC, Ca, Mg, Cu at Syferkuil and Phosphorus only at Ofcolaco. These nutrients concentrations were higher under tilled soil conditions compared to the no-till. Application of mulch significantly $(p \leq 0.001)$ affected the soil chemical properties at both localities. At Syferkuil soil nutrients were generally higher under the mulch application rate of 9 t ha^{-1} when compared to the control. Whereas at Ofcolaco, mulch application at all rates (3, 6 and 9 t ha^{-1}) exhibited higher nutrient concentration relative to non-mulched plots. However, at both locations, the concentration of phosphorus under the control plots was higher than the mulched plots. Furthermore, the concentration of soil pH changed from slightly acidic at pre-planting to almost neutral at harvest maturity, and the Organic carbon content changed from a lower concentration to a normal concentration at both Syferkuil and Ofcolaco. On average, Organic carbon content under mulch application was 0.25 and 0.20 percentage point higher than the control plots at Syferkuil and Ofcolaco, respectively.

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Table 3.5: Topsoil chemical and physical properties analysis prior to planting at Syferkuil and Ofcolaco.

Location	pH (KCl)	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	OC (%)	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})
Syferkuil	6.1	0.06	17.8	400.3	0.78	1233.3	699.7	1.4	17.3	5..00
Ofcolaco	6.2	0.02	24.1	109.5	0.68	911.8	198.7	2.2	11.4	3.78

N=Nitrogen, P=Phosphorus, K=Potassium, OC=Organic carbon, Ca= Calcium, Mg=Magnesium, Zn=Zinc, Mn=Manganese, Cu= Copper

Table 3.6: Topsoil chemical and physical properties analysis for harvest maturity at Syferkuil and Ofcolaco.

Treatment	**Syferkuil**										**Ofcolaco**									
Tillage	pH (KCL)	N (%)	P	K	OC (%)	Ca	Mg	Zn	Mn	Cu	pH (KCL)	N (%)	P	K	OC (%)	Ca	Mg	Zn	Mn	Cu
			---(mg kg^{-1})---			-------------------(mg kg^{-1})------------------							---(mg kg^{-1})---			-------------------(mg kg^{-1})------------------				
Till	6.7	0.07	26.9	464.3	0.89^{a}	1215.8^{a}	699.8^{a}	1.6	34.3	5.7^{a}	6.7	0.07	27.7^{a}	546.9	0.79	1235.9	733.6	1.7	24.1	4.7
No-till	6.7	0.07	26.6	466.9	0.82^{b}	1188.5^{b}	664.9^{b}	1.6	34.9	5.4^{b}	6.7	0.07	26.5^{b}	548.4	0.78	1234.5	733.8	1.7	23.9	4.7
P (≤ 0.05)	ns	ns	ns	ns	*	*	*	ns	ns	*	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
Mulch (t ha^{-1})																				
0 (M0)	6.6^{b}	0.05^{d}	28.2^{a}	436.8^{c}	0.66^{c}	1144.9^{b}	647.4^{b}	1.3^{c}	33.5^{b}	5.4^{b}	6.5^{c}	0.05^{c}	30.5^{a}	475.9^{c}	0.64^{d}	1161.0^{c}	676.5^{c}	1.4^{c}	23.0^{bc}	4.4^{d}
3 (M1)	6.7^{ab}	0.06^{c}	28.0^{a}	457.8^{b}	0.83^{b}	1180.4^{b}	671.8^{b}	1.6^{b}	34.6^{ab}	5.6^{ab}	6.6^{b}	0.06^{b}	25.3^{b}	570.5^{ab}	0.72^{c}	1240.0^{b}	740.5^{b}	1.5^{bc}	26.5^{a}	4.6^{c}
6 (M2)	6.7^{ab}	0.07^{b}	25.6^{b}	481.1^{a}	0.95^{a}	1238.9^{a}	683.5^{b}	1.7^{b}	35.1^{a}	5.7^{a}	6.8^{a}	0.07^{ab}	25.8^{b}	556.8^{b}	0.84^{b}	1264.1^{ab}	758.9^{b}	1.7^{b}	24.5^{ab}	4.8^{b}
9 (M3)	6.8^{a}	0.10^{a}	25.1^{b}	486.6^{a}	0.96^{a}	1244.5^{a}	726.8^{a}	1.9^{a}	35.3^{a}	5.5^{ab}	6.8^{a}	0.08^{a}	26.9^{b}	587.5^{a}	0.95^{a}	1275.6^{a}	768.9^{a}	2.2^{a}	22.1^{c}	5.0^{a}
P (≤ 0.05)	**	***	***	***	***	***	***	**	**	*	***	***	***	***	***	***	***	***	***	***

*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 0.01, ***significant at 0.001, ns = Not significant.* N=Nitrogen, P=Phosphorus, K=Potassium, OC=Organic carbon Ca=Calcium, Mg=Magnesium, Zn=Zinc, Mn=Manganese, Cu=Copper,

3.3.4 Days to 50% flowering and physiological maturity

Days to flowering and physiological maturity were influenced by the tillage system at Syferkuil but not at Ofcolaco (Table 3.7). Plants grown under no-till took a long time to flower and also to reach physiological maturity compared to plants under tilled conditions at Syferkuil. In absolute terms, the soybean plants flowered between 54 and 55 DAE and matured between 129 and 131 DAE at Syferkuil, whereas at Ofcolaco, flowering and maturity were 52 to 53 and 120 DAE, respectively.

Mulch application significantly (*$P \leq 0.01$*) influenced days to 50% flowering and physiological maturity at the two sites. The application of 9 t ha^{-1} mulch resulted in early flowering and maturity, and the plants, grown under the mulching rate of 3 and 6 t ha^{-1}, flowered and matured at the same time as the control plots plants at Syferkuil. However, at Ofcolaco, plants grown under mulch application flowered and matured earlier than plants under no-mulch plots (Table 3.7).

Table 3.7: Days to 50% flowering and physiological maturity at Syferkuil and Ofcolaco.

Treatment	**Syferkuil**		**Ofcolaco**	
	Days to flowering	Days to physiological maturity	Days to flowering	Days to physiological maturity
Tillage				
Till	55^{a}	132^{a}	53	120
No-till	54^{b}	129^{b}	52	120
P (≤ 0.05)	*	**	ns	ns
Mulch (t ha^{-1})				
0	57^{a}	135^{a}	55^{a}	126^{a}
3	54^{ab}	129^{ab}	53^{b}	121^{b}
6	54^{ab}	130^{ab}	51^{b}	116^{c}
9	53^{b}	128^{b}	51^{b}	116^{c}
P (≤ 0.05)	**	**	***	***

*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 0.01, ***significant at 0.001, ns = Not significant.*

3.3.5 Plant height as influenced by tillage and mulch

At Syferkuil, soybean plant height responded to tillage and mulching at 45, 60 and 80 DAE (Table 3.8). The height increased with time, and it was higher where the soil was tilled. From 45 DAE to 80 DAE, plant height ranged from 29 to 50 cm and 28 to 48 cm under till and no-till, respectively. With regard to mulching, the tallest soybean plants were recorded under the mulching rate of 9 t ha^{-1} followed by 6 t ha^{-1} at all sampling days. An application rate of 3 t ha^{-1} resulted in similar height as the control across sampling times at this location.

At Ofcolaco, the plant height was influenced by tillage only at 45 DAE and not at 60 and 80 DAE (Table 3.8). The plants were taller under no-till than under the till system at 45DAE. Similar to Syferkuil, the effect of mulch on soybean height was also significant (*$P \leq 0.001$*) at Ofcolaco. Mulched plots produced taller plants as compared to the control at all sampling days. However, the application rate of 9 t ha^{-1} led to taller plants than the rate of 3 and 6 t ha^{-1} only at 80 DAE (Table 3.8).

Table 3.8: Soybean height as influenced by tillage and mulch at Syferkuil and Ofcolaco locations.

Treatment	**Syferkuil**			**Ofcolaco**		
	Plant height (cm)			**Plant height (cm)**		
Tillage	45DAE	60DAE	80DAE	45DAE	60DAE	80DAE
Till	29^{a}	44^{a}	50^{a}	25^{b}	37	51
No-till	28^{b}	43^{b}	48^{b}	26^{a}	37	46
P (≤ 0.05)	*	*	*	**	ns	ns
Mulch (t ha^{-1})						
0	27^{c}	42^{c}	47^{c}	24^{b}	35^{b}	43^{c}
3	28^{c}	43^{bc}	48^{c}	25^{a}	37^{a}	46^{b}
6	28^{b}	44^{b}	49^{b}	26^{a}	38^{a}	46^{b}
9	29^{a}	46^{a}	52^{a}	26^{a}	38^{a}	48^{a}
P (≤ 0.05)	***	***	***	***	***	***

*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 0.01, ***significant at 0.001, ns = Not significant.*

3.3.6 Effect of tillage and mulch on leaf chlorophyll content

Tillage did not affect leaf chlorophyll content at Syferkuil but there was an effect at Ofcolaco (45 DAE only), whereby the chlorophyll content was 3% higher under tillage system relative to no-till (Table 3.9). The impact of mulching was significant (*$p \leq 0.001$*) at the different stages of growth at both locations, except at 45 DAE at Ofcolaco. Generally, the mulching rate of 6 and 9 t ha^{-1}, resulted in higher leaf chlorophyll content at 60 and 80 DAE than control plants but the impact of the mulch application at the rate of 3 t ha^{-1} was not significantly different from the no-mulched plots at Syferkuil. Whereas at Ofcolaco the highest leaf chlorophyll content was pronounced under the heaviest mulching rate of 9 t ha^{-1} relative to the control plots, but leaf chlorophyll content under the mulch application of 3 and 6 t ha^{-1} was statistically similar to that of the control plots at 60 and 80 DAE. The leaf Chlorophyll content was generally low at 80 DAE across tillage and mulching rates at both localities.

Table 3.9: Effect of tillage and mulch on soybean leaf chlorophyll content at Syferkuil and Ofcolaco.

Treatment	**Syferkuil**			**Ofcolaco**		
	Chlorophyll (μmol m^{-2})			**Chlorophyll (μmol m^{-2})**		
Tillage	45DAE	60DAE	80DAE	45DAE	60DAE	80DAE
Till	19.93	21.87	14.3	16.67^{a}	20.49	11.29
No-till	19.7	21.80	14.51	16.17^{b}	20.06	11.05
P (≤ 0.05)	ns	ns	ns	*	ns	ns
Mulch (t ha^{-1})						
0	17.92^{c}	20.38^{b}	13.38^{b}	16.59	19.64^{b}	10.66^{b}
3	19.75^{b}	21.08^{b}	14.13^{ab}	16.39	19.82^{b}	11.09^{ab}
6	20.40^{ab}	22.86^{a}	14.66^{ab}	16.07	20.46^{ab}	11.13^{ab}
9	21.19^{a}	23.01^{a}	15.46^{a}	16.62	21.18^{a}	11.81^{a}
P (≤ 0.05)	***	***	*	ns	***	*

*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 0.01, ***significant at 0.001, ns = Not significant.*

3.3.7 Effect of tillage and mulch on soil moisture at Syferkuil

Significant tillage and mulch, as well as interaction effects, were observed on soil moisture at Syferkuil. Across tillage and sampling depth, the control plots retained lower soil moisture compared to the mulched plots at the two growth stages (Table 3.10). Generally, under both tillage practices, the mulching rate of 9 t ha^{-1} had more soil moisture than the application of 3 and 6 t ha^{-1} at all sampling depth and growth stages.

Table 3.10: Interactive effect of tillage and mulch on soil moisture at Syferkuil.

Treatment		**Syferkuil**			
		GM (%) Flowering		**GM (%) Harvesting**	
Tillage	**Mulch t ha^{-1}**	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Till	0	8.53^{f}	9.48^{e}	5.27^{f}	6.10^{f}
Till	3	9.09^{d}	11.47^{c}	5.82^{d}	7.60^{d}
Till	6	10.57^{b}	12.77^{ab}	6.81^{b}	8.86^{b}
Till	9	10.72^{a}	12.90^{a}	6.98^{a}	9.12^{a}
No-till	0	8.52^{f}	9.43^{e}	5.29^{f}	6.03^{f}
No-till	3	8.79^{e}	10.83^{d}	5.64^{e}	7.43^{e}
No-till	6	10.31^{b}	12.46^{b}	6.55^{c}	8.48^{c}
No-till	9	10.49^{b}	12.60^{ab}	6.80^{b}	8.80^{b}
P (≤ 0.05)		***	***	***	***

*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 0.01, ***significant at 0.001, ns = Not significant. GM= Gravimetric Moisture*

3.3.8 Effect of tillage and mulch on soil moisture at Ofcolaco

Tillage and mulch influenced soil moisture at Ofcolaco. Generally, soil moisture was higher under no-tillage at all sampling stages and soil depths (Table 3.11). Amount of moisture increased under mulch application relative to the control plots. The mulching rate of 9 t ha^{-1} had a higher moisture content than the rates of 3 and 6 t ha^{-1} at all sampling depth and growth stages.

Table 3.11: Effect of tillage and mulch on soil moisture at Ofcolaco.

Treatment	**Ofcolaco**			
	GM (%) Flowering		**GM (%) Harvesting**	
Tillage	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Till	6.62^{b}	7.82^{b}	4.53^{b}	4.82^{b}
No-till	6.79^{a}	8.03^{a}	4.63^{a}	4.91^{a}
P (≤ 0.05)	**	*	***	***
Mulch (t ha^{-1})				
0	5.56^{d}	7.00^{d}	3.90^{d}	4.20^{d}
3	6.39^{c}	7.61^{c}	4.50^{c}	4.81^{c}
6	7.26^{b}	8.34^{b}	4.79^{b}	5.12^{b}
9	7.60^{a}	8.70^{a}	5.12^{a}	5.32^{a}
P (≤ 0.05)	***	***	***	***

*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 0.01, ***significant at 0.001, ns = Not significant. GM= Gravimetric Moisture.*

3.3.9 Effect of tillage and mulch on soil temperature

Tillage did not influence soil temperature at all sampling days at the two locations. However, the effect of mulch on soil temperature was significant at all measured dates at the two locations, with the exception of 45 DAE at Ofcolaco (Table 3.12). At 45 DAE, the mulch application rate of 9 t ha^{-1} decreased the soil temperature relative to the control. However, the application rate of 3 and 6 t ha^{-1} had a similar effect as the no-mulch plots. A trend of reducing soil temperatures with increasing rates of mulch application was observed at 60 and 80 DAE relative to the control plots at Syferkuil. With regard to Ofcolaco at 60 and 80 DAE, mulched plots reduced the soil temperatures more than the control plots. At 60 DAE, the mulching rate of 9 t ha^{-1} resulted in the lowest soil temperature compared to the application rates of 3 and 6 t ha^{-1} whereas at 80 DAE, the mulched plots showed no differences in soil temperature.

Table 3.12: Tillage and mulch effect on soil temperature at Syferkuil and Ofcolaco.

Treatment	**Syferkuil**			**Ofcolaco**		
	Soil Temperature ˚C			**Soil temperature ˚C**		
Tillage	45DAE	60DAE	80DAE	45DAE	60DAE	80DAE
Till	22.9	19.3	17.8	30.2	25.0	22.7
No-till	22.9	19.5	17.5	30.4	24.8	22.8
P (≤ 0.05)	ns	ns	ns	ns	ns	ns
Mulch (t ha^{-1})						
0	23.6^a	22.2^a	20.0^a	30.5	26.8^a	25.1^a
3	23.8^a	19.3^b	18.1^b	30.4	25.0^b	22.9^b
6	23.1^a	18.9^b	16.6^c	30.3	21.2^c	21.6^b
9	21.3^b	17.3^c	16.0^d	30.1	23.5^d	21.5^b
P (≤ 0.05)	***	***	***	ns	***	***

*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 0.01, ***significant at 0.001, ns = Not significant.*

3.3.10 Nitrogen content in shoots and roots as affected by tillage and mulch

Tillage practices had no effect on shoots and roots nitrogen concentration. However, the N concentration in shoots and roots of the plant differed significantly ($p<0.001$) with the application of mulch across both locations. The uptake of N by shoot and roots increased with concurrent increase in mulching rates with more N concentration accumulating in the shoots compared to the roots at both locations. At Syferkuil, shoot N concentration in plots receiving 6 and 9 t ha^{-1} of mulch was higher when compared to the control plots. The concentration under plants receiving 3 t ha^{-1} was similar to that of the control plots. With regard to the roots, N concentration plants under the mulched plots had higher concentration than the control. At Ofcolaco the shoot and roots N concentration of the mulched plots was higher relative to the control, but the concentration under the mulch application of 3 t ha^{-1} was lower when compared to that under the application rate of 6 and 9 t ha^{-1} (Table 3.13).

Table 3.13: Effect of tillage and mulch on the shoot and root nitrogen at Syferkuil and Ofcolaco.

Treatment	**Syferkuil**		**Ofcolaco**	
Tillage	Shoot N%	Roots N%	Shoot N%	Roots N%
Till	2.37	0.89	3.77	1.50
No-till	2.41	0.88	3.78	1.49
P (≤ 0.05)	ns	ns	ns	ns
Mulch (t ha^{-1})				
0	2.24^{c}	0.74^{b}	3.65^{c}	1.25^{c}
3	2.35^{bc}	0.93^{a}	3.75^{b}	1.45^{b}
6	2.44^{ab}	0.94^{a}	3.84^{a}	1.64^{a}
9	2.54^{a}	0.95^{a}	3.87^{a}	1.64^{a}
P (≤ 0.05)	***	***	***	***

*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 0.01, ***significant at 0.001, ns = Not significant.*

3.3.11 Effect of tillage and mulch on soybean biomass accumulation at Syferkuil and Ofcolaco

The effects of tillage and mulch on biomass accumulation at the two localities are presented in Table 3.14. Tillage effect on biomass was observable at Syferkuil but not at Ofcolaco. However, the effect of mulch application on biomass accumulation was significant at both locations. The interaction effect was also significant ($P<0.001$) at Syferkuil but not at Ofcolaco. Under tilled soil conditions, mulch application led to more crop biomass production by the plants, as compared to the control plots. The application rate of 3 t ha^{-1} resulted in a lower crop biomass relative to the rates of 6 and 9 t ha^{-1}. Under the no-till condition, biomass yield was higher with the mulch application rate of 6 and 9 t ha^{-1} when compared to the control plots. However, biomass produced under the control plots was similar to that under the application rate of 3 t ha^{-1}. At Ofcolaco, the application of mulch yielded more crop biomass than the control plots, with plants under the application rate of 9 t ha^{-1} having more biomass than those under the rates of 3 and 6 t ha^{-1} (Table 3.14).

Table 3.14: Tillage and mulch effect on soybean biomass at Syferkuil and Ofcolaco.

Treatment		**Syferkuil**	**Treatment**	**Ofcolaco**
	Interaction		**No-interaction**	
Tillage	**Mulch t ha^{-1}**	**Biomass (kg ha^{-1})**	**Tillage**	**Biomass (kg ha^{-1})**
Till	0	900.3^{e}	Till	889.91
Till	3	943.8^{bcd}	No-till	891.8
Till	6	1012.9^{a}	**P (≤ 0.05)**	ns
Till	9	1020.1^{a}	**Mulch (t ha^{-1})**	
No-till	0	877.8^{e}	0	774.38^{d}
No-till	3	929.2^{cde}	3	835.63^{c}
No-till	6	972.4^{abc}	6	965.48^{b}
No-till	9	985.1^{ab}	9	987.94^{a}
P (≤ 0.05)		***	**P (≤ 0.05)**	***

*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 0.01, ***significant at 0.001, ns = Not significant*

3.3.12 Effect of tillage and mulch on soybean grain yield at Syferkuil and Ofcolaco

Similar to biomass, soybean grain yield was significantly influenced by tillage at Syferkuil but not at Ofcolaco but the application of mulch was significant (*p≤0.001*) at both locations. A significant interaction effect of tillage and mulch *(p≤0.001*) was also observed on grain yield at Syferkuil but not at Ofcolaco. Across tillage practices, soybean grain yield was higher with mulch application and lower under the control plots. Furthermore, under tilled soils, grain yield was higher with the mulch application rate of 6 and 9 t ha^{-1} relative to the rate of 3 t ha^{-1}. Under no-till, it was higher at the mulch application rate of 9 t ha^{-1} followed by 6 t ha^{-1} (Table 3.15). At Ofcolaco more grains were produced by the mulched plots relative to the none-mulch plots. On average, the mulched plots increased soybean grain yield by 18%. The highest grain yield was obtained under the rate of 9 t ha^{-1} followed by 6 t ha^{-1} (Table 3.15).

Table 3.15: Effect of tillage and mulch on soybean grain yield at Syferkuil and Ofcolaco.

Treatment		**Syferkuil**	**Treatment**	**Ofcolaco**
	Interaction		**No-interaction**	
Tillage	**Mulch t ha^{-1}**	**Grain yield (kg ha^{-1})**	**Tillage**	**Grain yield (kg ha^{-1})**
Till	0	326.5^{e}	Till	279.73
Till	3	335.8^{d}	No-till	282.54
Till	6	411.9^{a}	**P (≤ 0.05)**	ns
Till	9	415.1^{a}	**Mulch (t ha^{-1})**	
No-till	0	315.0^{f}	0	240.42^{d}
No-till	3	329.0^{de}	3	263.92^{c}
No-till	6	365.0^{c}	6	305.28^{b}
No-till	9	383.9^{b}	9	314.91^{a}
P (≤ 0.05)		***	**P (≤ 0.05)**	***

*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 0.01, ***significant at 0.001, ns = Not significant*

3.3.13 Tillage and mulch effect on soybean yield components

The yield components of soybean at the two locations are presented in Table 3.16. All the yield component parameters measured were not influenced by tillage at both Syferkuil and Ofcolaco during the growing season. Mulching had a significant (*p≤0.001*) effect on the number of pods per plant and hundred seed weight, but not on the number of seeds per pod at Syferkuil and Ofcolaco. Across both locations, the number of pods per plant and hundred seed weight were higher under the mulch application at the rate of 9 t ha^{-1} relative to the control plots.

Table 3.16: Effect of tillage and mulch on Pods plant^{-1}, Seeds pod^{-1} and 100-grain weight of Soybean at Syferkuil and Ofcolaco.

Treatment	**Syferkuil**			**Ofcolaco**		
Tillage	Pods plant^{-1}	Seeds pod^{-1}	100 seed weight (g)	Pods plant^{-1}	Seeds pods^{-1}	100 seed weight (g)
Till	46.00	2.00	12.34	23.56	2.00	13.31
No-till	45.69	2.00	12.03	23.50	2.00	13.41
P (≤ 0.05)	ns	ns	ns	ns	ns	ns
Mulch (t/ha)						
0	40.50^{d}	2.00	11.44^{b}	22.38^{b}	2.00	12.69^{b}
3	44.75^{c}	2.00	11.89^{b}	23.00^{ab}	2.00	13.50^{a}
6	47.63^{b}	2.00	12.31^{ab}	24.13^{ab}	2.00	13.50^{a}
9	50.50^{a}	2.00	13.13^{a}	24.63^{a}	2.00	13.75^{a}
P (≤ 0.05)	***	ns	***	*	ns	***

*Means in the same column followed by the same letter are not significantly different from each other at the 5% probability level,*Significant at $p \le 0.05$, **significant at 0.01, ***significant at 0.001, ns = Not significant.*

3.4 Regression relation between mulching rate and biomass accumulation and grain yield

Figures 3.4 and 3.5 shows the relationship between mulching rates and biomass as well as mulching rates and grain yield under two tillage practices at Syferkuil and Ofcolaco. The results revealed a highly positive relationship of over 90% R^2 between mulching rates and biomass as well as grain yield under all tillage practices. Biomass and grain yield increased with an increment of mulching rates at both locations either with or without tillage.

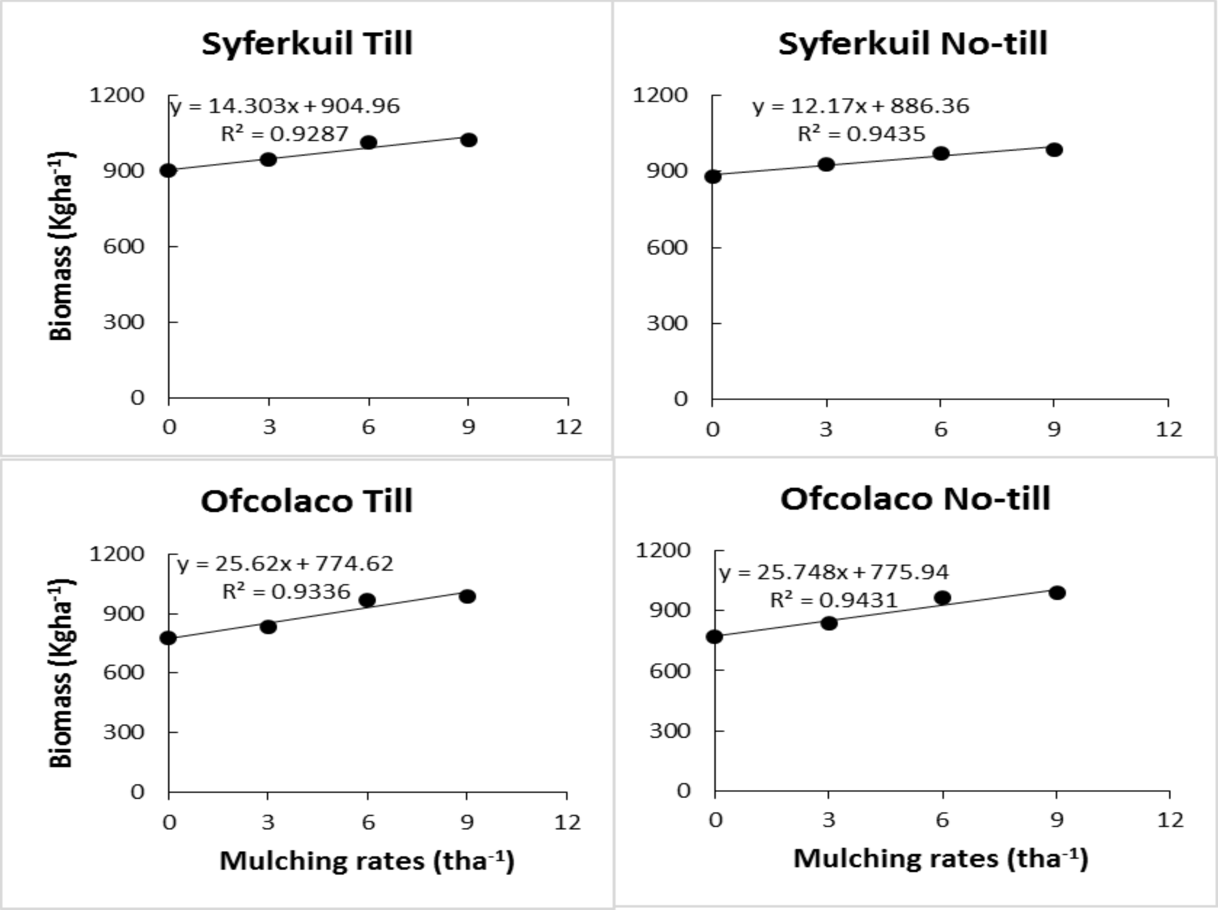

Figure 3.5: Regression analysis between mulching rates and biomass at Syferkuil and Ofcolaco.

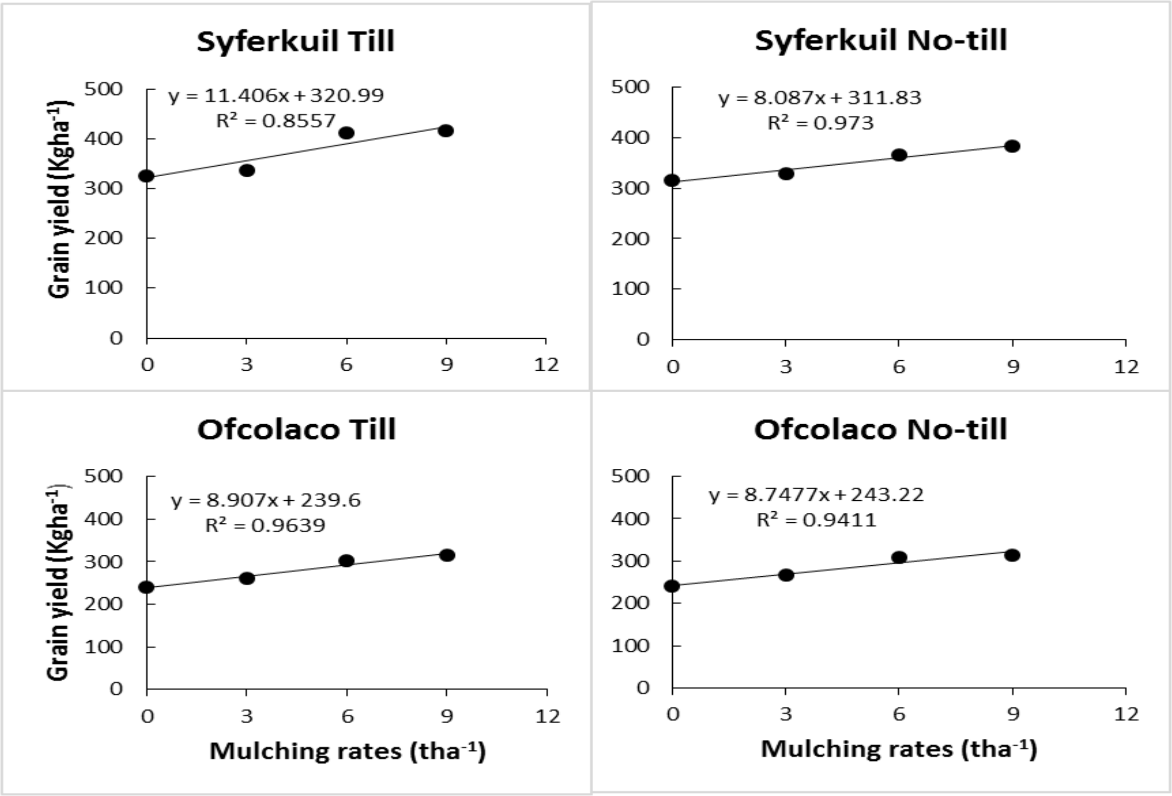

Figure 3.6: Regression analysis between mulching rates and grain yield at Syferkuil and Ofcolaco.

3.5 Crop simulation

The accuracy of the APSIM-Soybean model simulations and performance of tillage practices were assessed by running the independent data sets collected during the growing season for four mulching rates at two locations in Limpopo Province.

3.6.1 Biomass

The simulation results of crop biomass are presented in Figure 3.6. The APSIM-Soybean model simulated biomass with good agreement with the observed data collected during the growing season. Across tillage practices and at both location biomass was well simulated by the model at all mulching rates and it was higher at the mulching rate of 9 t ha^{-1} and lower with the control for both the simulated and observed data. Overall, RMSE ranged from 107.8 kg ha^{-1} to 127.0 kg ha^{-1} and from 139.1 kg ha^{-1} to 139.7 kg ha^{-1}, at Syferkuil and Ofcolaco respectively.

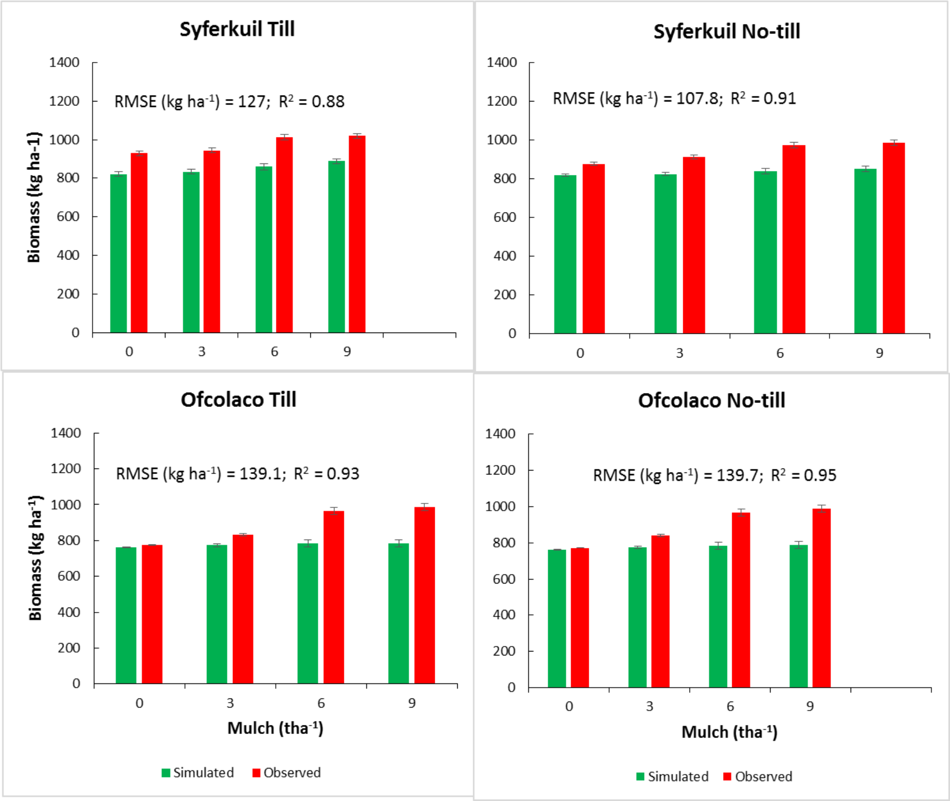

Figure 3.7: Comparison of the observed and simulated biomass at different mulching rates at Syferkuil and Ofcolaco during the year 2017. *RMSE= root mean square error, R^2=Coefficient of determination.*

3.6.2 Grain yield

A comparison between the observed and simulated grain yield is presented in Figure 3.7. In general, grain yield was better simulated by the model at both locations and across tillage practices except for till at Syferkuil at the mulching rate of 6 and 9 t ha^{-1} showing a difference between the observed and simulated data., as evidenced by a higher RMSE of 84 kg ha^{-1} when compared to the other tillage practices with RMSE ranging from 58.7 to 60.9 kg ha^{-1}. In terms of mulch application, the simulated trend was quite similar to the observed trend across the mulch application rates, except for the application rate of 6 and 9 t ha^{-1} at Syferkuil. However, the application rate of 0 and 3 t ha^{-1} were observed to be better simulated across both locations and tillage practices.

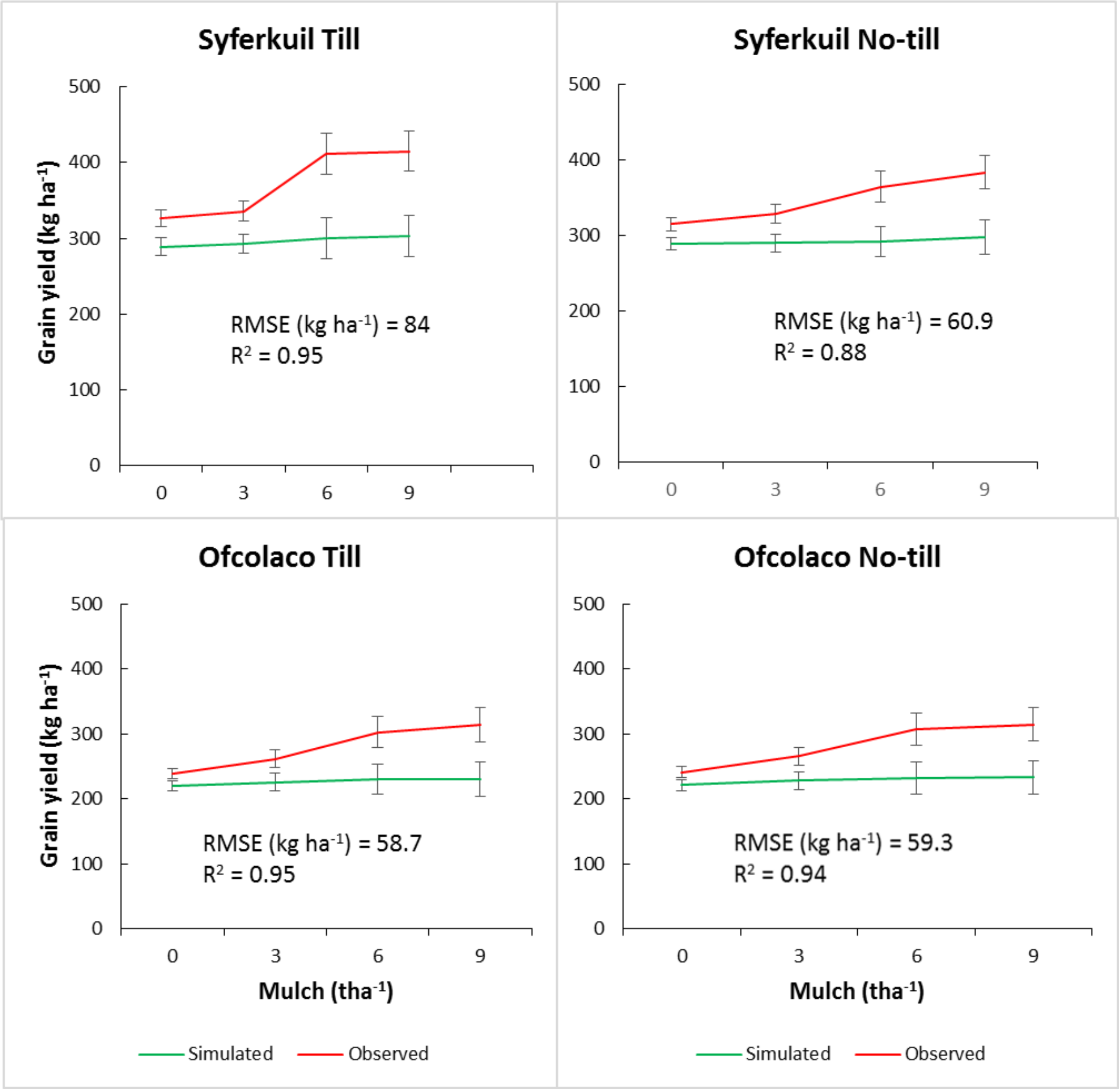

Figure 3.8: Comparison of the observed and simulated grain yield at different mulching rates at Syferkuil and Ofcolaco during the year 2017.*RMSE= root mean square error, R^2=Coefficient of determination.*

3.6 Discussion

3.6.1 Soil nutrients as influenced by tillage and mulch

Soil chemical properties changed from pre-planting to harvest maturity at both locations. The effect of tillage practices on the soil nutrients was minor, however, grass mulching improved soil properties significantly at both locations. Available P increased from pre-planting to harvest maturity, the results showed high soil P as compared to the ratings of Landon (1984), whereby soil P concentration of 0-9 mg/kg is considered very low, 10-15 mg/kg is low, 16-25 mg/kg is moderate and > 25 mg/kg is high. Phosphorus was higher under the tilled soil as well as the control plots. This could be attributed to the inability of the no-till soil to release organic P fraction and also that the mulch material contributes low phosphorus. The results concur with those of Obalum *et al* (2011), who stated that in a soybean field, main effects of both the tillage and mulch factors on P were significant, whereby the P concentration was enhanced under the conventional tillage compared to the no-till. The authors further stated that bare-fallowed plots (control) were observed to have enhanced P concentration compared to the straw mulch-covered plots.

Soil pH changed from slightly acidic at planting to neutral at harvest maturity under all treatments at both locations. The increase in soil pH, in this case, may be associated with reduced biological activity. Peverill (1999), stated that neutral soil pH leads to more available calcium in the soil. Hence the increased calcium concentration under the mulch application (3, 6 and 9 t ha^{-1}) at Ofcolaco and the application rate of 6 and 9 t ha^{-1} at Syferkuil. The increased soil pH under residue application is in agreement with Ogbodo (2011), who observed an increase in soil pH in rice straw mulch and in burnt rice husk when compared to the control.

Soil organic carbon was higher under tilled soil conditions at Syferkuil but no tillage difference observed at Ofcolaco. With respect to mulching, the application of mulch material increased the organic carbon at both locations. This could be attributed to deterioration of the mulch material which improved the soil organic pool and increased the soil organic carbon content, resulting in improved crop growth (Ogban *et al*., 2008; Malhi *et al*., 2006). The concentration of soil organic carbon at harvest maturity across treatments was however, normal. According to Peverill *et al*. (1999) under relatively low rainfall condition, and for soils intended for crop production**,** soil organic carbon is classified as follows: low: <9.0g C per kg soil (<0.9%); Normal: 9.0-14.5g C per kg soil (0.9 to 1.45%); high: >14.5g C kg^{-1} soil (>1.45). The results in this study are in agreement with those of Pal and Mahajan (2017), who reported low SOC under zero tilled soil compared to conventionally tilled soil. The authors further reported that the application of pine needle mulch was shown to increase SOC in all the cropping seasons compared to no-mulch treatment, irrespective of tillage systems. However, Al-Kaisi *et al*. (2005), reported that the response of soil carbon sequestration to zero-tillage practices is expected to be a delayed response which can be attained in 5 to 10 years.

3.6.2 Days to 50% flowering and physiological maturity

This study revealed that tilled soil conditions reduced the time taken for soybean plants to flower and reach maturity at Syferkuil but not at Ofcolaco. It was further revealed that, plants grown under the mulch application rate of 9 t ha^{-1} at Syferkuil and all mulched plots (3, 6 and 9 t ha^{-1}) at Ofcolaco took the least time to flower and mature. This is attributed to the tillage operation and mulch application which improved soil aeration for early crop growth. Kiszonas (2010), reported that, in soybean production, growth differences exist between the impacts of conventional tillage and no-tillage. This study is also in agreement with Lalitha *et al*. (2010), who stated that plastic mulch application induced early crop emergence, flowering, growth, and maturity, resulting in increased biomass production at early stages of the crop growth.

3.6.3 Plant height as influenced by tillage and mulch

Soybean height was affected by tillage method at Syferkuil but not at Ofcolaco. Plant height increased under tillage relative to no-till at Syferkuil. Mulch application also improved soybean height at the application rate of 6 and 9 t ha^{-1} at Syferkuil and under mulched plots at Ofcolaco. This might be due to the tillage operation which improved soil aeration and organic matter content in the soil and also improved moisture availability under mulch, leading to the improved vegetative growth of soybean and ultimately increased soybean biomass yield and yield parameters. Plant height was generally higher at Syferkuil and lower at Ofcolaco. This could be attributed to prevailing weather, particularly rainfall which led to improved growth. Lasisi and Aluko (2009), reported similar results where conventional tillage produced a significantly taller soybean plant than that obtained under the conservation tillage. This study is also in agreement with the report by Kader *et al*. (2017b), who showed that straw mulch significantly increased soybean height compared to the bare soil.

3.6.4 Effect of tillage and mulch on leaf chlorophyll content

The result showed a positive response of chlorophyll content to mulching at both localities. In general, chlorophyll was higher under the mulch application rate of 6 and 9 t ha^{-1} at Syferkuil and 9 t ha^{-1} at Ofcolaco. This may be due to improved moisture content under the mulch condition, which led to improved crop growth and development. This observation is contrary to the report by Kader *et al*. (2017b), whereby the leaf chlorophyll content was reported to remain invariable for the mulched treatments and bare soil.

3.6.5 Soil moisture as influenced by tillage and mulch

Tillage and mulch have shown the capabilities to retain more moisture in the soil across the two locations. Tilled soil conditions with mulch application retained more moisture at Syferkuil, whereas at Ofcolaco high moisture was found under no-till and mulch application. This is attributed to the ability of mulch to conserve moisture by lowering the soil temperature as it protects the soil against direct solar radiation impact. In general soil moisture was higher at Syferkuil than Ofcolaco and the differences in the trend of soil moisture content may be attributed to the higher rainfall at the former than at the latter (Figure 3.2). However, soil moisture was reduced with time as a result of lower rainfall received since this study was conducted under rainfed conditions. Arsyid *et al*. (2009), stated that soil moisture is highly critical in ensuring good and uniform seed establishment, crop growth and yield. These results are in agreement with the finding of Khurshid *et al*. (2006), who observed a significant interaction between tillage methods and straw mulch levels for soil moisture content. Similar results were also reported by Olaoye (2001), who observed more water retention in zero tillage than conventional tillage. Furthermore, a study from Xing *et al*. (2012), revealed that, hay mulch application rates of 2.25 and 9 Mgha^{-1} showed the ability to conserve soil moisture in non-irrigation treatments, with an increase of 5.7 to 9.5% in soil moisture content relative to a control (Xing *et al*., 2012).

3.6.6 Effect of tillage and mulch on soil temperature

This study showed that soil temperature decreased under mulch application at both locations. This may be due to the fact that mulching protects the soil against direct sunlight impact than none-mulched plot. The decrease in soil temperature was more at Syferkuil than at Ofcolaco, this might be attributed to higher temperatures at the latter (Figure 3.10) and also more soil moisture experienced at Syferkuil. Soil temperature is influenced by soil moisture, high soil moisture reduces the rate of change in temperature because water has a high specific heat capacity. (Vyn and Raimbault, 1993). These findings concur with those of Eruola *et al*. (2012), who showed soil temperature values to be the highest for the non-mulched soil than grass-mulched soil as a result of infiltration of water by non-mulched soil which emitted the high longwave radiation from the soil.

3.6.7 Nitrogen content in shoots and roots as affected by tillage and mulch

The results showed that the nitrogen content of soybean shoots and roots increased with mulch application. This could be due to more nitrogen content in the mulch which added to the soil mineralized nitrogen and led to increased nitrogen content in the shoots and roots. No findings have been reported in regard to the effect of tillage and mulch on soybean shoots and roots nitrogen yield.

3.6.8 Effect of tillage and mulch on soybean biomass accumulation

Tillage influenced biomass accumulation at Syferkuil, with mulched plots accumulating more biomass than the non-mulched plots. The effect of tillage at Ofcolaco was not significant but the application of mulch at all rates increased soybean biomass yield. A plausible explanation for this observation can be attributed to the direct impact of tillage as well as an improvement in soil condition created by mulch application. Soybean grown under mulched conditions grew faster as a result of more moisture retained by the mulch and lower soil temperature, leading to more biomass production. The effect can also be attributed to the release of nutrients from the mulch through the process of mineralization. Abdukadirova *et al*. (2016), reported a positive influence of the mulching film on the accumulation of biomass of soybean plants, in comparison with none-mulched plants. The results also concur with those of Kabirigi (2015), who reported the interactive effect of tillage and maize stover mulch to be significant ($P \leq 0.01$) in beans biomass accumulation with a 68% percent increase in conventional tillage and mulch relative to the control.

3.6.9 Effect of tillage and mulch on grain yield

Findings from this study demonstrated that, across tillage practices, soybean grain yield increased with mulched plots at Syferkuil, with no tillage effect at Ofcolaco but increased mulch application contributed more to soybean yield. This could be attributed to more soil moisture conservation through the mulching effects, improved nutrient availability (nitrogen mineralization and organic matter) and slow decomposition rate as a result of lower temperatures. Mupangwa *et al*. (2007), stated that the positive yield responses to mulching can be attributed to increased soil water in the plough layer. The findings are in agreement with those of Arora *et al*. (2011); Sekhon *et al*. (2005), who reported an increase in soybean yield with straw mulch than bare soil. While, Kabirigi (2015), reported significant interaction effect of tillage and maize stover mulch application on beans grain yield. An increase in beans grain yield of 68% was observed in conventional tillage with mulch in comparison to the conventional tillage with the control. Furthermore, no-till with mulch treatment was observed to produce higher bean grain yield relative to the control.

In general, grain yield was extremely low at the two locations during the growing season. This could be the result of the high temperatures and low rainfall experienced in study sites between January and June (Figure 3.1 and 3.2). The prevailing drought conditions negatively affected soybean grain yield at both locations. This is also supported by the simulated results of the model, which showed lower yield due to a set climatic conditions in the model. Royo *et al*. (2000); Kobraei *et al*. (2011), reported that water deficit and high temperature earlier at flowering until maturity tend to shorten the seed filling period resulting in reduced grain weight.

3.6.10 Tillage and mulch effect on soybean yield components

Generally, the results from the study showed an improvement in the number of pods plant^{-1} and 100 seed weight with mulch application at both locations. This linked to the improved crop growth and yield under mulched plots as compared to the control plots. This study is in agreement with Polthanee and Wannapat (2000) who reported that the application of 2 t ha^{-1} of rice straw mulch in cowpea resulted in increased number of pods per plant as compared to non-mulched plots. The results concur with that of Kumar and Angadi (2016), who reported a significantly higher 100-grain weight in chickpea with mulching practice (15.82 g) as compared to no mulching practice (15.19 g/ plant).

3.6.11 APSIM simulation

Capabilities of the APSIM model in validating soybean biomass and grain yield in response to different tillage and mulching practices was shown with the satisfactory degree of precision. Generally, across tillage practices and at both location biomass was well simulated by the model, with the grain yield being well simulated especially at the mulch application rate of 0 and 3 t ha^{-1}. In all, the results showed a good performance of APSIM-Soybean model during evaluation and validation under the given set of conditions. This is in agreement to the study conducted by Mabapa *et al*. (2010), that APSIM is capable of simulating crop growth and grain yield for soybean in Limpopo Province.

3.7 Conclusion

In conclusion, tillage practices had an effect on most parameters at Syferkuil than at Ofcolaco, whereby most measured parameters were not responsive to the effect of tillage. Tilled soil conditions gave a better performance. Mulch application affected all studied parameters than the non-mulch application under both locations. The heaviest application rate of 9 t ha^{-1} resulted in higher improved growth, soil moisture, soil temperature, nitrogen yield, biomass and grain yield performance at both sites. With the control plots having a poor performance across the locations. The APSIM-Soybean model better-simulated biomass and grain biomass accumulation for the tillage practices under different mulch application rates at Syferkuil and Ofcolaco. In terms of biomass production and grain yield, the results from the simulation showed a close agreement with observations from experiments at both sites.

CHAPTER 4

SYMBIOTIC ACTIVITIES, GROWTH AND PHYSIOLOGICAL DEVELOPMENT OF SOYBEAN CULTIVARS UNDER GREENHOUSE CONDITION

4.1 Introduction

Soybeans have great genotypic variations in terms of agronomic performance, chemical composition, and physical appearance (Roth *et al*., 2003). Therefore, cultivar selection is essential for successful soybean production. However, some of the differences are determined by growing environments (Liu *et al*. 2008). Symbiotic activities could not be assessed under field conditions due to lack of nodule. Hence this greenhouse study was conducted as a complementary to the field study (chapter 3) to assess the symbiotic activities, growth, and physiological development of three soybean cultivars in low nitrogen soils under greenhouse conditions. To assess whether the lack of nodulation under field condition was a results of genotype or the environment and to check for growth differences among the cultivars.

4.2 Materials and Methods

4.2.1 Study location

The pot experiment study was conducted from December 2017 to February 2018 at the Green Biotechnology Research Centre of Excellence (GBRCE), University of Limpopo South Africa (23˚53ˈ10˝S, 29˚44’15˝E). The average day/night temperature during the crop growing season in the greenhouse was recorded as 28/21 ˚C. Relative humidity was kept between 60 and 70% through wet walls.

4.2.2 Experimental design, procedures and treatments

The experiment was laid out in a randomized complete block design (RCBD), with three soybean cultivars replicated four times. The reason for blocking was to block against the light effect within the greenhouse. Three soybean types; Donmario 8.6IRR, a commercial cultivar sourced from a commercial Seed Company, Agricol), Dundee commercial cultivar and Ibis 2000, a breeder’s line sourced from Agricultural Research Council were used. These seeds were inoculated with a commercial *Bradyrhizobium* line prior to planting. Planting of the crop was timed to coincide with their normal growing season. Planting was done on 11 December 2017 and harvesting carried out on the 1st February 2018. Plastic pots of 25 cm diameter and 22 cm depth with five perforations at the bottom were used as experimental units for the trial. The pots were placed in trays so that drained water can be collected and returned to the pots after irrigation. This ensured that nutrient loss is minimized as much as possible. Soil with low nitrogen content was used to fill the pots in the experiment. Thinning of the plants occurred when the plants had reached the third leaf stage and a single, healthy seedling was left in each pot. Seedlings that were pulled out during thinning were left on top of the soil in the pot, to allow decomposition and release of the nutrients. Irrigation was done every two days at a rate of 600 ml per pot. Weeds were controlled by hand picking, when necessary.

4.2.3 Data collection

The following agronomic and physiological data were collected at 21, 28, 35 and 42 days after emergence (DAE): plant height and days to 50% flowering using the same procedure reported in chapter 3; biomass yield, above- (shoot) and below-ground (root) dry biomass at 50% flowering. The shoot biomass was separated from the root biomass using a pair of sheers. The sampled roots were washed with water on a sieve to remove bound soils and loose root biomass before separating the nodules. The dry weight of the shoot and roots were determined separately in the oven at 65°C to constant weight.

Leaf chlorophyll content was measured using CCM-200 Plus, Opti-Sciences. Data for stomatal conductance, photosynthetic rate, and transpiration rate measurements were carried out under greenhouse conditions between 10:00 am and 13:00 pm (Clifford *et al*., 1997), and the temperatures during this period of data collection was between 24.8 and 25.1. The LCi-SD Ultra Compact Photosynthesis System (ADC Bio Scientific, Hoddesdon, UK) was used for the data collection at the same sampling days. The measurements were done on a single youngest fully matured leaf per pot.

Root nodule count was carried out at 50% flowering. The whole plant was carefully removed from the soil by hand. The plants were placed in a plastic bucket filled with water to loosen the soil with the sieve to catch detached nodules. The nodules were hand-picked from the roots and the following were recorded: (a) number of nodules/plant, (b) number of effective nodules/plant (to identify the number of effective nodules fresh nodules were opened to see the color inside the nodules, effective nodules were denoted by a pink to reddish colour), (c) nodule dry weight (for nodule dry weight nodules were oven dried at 65°C for 24 hours, and weighed using an electronic weighing balance).

4.2.4 Data analysis

Growth, physiological development, and nodulation data were analyzed using the statistical analysis software, Version 9.3.1 (SAS, 2008). Regression analyses were carried out on some of the data to determine the cultivar responses as a function of time. Multiple comparisons of observed means were done using the Least Significant Difference (LSD) to determine differences among the means. The different means were denoted by *, ** or *** for significance levels $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively.

4.3 Results

4.3.1 Effect of soybean cultivars on plant height

Based on a regression analysis, a significant ($p \leq 0.001$) linear relationship of over 90% in plant height over time was observed across all soybean cultivars (Fig. 4.1). The increase in plant height ranged from 36 cm to 72 cm, at 21 DAE to 42 DAE. The cultivar, Ibis 2000 consistently produced taller plants of over 50 cm from 21 to 42 DAE, when compared to Donmario and Dundee cultivars, which were statistically similar.

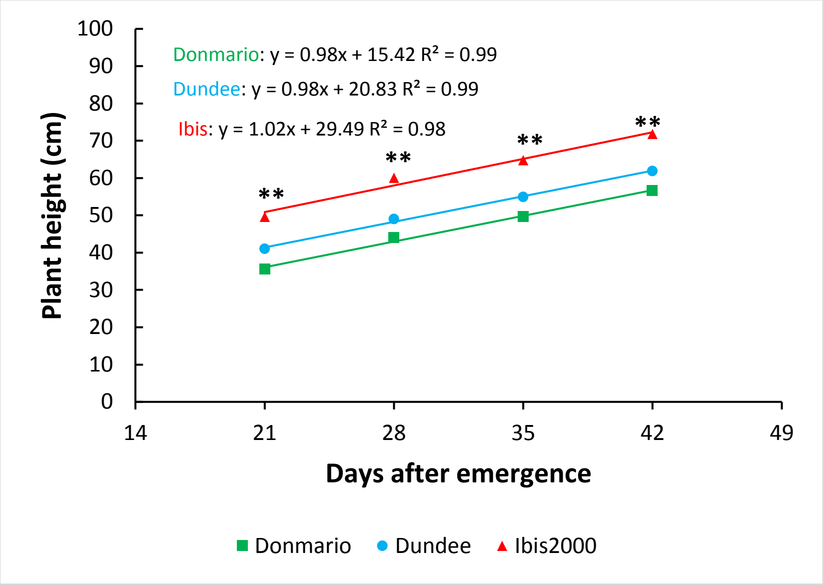

Figure 4.1: Effect of soybean cultivars on plant height at different sampling days after emergence.

4.3.2 Days to 50% flowering as influenced by soybean cultivars

There were a highly significant (*P≤0.001*) difference among the days to flowering. Days to flowering ranged from 42 to 49 days among the cultivars. Ibis 2000 cultivar flowered earlier at 42 days, followed by Dundee at 46 and lastly Donmario cultivar at 49 days (Table 4.1).

4.3.3 Shoot and root biomass as influenced by soybean cultivars

Soybean shoot biomass response to cultivar was significant (*P≤0.001*). The shoot biomass ranged from 6.7 to 10.3 g per plant. Ibis 2000 cultivar had a higher shoots biomass than Donmario and Dundee cultivars. Shoot biomass of Ibis 200 was 35 and 16.5 % higher than that of Donmario and Dundee respectively (Table 4.1).

Similar to shoot biomass production, the soybean cultivars differed significantly (*P≤0.001*) in roots biomass production. Roots biomass ranged between 3.3 and 7.0 g per plant. Higher root biomass was produced by cultivar Ibis 2000 relative to that produced by Donmario and Dundee cultivars. On a percentage basis, Ibis 2000 was 50.7 and 45.7 % higher than Donmario and Dundee, respectively (Table 4.1).

Table 4.1: Days to flowering and biomass as influenced by cultivars.

Treatment	Days to 50% flowering	Shoot biomass (g)	Root biomass (g)
Donmario	49^a	6.7^c	3.3^b
Dundee	46^b	8.6^b	3.8^b
Ibis 2000	42^c	10.3^a	7.0^a
LSD (0.05)	***	***	***

*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 0.01 ***significant at 0.001 ns = Not significant.*

4.3.4 Effect of soybean cultivars on leaf chlorophyll content

Regression analysis showed a significant positive linear relationship between chlorophyll content and days after emergence for all soybean cultivars. From 21 to 35 DAE, cultivar Ibis 2000 had the highest chlorophyll content as compared to Donmario and Dundee cultivars. Dundee cultivar had the lowest chlorophyll content among the three cultivars. Chlorophyll content was statistically similar among soybean cultivars at 42 DAE (Figure 4.2).

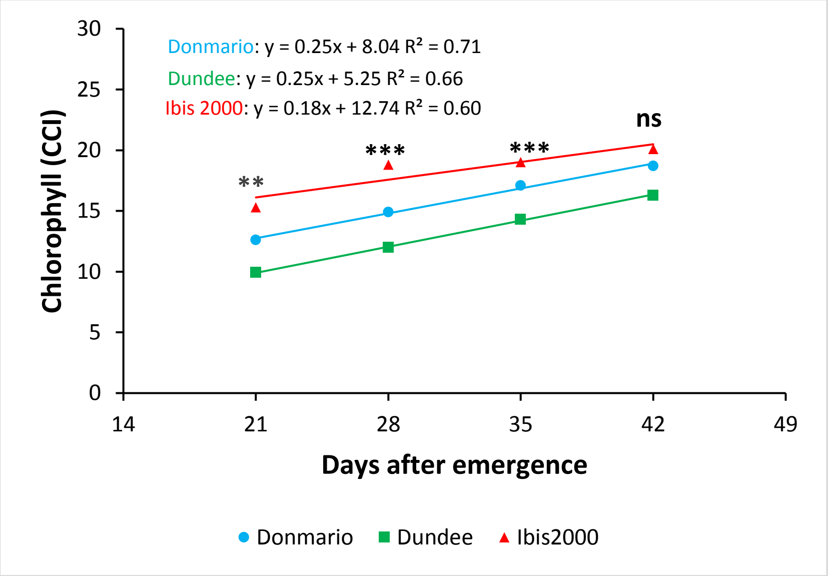

Figure 4.2: Effect of soybean cultivars on chlorophyll content at different sampling days.

4.3.5 Effect of soybean cultivars on stomatal conductance (gs)

The effect of soybean cultivars on stomatal conductance (gs) is presented in Figure 4.3 Regression analysis revealed a highly negative relationship between stomatal conductance and sampling days across all soybean cultivars with an R^2 of over 90% at $p < 0.001$. It was observed that stomatal conductance consistently decreased with sampling days in all cultivars. Donmario and Ibis 2000 cultivars had a higher gs from 21 to 42 DAE, while, Dundee cultivar had the lowest gs at all sampling days.

4.3.6 Photosynthetic rate (A) as influenced by soybean cultivars.

Based on regression analysis, a significant ($p < 0.001$) negative linear relationship was observed between photosynthetic rate and sampling days in the soybean cultivars studies. No increase in A was observed in all cultivars but rather a steady decrease with time from the first measurement (21 DAE) to the last (42 DAE). Ibis 2000 cultivar exhibited a superior rate compared to Donmario and Dundee cultivars which were statistically similar (Figure 4.3).

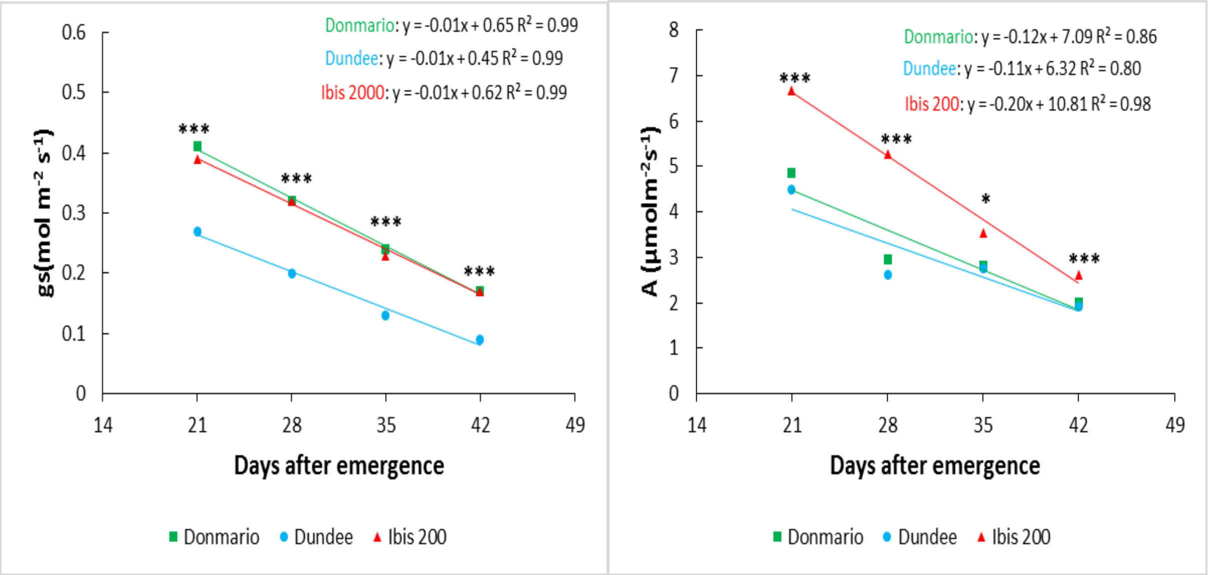

Figure 4.3: Influence of soybean cultivars on stomatal conductance (gs) and photosynthetic rate (A) at different sampling days.

4.3.7 Transpiration rate as influenced by soybean cultivars

Transpiration rate varied significantly (p < 0.001) amongst the soybean cultivars and decreased with time. At 21, 28 and 42 DAE, Dundee and Ibis 2000 cultivars had a higher E, with Donmario having the lowest E relative to Ibis 2000 cultivar but not significantly different from Dundee. At 35 DAE Ibis 2000 cultivar exhibited a higher E when compared to Donmario and Dundee which were statistically similar (Table 4.2).

Table 4.2: Effect of soybean cultivars on transpiration rate (E).

Treatment	**Transpiration rate (mmol m^{-2} s^{-1})**			
Cultivar	21DAE	28DAE	35DAE	42DAE
Donmario	4.18^{b}	3.66^{b}	3.44^{b}	2.75^{b}
Dundee	4.36^{ab}	3.76^{ab}	3.44^{b}	2.94^{ab}
Ibis2000	4.46^{a}	4.15^{a}	3.60^{a}	3.16^{a}
LSD (0.05)	*	*	**	**

*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 0.01 ***significant at 0.001 ns = Not significant.*

4.3.8 Soybean nodulation as influenced by cultivars

Statistical analysis revealed that the nodule formation and nodule dry weight varied significantly (*P≤0.001*) with soybean cultivar. Cultivar Ibis 2000 produced the highest number of nodules per plant and nodule dry weight when compared to Donmario and Dundee cultivars. While Donmario had the lowest number of nodules and nodule dry weight in comparison to Dundee cultivar (Table 4.3).

The number of active nodules was significantly (*p≤0.05*) influenced by cultivars. The highest number of active nodules was obtained from Dundee and Ibis 2000 cultivars. However, the number of active nodules under Donmario cultivar was not significantly different from Dundee but was lower than Ibis 2000 cultivar (Table 4.3).

Table 4.3: Nodulation of soybean cultivars at flowering to early podding.

Treatment	NN/plant	NDW/plant (g)	No of AN/plant
Donmario	1.50^{c}	0.26^{c}	1.00^{b}
Dundee	3.75^{b}	0.70^{b}	2.25^{ab}
Ibis 2000	5.75^{a}	0.87^{a}	3.25^{a}
LSD (0.05)	***	***	*

*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 0.01, ***significant at 0.001, ns = Not significant.* NN= number of nodules, NDW= nodule dry weight, AN=Active nodules

4.4 Discussion

4.4.1 Effect of soybean cultivars on plant height

Statistical analysis showed a significant cultivar response of soybean of height over time. On average, the tallest cultivar was Ibis 2000. This observation could be attributed to the genetic differences amongst the soybean cultivars. Khan *et al*. (2008) reported that cultivars differ in height as a result of their growth habit, which is genotypic in nature. The results are in line with Tekola *et al*. (2018), who reported a highly significant ($P<0.01$) effect of soybean varieties on plant height, and the observed difference was attributed to the inherent genotypic difference.

4.4.2 Growth and biomass yield as influenced by soybean cultivars

Results obtained from the study showed that days to 50% flowering and biomass yield is influenced by cultivar. Ibis 2000 cultivar took the least time to reach flowering and had a higher shoot and root biomass yield. This can be attributed to the different genetic makeup of the cultivars. The substantially higher biomass of Ibis 2000 could help protect the soil from increased evaporation and also contribute to soil fertility. For example, when the leaves fall into the soil they will decompose thereby adding organic matter, and thus, improving the nutrient conditions in the soil. The results of this study are in agreement with that of Maphosa (2015), who reported that soybean variety significantly affects days to 50% flowering under glasshouse conditions in the Limpopo Province. The results further concur with that of Tekola *et al*. (2018), who reported plant growth measured as shoots and roots dry weight to be significantly (*$p \leq 0.01$*) affected by soybean variety and the observed differences could be genetic or difference due to the ability of N^2- fixing among the varieties. Singh *et al*. (2011), also found that some cultivars exhibit superior plant growth and have the ability to out-yield the other cultivars.

4.4.3 Effect of soybean cultivars on leaf chlorophyll content

Soybean chlorophyll content was influenced by cultivars. The chlorophyll content increased with time and this may be due to the fact that the cultivars were still at vegetative stage. Ibis 2000 cultivar had the highest chlorophyll content. This may be associated with physiological differences in cultivars. Minotti *et al* (1994) reported that cultivars influence chlorophyll content of plants as leaves of certain cultivar tend to have certain morphological and physiological traits, such as thickness, pigment content and internal structure which may influence the spectral properties of a leaf. These findings are in agreement with those of Maphosa (2015), who showed that both the promiscuous and non-promiscuous soybean varieties influenced leaf chlorophyll content in different soils of Limpopo under glasshouse conditions.

4.4.4 Effect of soybean cultivars on stomatal conductance (gs)

The findings from this study revealed that soybean cultivars vary in stomatal conductance under greenhouse conditions, along with a highly positive relationship between soybean cultivar and time. Stomatal conductance displayed a gradual decrease in all the cultivars with time. Generally, Donmario and Ibis 2000 cultivars had a higher gs. Hufstetler *et al*. (2007), stated that stomatal conductance is an important physiological trait that governs dry matter accumulation and plant water balance. Hence, the improved biomass accumulation under different cultivars in this study. The results are in agreement with Bunce (2016), who reported soybean cultivars to differ significantly in gs under greenhouse conditions.

4.4.5 Photosynthetic rate (A) as influenced by soybean cultivars

The result from this study showed that cultivar had an influence on photosynthetic rate as photosynthetic rate decreased with time in all the three cultivars. Ibis 2000 cultivar had a higher A and this could be attributed to a relatively higher duration of stomatal opening. In a study, Jadoski *et al*. (2005), reported that a decrease in photosynthetic rate was related to the lower concentration of CO_2 found within the leaves, which may result from the stomatal opening. Bosco *et al*. (2009), also stated stomatal limitation to be the main factor of the photosynthetic performance limitation time. The results concur with those of Krenchinski *et al*. (2017), who reported four RR2 soybean cultivars to differ in photosynthetic rate.

4.4.6 Transpiration rate (E) as influenced by soybean cultivars

The results from this study showed transpiration rate to vary greatly among soybean cultivars and also decreased with time. This may be due to stomatal closure, where a reduction in stomata opening decreases transpiration rate. Cultivar Donmario and Ibis 2000 had higher transpiration rate. The variation could be attributed to genetic differences in the cultivars. According to Krenchinski *et al*. (2017), higher transpiration is related to the higher photosynthesis rate. In the present study, a decrease in photosynthesis led to a decrease in transpiration rate. Hartmann (2010), stated that transpiration differs with cultivars. The results are contrary to those of Krenchinski *et al*. (2017), who found that four cultivars studied under greenhouse conditions did not differ in the transpiration rate (E).

4.4.7 Nodule production as influenced by soybean cultivars

The results revealed that, soybean cultivar influenced the number of nodules, nodule dry weight, and number of active nodules. Ibis 2000 cultivar produced the highest number of nodules per plant, nodule dry weight, while for the number of active nodules, Ibis 2000 cultivar and Dundee had the highest. This might be due to the improved growth and biomass yield of Ibis 2000 cultivars. Bekere *et al.* (2012), reported that, a high number of nodules is associated with taller soybean plants. These results are in agreement with the study of Arulnandhy (undated), who investigated 15 soybean cultivars and indicated that there was a remarkable difference in nodule number and nodule dry weight among investigated cultivars, which indicated a wide variation in their ability to nodulate. The results are also in line with those of Tekola *et al*. (2018), who showed the number of nodules per plant and nodule dry weight of soybean to be significantly ($P \leq 0.01$) influenced by the soybean varieties. In the study, the number of nodules per plant ranged from 9 to 18, while the highest nodule dry weight was 0.18 g plant^{-1} and the lowest was 0.10 g plant^{-1}.

4.5 Conclusion

In general, there was a highly significant cultivar effect on all the parameters studied. The findings revealed that growth, physiological development, and nodulation responded to variation in cultivars, with cultivar Ibis 2000 performing better than Donmario and Dundee in almost all the parameters. This study led to the conclusion that Donmario is a non-promiscuous cultivar with poor nodulation. Further studies should be conducted to evaluate various soybean cultivars under diverse soil types.

CHAPTER 5

GENERAL CONCLUSION AND RECOMMENDATIONS

5.1 Overview

This chapter covers the summary of the findings from chapters 3 and 4, conclusions drawn from the findings as per objectives and finally the recommendations for future studies.

5.2 Conclusion

In line with hypothesis 1 that tillage and mulch influence soybean growth and yield, the hypothesis is accepted. Secondly, hypothesis number 2 is accepted as APSIM model validates soybean biomass and yield accumulation under tillage and mulch with good precision. The 3rd hypothesis is also accepted the cultivars influenced symbiotic activities, growth and physiological development under greenhouse conditions. The results also revealed mulch application to be important in soybean production as it significantly influenced all studied parameters at both sites. The application of mulch at the rate of 9 t ha^{-1} yielded better results in all the parameters studied, followed by 6 t ha^{-1}. This could be the result of the mulch capacity to store more soil moisture. However, very low grain yield was experienced at both sites during the growing season which is the result of extreme drought expereineced during the growing season.

Results from the greenhouse study revealed differences in soybean cultivars in terms of growth, physiological response and nodulation performance, with Ibis 2000 performing better than the commercial cultivars (Donmario and Dundee). The study thus, highlights the need to evaluate soybean cultivars under different climatic locations in order to ensure their adaptability to various conditions for improved growth, nodulation and productivity on farmers' fields.

The APSIM-Soybean model satisfactorily simulated the biomass accumulation and grain yield under the two tillage practices at different mulching rates in the selected locations of the areas of Limpopo Province. In general, grain and biomass yield were satisfactorily simulated by the model at the mulching rates of 0 and 3 t ha^{-1} at both locations. The results suggest that the model can be used to guide alternate ways of improving soybean production in Limpopo Province.

5.3 Recommendations

Continuous no-till experiment is required in diverse locations to realize the benefit of this practice in soybean production. Given the good impact of mulching on soybean productivity in the study, further studies involving increased mulching rates, more growing seasons and multiple locations in the Limpopo Province are required to identify the suitable mulching rates that will results in optimum grain yield under contrasting climatic conditions of the Province. Early plantings should also be considered due to prevailing drought conditions for improved soybean yield. Further research on modeling the growth and yield of soybean and other field crops grown under rainfed conditions of Limpopo Province should also be initiated.

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LIST OF APPENDICES

Analysis of variance (ANOVA) tables for soybean at Syferkuil

Appendix 3.1: soil PH

Source of variance	DF	SS	MS	F	P
Replication	3	0.03008	0.01003		
Tillage	1	0.00911	0.00911	0.82	0.4324
Error rep*tillage	3	0.03341	0.01114		
Mulch	3	0.17015	0.05672	4.97	0.0110
Tillage*mulch	3	0.02974	0.00991	0.87	0.4752
Error rep*tillage*mulch	18	0.20526	0.01140		
Total	31	0.47775			

Appendix 3.2: Soil Phosphorus

Source of variance	DF	SS	MS	F	P
Replication	3	3.6950	1.2317		
Tillage	1	0.7813	0.7813	0.70	0.4633
Error rep*tillage	3	3.3338	1.1113		
Mulch	3	60.5650	20.1883	51.28	0.0000
Tillage*mulch	3	0.5938	0.1979	0.50	0.6852
Error rep*tillage*mulch	18	7.0862	0.3937		
Total	31	76.0550			

Appendix 3.3: Soil Potassium

Source of variance	DF	SS	MS	F	P
Replication	3	116.1	38.71		
Tillage	1	55.1	55.13	3.66	0.1515
Error rep*tillage	3	45.1	15.04		
Mulch	3	12616.1	4205.37	141.95	0.0000
Tillage*mulch	3	60.1	20.04	0.68	0.5777
Error rep*tillage*mulch	18	533.2	29.62		
Total	31	13425.9			

Appendix 3.4: Soil Calcium

Source of variance	DF	SS	MS	F	P
Replication	3	2584.3	861.4		
Tillage	1	5967.8	5967.8	62.20	0.0042
Error rep*tillage	3	287.8	95.9		
Mulch	3	55174.6	18391.5	12.28	0.0001
Tillage*mulch	3	7090.6	2363.5	1.58	0.2294
Error rep*tillage*mulch	18	26957.1	1497.6		
Total	31	98062.2			

Appendix 3.5: Soil Magnesium

Source of variance	DF	SS	MS	F	P
Replication	3	591.2	197.08		
Tillage	1	9800.0	9800.00	23.87	0.0164
Error rep*tillage	3	1231.8	410.58		
Mulch	3	26445.2	8815.08	9.59	0.0005
Tillage*mulch	3	3820.7	1273.58	1.38	0.2795
Error rep*tillage*mulch	18	16552.5	919.58		
Total	31	58441.5			

Appendix 3.6: Soil Zinc

Source of variance	DF	SS	MS	F	P
Replication	3	0.04094	0.01365		
Tillage	1	0.00281	0.00281	0.14	0.7345
Error rep*tillage	3	0.06094	0.02031		
Mulch	3	1.44344	0.48115	34.56	0.0000
Tillage*mulch	3	0.00344	0.00115	0.08	0.9688
Error rep*tillage*mulch	18	0.25063	0.01392		
Total	31	1.80219			

Appendix 3.7: Soil Manganese

Source of variance	DF	SS	MS	F	P
Replication	3	5.2500	1.75000		
Tillage	1	3.1250	3.12500	5.77	0.0957
Error rep*tillage	3	1.6250	0.54167		
Mulch	3	15.2500	5.08333	6.97	0.0026
Tillage*mulch	3	5.1250	1.70833	2.34	0.1073
Error rep*tillage*mulch	18	13.1250	0.72917		
Total	31	43.5000			

Appendix 3.8: Soil Copper

Source of variance	DF	SS	MS	F	P
Replication	3	0.06375	0.02125		
Tillage	1	0.40500	0.40500	17.36	0.0252
Error rep*tillage	3	0.07000	0.02333		
Mulch	3	0.41125	0.13708	4.21	0.0202
Tillage*mulch	3	0.18250	0.06083	1.87	0.1712
Error rep*tillage*mulch	18	0.58625	0.03257		
Total	31	1.71875			

Appendix 3.9: Soil Nitrogen

Source of variance	DF	SS	MS	F	P
Replication	3	8.25006	2.75006		
Tillage	1	5.00007	5.00007	0.02	0.8990
Error rep*tillage	3	7.87505	2.62505		
Mulch	3	0.01049	3.49703	93.96	0.0000
Tillage*mulch	3	1.27505	4.25006	0.11	0.9507
Error rep*tillage*mulch	18	6.70004	3.72205		
Total	31	0.01126			

Appendix 3.10: Soil Organic Carbon

Source of variance	DF	SS	MS	F	P
Replication	3	0.00623	0.00208		
Tillage	1	0.03283	0.03283	50.79	0.0057
Error rep*tillage	3	0.00194	0.00065		
Mulch	3	0.52534	0.17511	73.30	0.0000
Tillage*mulch	3	0.00797	0.00266	1.11	0.3701
Error rep*tillage*mulch	18	0.04300	0.00239		
Total	31	0.61731			

Appendix 3.11: Days to 50% flowering

Source	DF	SS	MS	F	P
Replication	3	16.375	5.4583		
Tillage	1	15.125	15.1250	10.37	0.0486
Error rep*tillage	3	4.375	1.4583		
Mulch	3	62.375	20.7917	5.04	0.0104
Tillage*mulch	3	0.375	0.1250	0.03	0.9926
Error rep*tillage*mulch	18	74.250	4.1250		
Total	31	172.875			

Appendix 3.12: Days to physiological maturity

Source of variance	DF	SS	MS	F	P
Replication	3	50.625	16.8750		
Tillage	1	66.125	66.1250	63.48	0.0041
Error rep*tillage	3	3.125	1.0417		
Mulch	3	200.625	66.8750	4.28	0.0191
Tillage*mulch	3	26.125	8.7083	0.56	0.6499
Error rep*tillage*mulch	18	281.250	15.6250		
Total	31	627.875			

Appendix 3.13: Plant height at 45 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	2.4675	0.82250		
Tillage	1	7.0313	7.03125	11.27	0.0438
Error rep*tillage	3	1.8713	0.62375		
Mulch	3	20.7850	6.92833	27.58	0.0000
Tillage*mulch	3	0.7838	0.26125	1.04	0.3987
Error rep*tillage*mulch	18	4.5213	0.25118		
Total	31	37.4600			

Appendix 3.14: Plant height at 60 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	3.4300	1.1433		
Tillage	1	15.9613	15.9613	9.35	0.0551
Error rep*tillage	3	5.1237	1.7079		
Mulch	3	61.3375	20.4458	36.04	0.0000
Tillage*mulch	3	1.4162	0.4721	0.83	0.4935
Error rep*tillage*mulch	18	10.2112	0.5673		
Total	31	97.4800			

Appendix 3.15: Plant height at 80 DAE

Source	DF	SS	MS	F	P
Replication	3	0.648	0.2161		
Tillage	1	14.178	14.1778	16.14	0.0277
Error rep*tillage	3	2.636	0.8786		
Mulch	3	103.713	34.5711	60.08	0.0000
Tillage*mulch	3	1.581	0.5270	0.92	0.4531
Error rep*tillage*mulch	18	10.358	0.5755		
Total	31	133.115			

Appendix 3.16: Chlorophyll content at 45 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	5.6821	1.8940		
Tillage	1	0.4371	0.4371	0.35	0.5933
Error rep*tillage	3	3.6952	1.2317		
Mulch	3	46.5175	15.5058	16.67	0.0000
Tillage*mulch	3	1.4059	0.4686	0.50	0.6845
Error rep*tillage*mulch	18	16.7472	0.9304		
Total	31	74.4850			

Appendix 3.17: Chlorophyll content at 60 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	6.8154	2.2718		
Tillage	1	0.0378	0.0378	0.02	0.8873
Error rep*tillage	3	4.7734	1.5911		
Mulch	3	40.7732	13.5911	19.37	0.0000
Tillage*mulch	3	2.0183	0.6728	0.96	0.4335
Error rep*tillage*mulch	18	12.6312	0.7017		
Total	31	67.0492			

Appendix 3.18: Chlorophyll content at 80 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	10.2283	3.40945		
Tillage	1	0.3717	0.37174	0.15	0.7236
Error rep*tillage	3	7.3906	2.46353		
Mulch	3	18.3534	6.11778	3.24	0.0465
Tillage*mulch	3	6.8312	2.27707	1.21	0.3360
Error rep*tillage*mulch	18	33.9875	1.88819		
Total	31	77.1627			

Appendix 3.19: Soil moisture (0-30 cm) at flowering

Source of variance	DF	SS	MS	F	P
Replication	3	0.0315	0.01051		
Tillage	1	0.3103	0.31031	233.09	0.0006
Error rep*tillage	3	0.0040	0.00133		
Mulch	3	26.5041	8.83470	3366.75	0.0000
Tillage*mulch	3	0.1139	0.03798	14.47	0.0000
Error rep*tillage*mulch	18	0.0472	0.00262		
Total	31	27.0111			

Appendix 3.20: Soil moisture content (30-60 cm) at flowering

Source of variance	DF	SS	MS	F	P
Replication	3	0.0434	0.0145		
Tillage	1	0.7007	0.7007	47.72	0.0062
Error rep*tillage	3	0.0440	0.0147		
Mulch	3	56.8056	18.9352	1223.12	0.0000
Tillage*mulch	3	0.4773	0.1591	10.28	0.0004
Error rep*tillage*mulch	18	0.2787	0.0155		
Total	31	58.3496			

Appendix 3.21: Soil moisture content (0-30 cm) at Harvesting

Source of variance	DF	SS	MS	F	P
Replication	3	0.0050	0.00167		
Tillage	1	0.1815	0.18153	42.13	0.0074
Error rep*tillage	3	0.0129	0.00431		
Mulch	3	14.0484	4.68279	1721.29	0.0000
Tillage*mulch	3	0.0859	0.02862	10.52	0.0003
Error rep*tillage*mulch	18	0.0490	0.00272		
Total	31	14.3827			

Appendix 3.22: Soil moisture content (30-60 cm) at Harvesting

Source of variance	DF	SS	MS	F	P
Replication	3	0.0113	0.00378		
Tillage	1	0.0782	0.07824	25.69	0.0148
Error rep*tillage	3	0.0091	0.00305		
Mulch	3	18.4954	6.16514	1687.06	0.0000
Tillage*mulch	3	0.0031	0.00103	0.28	0.8384
Error rep*tillage*mulch	18	0.0658	0.00365		
Total	31	18.6630			

Appendix 3.23: Soil temperature 45 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	0.7084	0.2361		
Tillage	1	0.0253	0.0253	0.09	0.7789
Error rep*tillage	3	0.8059	0.2686		
Mulch	3	30.1984	10.0661	43.16	0.0000
Tillage*mulch	3	1.0459	0.3486	1.49	0.2497
Error rep*tillage*mulch	18	4.1981	0.2332		
Total	31	36.9822			

Appendix 3.24: Soil temperature 60 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	0.818	0.2728		
Tillage	1	0.165	0.1653	3.40	0.1625
Error rep*tillage	3	0.146	0.0486		
Mulch	3	97.673	32.5578	113.18	0.0000
Tillage*mulch	3	0.226	0.0753	0.26	0.8520
Error rep*tillage*mulch	18	5.178	0.2877		
Total	31	104.207			

Appendix 3.25: Soil temperature 80 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	4.4438	1.4813		
Tillage	1	0.6050	0.6050	2.77	0.1946
Error rep*tillage	3	0.6550	0.2183		
Mulch	3	75.4113	25.1371	78.88	0.0000
Tillage*mulch	3	1.0375	0.3458	1.09	0.3806
Error rep*tillage*mulch	18	5.7363	0.3187		
Total	31	87.8888			

Appendix 3.26: Roots Nitrogen yield

Source of variance	DF	SS	MS	F	P
Replication	3	0.00188	0.00063		
Tillage	1	0.00070	0.00070	4.59	0.1215
Error rep*tillage	3	0.00046	0.00015		
Mulch	3	0.24626	0.08209	86.76	0.0000
Tillage*mulch	3	0.00453	0.00151	1.60	0.2249
Error rep*tillage*mulch	18	0.01703	0.00095		
Total	31	0.27087			

Appendix 3.27: Shoots Nitrogen yield

Source of variance	DF	SS	MS	F	P
Replication	3	0.02974	0.00991		
Tillage	1	0.01125	0.01125	0.67	0.4735
Error rep*tillage	3	0.05050	0.01683		
Mulch	3	0.38551	0.12850	10.34	0.0003
Tillage*mulch	3	0.03843	0.01281	1.03	0.4025
Error rep*tillage*mulch	18	0.22366	0.01243		
Total	31	0.73909			

Appendix 3.28: Biomass

Source of variance	DF	SS	MS	F	P
Replication	3	1631.0	543.7		
Tillage	1	12728.1	12728.1	43.83	0.0070
Error rep*tillage	3	871.2	290.4		
Mulch	3	56754.5	18918.2	47.76	0.0000
Tillage*mulch	3	422.0	140.7	0.36	0.0078
Error rep*tillage*mulch	18	7129.2	396.1		
Total	31	79536.1			

Appendix 3.29: Grain yield

Source of variance	DF	SS	MS	F	P
Replication	3	4.0	1.3		
Tillage	1	4642.5	4642.5	278.91	0.0005
Error rep*tillage	3	49.9	16.6		
Mulch	3	37392.0	12464.0	1637.24	0.0000
Tillage*mulch	3	2069.2	689.7	90.60	0.0000
Error rep*tillage*mulch	18	137.0	7.6		
Total	31	44294.7			

Appendix 3.30: Pods plant^{-1}

Source of variance	DF	SS	MS	F	P
Replication	3	9.844	3.281		
Tillage	1	0.781	0.781	0.19	0.6925
Error rep*tillage	3	12.344	4.115		
Mulch	3	436.844	145.615	87.19	0.0000
Tillage*mulch	3	4.344	1.448	0.87	0.4763
Error rep*tillage*mulch	18	30.062	1.670		
Total	31	494.219			

Appendix 3.31: 100 seed weight

Source	DF	SS	MS	F	P
Replication	3	2.6250	0.87500		
Tillage	1	0.7813	0.78125	3.95	0.1411
Error rep*tillage	3	0.5938	0.19792		
Mulch	3	12.4375	4.14583	10.61	0.0003
Tillage*mulch	3	3.4063	1.13542	2.91	0.0630
Error rep*tillage*mulch	18	7.0312	0.39062		
Total	31	26.8750			

Appendix 3.32: seed pods^{-15}

Source of variance	DF	SS	MS	F	P
Replication	3	27.625	9.208		
Tillage	1	136.125	136.125	6.32	0.0866
Error rep*tillage	3	64.625	21.542		
Mulch	3	38.375	12.792	0.99	0.4183
Tillage*mulch	3	65.375	21.792	1.69	0.2042
Error rep*tillage*mulch	18	231.750	12.875		
Total	31	563.875			

Analysis of variance (ANOVA) tables for soybean at Ofcolaco

Appendix 3.33: Soil PH

Source of variance	DF	SS	MS	F	P
Replication	3	0.01094	0.00365		
Tillage	1	0.00281	0.00281	0.53	0.5195
Error rep*tillage	3	0.01594	0.00531		
Mulch	3	0.72344	0.24115	37.54	0.0000
Tillage*mulch	3	0.00344	0.00115	0.18	0.9097
Error rep*tillage*mulch	18	0.11563	0.00642		
Total	31	0.87219			

Appendix 3.34: Soil Phosphorus

Source of variance	DF	SS	MS	F	P
Replication	3	1.094	0.3646		
Tillage	1	11.281	11.2812	9.42	0.0546
Error rep*tillage	3	3.594	1.1979		
Mulch	3	134.844	44.9479	24.85	0.0000
Tillage*mulch	3	9.344	3.1146	1.72	0.1983
Error rep*tillage*mulch	18	32.563	1.8090		
Total	31	192.719			

Appendix 3.35: Soil Potassium

Source	DF	SS	MS	F	P
Replication	3	124.1	41.4		
Tillage	1	19.5	19.5	0.08	0.7919
Error rep*tillage	3	705.3	235.1		
Mulch	3	58756.8	19585.6	107.19	0.0000
Tillage*mulch	3	602.6	200.9	1.10	0.3751
Error rep*tillage*mulch	18	3288.8	182.7		
Total	31	63497.2			

Appendix 3.36: Soil Calcium

Source of variance	DF	SS	MS	F	P
Replication	3	3354.4	1118.1		
Tillage	1	15.1	15.1	0.07	0.8037
Error rep*tillage	3	616.4	205.5		
Mulch	3	63996.1	21332.0	65.86	0.0000
Tillage*mulch	3	504.6	168.2	0.52	0.6743
Error rep*tillage*mulch	18	5830.3	323.9		
Total	31	74316.9			

Appendix 3.37: Soil Magnesium

Source of variance	DF	SS	MS	F	P
Replication	3	815.1	271.7		
Tillage	1	0.5	0.5	0.01	0.9464
Error rep*tillage	3	281.7	93.9		
Mulch	3	38285.1	12761.7	218.23	0.0000
Tillage*mulch	3	687.7	229.2	3.92	0.0257
Error rep*tillage*mulch	18	1052.6	58.5		
Total	31	41122.9			

Appendix 3.38: Soil Zinc

Source of variance	DF	SS	MS	F	P
Replication	3	0.09625	0.03208		
Tillage	1	0.00500	0.00500	0.67	0.4740
Error rep*tillage	3	0.02250	0.00750		
Mulch	3	2.75125	0.91708	45.07	0.0000
Tillage*mulch	3	0.02750	0.00917	0.45	0.7200
Error rep*tillage*mulch	18	0.36625	0.02035		
Total	31	3.26875			

Appendix 3.39: Soil Manganese

Source of variance	DF	SS	MS	F	P
Replication	3	7.094	2.3646		
Tillage	1	0.281	0.2812	1.00	0.3910
Error rep*tillage	3	0.844	0.2812		
Mulch	3	88.094	29.3646	12.64	0.0001
Tillage*mulch	3	4.844	1.6146	0.70	0.5670
Error rep*tillage*mulch	18	41.812	2.3229		
Total	31	142.969			

Appendix 3.40: Soil Copper

Source of variance	DF	SS	MS	F	P
Replication	3	0.05594	0.01865		
Tillage	1	0.00281	0.00281	0.16	0.7177
Error rep*tillage	3	0.05344	0.01781		
Mulch	3	1.59844	0.53281	58.79	0.0000
Tillage*mulch	3	0.00094	0.00031	0.03	0.9911
Error rep*tillage*mulch	18	0.16312	0.00906		
Total	31	1.87469			

Appendix 3.41: Soil Nitrogen

Source of variance	DF	SS	MS	F	P
Replication	3	1.75004	5.83305		
Tillage	1	5.00005	5.00005	0.40	0.5720
Error rep*tillage	3	3.75004	1.25004		
Mulch	3	4.05003	1.35003	19.44	0.0000
Tillage*mulch	3	1.00004	3.33305	0.48	0.7002
Error rep*tillage*mulch	18	1.25003	6.94405		
Total	31	6.00003			

Appendix 3.42: Soil Organic carbon

Source of variance	DF	SS	MS	F	P
Replication	3	0.00166	0.00055		
Tillage	1	0.00038	0.00038	1.21	0.3510
Error rep*tillage	3	0.00093	0.00031		
Mulch	3	0.45756	0.15252	433.62	0.0000
Tillage*mulch	3	0.00098	0.00033	0.93	0.4452
Error rep*tillage*mulch	18	0.00633	0.00035		
Total	31	0.46785			

Appendix 3.43: Days to 50% flowering

Source of variance	DF	SS	MS	F	P
Replication	3	8.844	2.9479		
Tillage	1	0.781	0.7813	0.25	0.6509
Error rep*tillage	3	9.344	3.1146		
Mulch	3	59.344	19.7812	15.11	0.0000
Tillage*mulch	3	1.344	0.4479	0.34	0.7951
Error rep*tillage*mulch	18	23.563	1.3090		
Total	31	103.219			

Appendix 3.44: Days to physiological maturity

Source of variance	DF	SS	MS	F	P
Replication	3	12.5000	4.16667		
Tillage	1	0.00000	0.00000	0.00	1.0000
Error rep*tillage	3	4.00000	1.33333		
Mulch	3	501.500	167.167	118.00	0.0000
Tillage*Mulch	3	0.00000	0.00000	0.00	1.0000
Error rep*tillage*mulch	18	25.5000	1.41667		
Total	31	543.500			

Appendix 3.45: Plant height at 45 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	0.0812	0.02708		
Tillage	1	3.3800	3.38000	27.97	0.0132
Error rep*tillage	3	0.3625	0.12083		
Mulch	3	26.6013	8.86708	15.29	0.0000
Tillage*Mulch	3	0.9925	0.33083	0.57	0.6417
Error rep*tillage*mulch	18	10.4412	0.58007		
Total	31	41.8588			

Appendix 3.46: Plant height at 60 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	3.0584	1.0195		
Tillage	1	1.4028	1.4028	4.50	0.1241
Error rep*tillage	3	0.9359	0.3120		
Mulch	3	38.2084	12.7361	27.01	0.0000
Tillage*mulch	3	1.4159	0.4720	1.00	0.4151
Error rep*tillage*mulch	18	8.4881	0.4716		
Total	31	53.5097			

Appendix 3.47: Plant height at 80 DAE

Source of variance	DF	SS	MS	F	P
Rep	3	3.453	1.1511		
Tillage	1	0.813	0.8128	3.29	0.1673
Error rep*tillage	3	0.741	0.2470		
Mulch	3	87.106	29.0353	32.83	0.0000
Tillage*mulch	3	2.533	0.8445	0.95	0.4352
Error rep*Ttillage*mulch	18	15.918	0.8843		
Total	31	110.565			

Appendix 3.48: Chlorophyll content 45 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	0.57873	0.19291		
Tillage	1	2.02005	2.02005	13.28	0.0356
Error rep*tillage	3	0.45638	0.15213		
Mulch	3	1.52712	0.50904	2.64	0.0807
Tillage*mulch	3	0.92248	0.30749	1.60	0.2254
Error rep*tillage*mulch	18	3.46905	0.19273		
Total	31	8.97380			

Appendix 3.49: Chlorophyll content 60 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	1.0834	0.36113		
Tillage	1	1.5313	1.53125	4.25	0.1313
Error rep*tillage	3	1.0811	0.36036		
Mulch	3	11.7103	3.90344	8.95	0.0008
Tillage*mulch	3	1.2976	0.43252	0.99	0.4191
Error rep*tillage*mulch	18	7.8518	0.43621		
Total	31	24.5554			

Appendix 3.50: Chlorophyll content 80 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	0.5584	0.18613		
Tillage	1	0.4348	0.43478	1.53	0.3041
Error rep*tillage	3	0.8525	0.28417		
Mulch	3	5.3954	1.79845	3.06	0.0548
Tillage*mulch	3	1.2739	0.42464	0.72	0.5518
Error rep*tillage*mulch	18	10.5861	0.58812		
Total	31	19.1011			

Appendix 3.51: Soil moisture (0-30 cm) at flowering

Source of variance	DF	SS	MS	F	P
Replication	3	0.1618	0.05394		
Tillage	1	0.2448	0.24477	32.29	0.0108
Error rep*tillage	3	0.0227	0.00758		
Mulch	3	20.1789	6.72630	386.52	0.0000
Tillage*mulch	3	0.0723	0.02411	1.39	0.2793
Error rep*tillage*mulch	18	0.3132	0.01740		
Total	31	20.9938			

Appendix 3.52: Soil moisture (30-60 cm) at flowering

Source of variance	DF	SS	MS	F	P
Replication	3	0.0996	0.03320		
Tillage	1	0.3383	0.33834	18.95	0.0224
Error rep*tillage	3	0.0536	0.01785		
Mulch	3	14.1183	4.70611	166.83	0.0000
Tillage*mulch	3	0.1775	0.05916	2.10	0.1364
Error rep*tillage*mulch	18	0.5078	0.02821		
Total	31	15.2950			

Appendix 3.53: Soil moisture (0-30 cm) at Harvesting

Source of variance	DF	SS	MS	F	P
Replication	3	0.00116	0.00039		
Tillage	1	0.07057	0.07057	312.66	0.0004
Error rep*tillage	3	0.00068	0.00023		
Mulch	3	6.42011	2.14004	3104.56	0.0000
Tillage*mulch	3	0.00316	0.00105	1.53	0.2418
Error rep*tillage*mulch	18	0.01241	0.00069		
Total	31	6.50808			

Appendix 3.54: Soil moisture (30-60 cm) at Harvesting

Source of variance	DF	SS	MS	F	P
Replication	3	0.00031	0.00010		
Tillage	1	0.06619	0.06619	217.91	0.0007
Error rep*tillage	3	0.00091	0.00030		
Mulch	3	5.76445	1.92148	3150.03	0.0000
Tillage*mulch	3	0.00073	0.00024	0.40	0.7545
Error rep*tillage*mulch	18	0.01098	0.00061		
Total	31	5.84358			

Appendix 3.55: Soil temperature at 45 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	0.54344	0.18115		
Tillage	1	0.26281	0.26281	4.55	0.1228
Error rep*tillage	3	0.17344	0.05781		
Mulch	3	0.72844	0.24281	0.87	0.4750
Tillage*mulch	3	0.76844	0.25615	0.92	0.4523
Error rep*tillage*mulch	18	5.02563	0.27920		
Total	31	7.50219			

Appendix 3.56: Soil temperature at 60 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	0.6363	0.2121		
Tillage	1	0.2813	0.2813	0.28	0.6346
Error rep*tillage	3	3.0362	1.0121		
Mulch	3	53.0613	17.6871	120.25	0.0000
Tillage*mulch	3	1.1062	0.3687	2.51	0.0917
Error rep*tillage*mulch	18	2.6475	0.1471		
Total	31	60.7688			

Appendix 3.57: Soil temperature at 80 DAE

Source of variance	DF	SS	MS	F	P
Replication	3	0.3712	0.1237		
Tillage	1	0.0050	0.0050	0.01	0.9113
Error rep*tillage	3	1.0225	0.3408		
Mulch	3	70.7913	23.5971	27.00	0.0000
Tillage*mulch	3	0.1575	0.0525	0.06	0.9801
Error rep*tillage*mulch	18	15.7313	0.8740		
Total	31	88.0788			

Appendix 3.58: Roots nitrogen yield

Source of variance	DF	SS	MS	F	P
Replication	3	0.00051	0.00017		
Tillage	1	0.00020	0.00020	0.07	0.8132
Error rep*tillage	3	0.00902	0.00301		
Mulch	3	0.81941	0.27314	152.63	0.0000
Tillage*mulch	3	0.00932	0.00311	1.74	0.1953
Error rep*tillage*mulch	18	0.03221	0.00179		
Total	31	0.87069			

Appendix 3.59: Shoots nitrogen yield

Source of variance	DF	SS	MS	F	P
Replication	3	0.00111	0.00037		
Tillage	1	0.00138	0.00138	2.79	0.1937
Error rep*tillage	3	0.00148	0.00049		
Mulch	3	0.23568	0.07856	107.69	0.0000
Tillage*mulch	3	0.00181	0.00060	0.83	0.4962
Error rep*tillage*mulch	18	0.01313	0.00073		
Total	31	0.25460			

Appendix 3.60: Biomass

Source of variance	DF	SS	MS	F	P
Replication	3	238	79.3		
Tillage	1	29	28.7	0.13	0.7416
Error rep*tillage	3	658	219.3		
Mulch	3	252889	84296.3	574.74	0.0000
Tillage*mulch	3	201	67.1	0.46	0.7155
Error rep*tillage*mulch	18	2640	146.7		
Total	31	256655			

Appendix 3.61: Grain yield

Source of variance	DF	SS	MS	F	P
Replication	3	25.4	8.47		
Tillage	1	63.1	63.09	3.91	0.1422
Error rep*tillage	3	48.3	16.12		
Mulch	3	29421.1	9807.03	1292.78	0.0000
Tillage*mulch	3	33.0	11.01	1.45	0.2610
Error rep*tillage*mulch	18	136.5	7.59		
Total	31	29727.5			

Appendix 3.62: Pod plant^{-1}

Source of variance	DF	SS	MS	F	P
Rep	3	7.5937	2.53125		
Tillage	1	0.0312	0.03125	0.02	0.9052
Error rep*tillage	3	5.5937	1.86458		
Mulch	3	25.3437	8.44792	4.10	0.0221
Tillage*mulch	3	2.3438	0.78125	0.38	0.7690
Error rep*tillage*mulch	18	37.0625	2.05903		
Total	31	77.9687			

Appendix 3.63: 100 seed weight

Source of variance	DF	SS	MS	F	P
Replication	3	1.2734	0.42448		
Tillage	1	0.0703	0.07031	0.46	0.5472
Error rep*tillage	3	0.4609	0.15365		
Mulch	3	5.1484	1.71615	8.95	0.0008
Tillage*mulch	3	0.2109	0.07031	0.37	0.7780
Error rep*tillage*mulch	18	3.4531	0.19184		
Total	31	10.6172			

Appendix 3.64: seeds pod^{-1}

Source of variance	DF	SS	MS	F	P
Replication	3	1.344	0.4479		
Tillage	1	34.031	34.0312	0.78	0.4417
Error rep*tillage	3	130.594	43.5312		
Mulch	3	19.094	6.3646	0.52	0.6769
Tillage*mulch	3	3.344	1.1146	0.09	0.9645
Error rep*tillage*mulch	18	222.313	12.3507		
Total	31	410.719			

Analysis of variance (ANOVA) tables for soybean at Greenhouse

Appendix 4.1: Plant height at 21 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	148.1250000	49.3750000	1.17	0.3499
Cultivar	2	811.0833333	405.5416667	9.58	0.0015
Error	18	761.750000	42.319444		
Total	23	1720.958333			

Appendix 4.2: Plant height at 28 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	206.458333	68.819444	1.53	0.2413
Cultivar	2	1090.083333	545.041667	12.11	0.0005
Error	18	810.416667	45.023148		
Total	23	2106.958333			

Appendix 4.3: Plant height at 35 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	247.5000000	82.5000000	1.75	0.1936
Cultivar	2	943.5833333	471.7916667	9.98	0.0012
Error	18	850.750000	47.263889		
Total	23	2041.833333			

Appendix 4.4: Plant height at 42 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	247.5000000	82.5000000	1.75	0.1936
Cultivar	2	943.5833333	471.7916667	9.98	0.0012
Error	18	850.750000	47.263889		
Total	23	2041.833333			

Appendix 4.5: Days to 50% flowering

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.0000000	0.0000000	0.00	1.0000
Cultivar	2	162.7500000	81.3750000	279.00	<.0001
Error	18	5.2500000	0.2916667		
Total	23	168.0000000			

Appendix 4.6: Shoots Biomass

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.26567917	0.08855972	0.23	0.8750
Cultivar	2	54.18415833	27.09207917	70.03	<.0001
Error	18	6.96376833	0.38687546		
Total	23	61.41359683			

Appendix 4.7: Roots Biomass

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.39588333	0.13196111	0.37	0.7773
Cultivar	2	63.97145833	31.98572917	89.10	<.0001
Error	18	6.46164167	0.35898009		
Total	23	70.82898333			

Appendix 4.8: Chlorophyll content at 21 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	11.1150000	3.7050000	0.66	0.5866
Cultivar	2	115.0258333	57.5129167	10.26	0.0011
Error	18	100.8775000	5.6043056		
Total	23	227.0183333			

Appendix 4.9: Chlorophyll content at 28 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	8.5345833	2.8448611	0.91	0.4565
Cultivar	2	187.0075000	93.5037500	29.86	<.0001
Error	18	56.3741667	3.1318981		
Total	23	251.9162500			

Appendix 4.10: Chlorophyll content at 35 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	18.9566667	6.3188889	2.12	0.1339
Cultivar	2	129.9733333	64.9866667	21.76	<.0001
Error	18	53.7633333	2.9868519		
Total	23	202.6933333			

Appendix 4.11: Chlorophyll content at 42 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	24.67166667	8.22388889	1.09	0.3794
Cultivar	2	35.32333333	17.66166667	2.34	0.1252
Error	18	136.0233333	7.5568519		
Total	23	196.1083333			

Appendix 4.12: Stomatal conductance at 21 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.00794583	0.00264861	1.38	0.2803
Cultivar	2	0.09075833	0.04537917	23.68	<.0001
Error	18	0.03449167	0.00191620		
Total	23	0.13319583			

Appendix 4.13: Stomatal conductance at 28 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.00979512	0.00326504	1.51	0.2452
Cultivar	2	0.07737908	0.03868954	17.93	<.0001
Error	18	0.03884975	0.00215832		
Total	23	0.12602396			

Appendix 4.14: Stomatal conductance at 35 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.01382479	0.00460826	1.47	0.2551
Cultivar	2	0.06796508	0.03398254	10.87	0.0008
Error	18	0.05626508	0.00312584		
Total	23	0.13805496			

Appendix 4.15: Stomatal conductance at 42 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.00797846	0.00265949	1.82	0.1792
Cultivar	2	0.02958475	0.01479238	10.14	0.0011
Error	18	0.02626742	0.00145930		
Total	23	0.06383063			

Appendix 4.16: Photosynthetic rate at 21 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.18378333	0.06126111	0.08	0.9725
Cultivar	2	22.04853333	11.02426667	13.55	0.0003
Error	18	14.63966667	0.81331481		
Total	23	36.87198333			

Appendix 4.17: Photosynthetic rate at 28 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.12516667	0.04172222	0.22	0.8831
Cultivar	2	33.91727500	16.95863750	88.30	<.0001
Error	18	3.45695833	0.19205324		
Total	23	37.49440000			

Appendix 4.18: Photosynthetic rate at 35 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.01161250	0.00387083	0.01	0.9986
Cultivar	2	3.13560000	1.56780000	4.01	0.0363
Error	18	7.03725000	0.39095833		
Total	23	10.18446250			

Appendix 4.19: Photosynthetic rate at 42 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.00974583	0.00324861	0.02	0.9963
Cultivar	2	2.17943333	1.08971667	6.34	0.0082
Error	18	3.09191667	0.17177315		
Total	23	5.28109583			

Appendix 4.20: Transpiration rate at 21 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.04624583	0.01541528	0.39	0.7625
Cultivar	2	0.32110000	0.16055000	4.05	0.0353
Error	18	0.71371667	0.03965093		
Total	23	1.08106250			

Appendix 4.21: Transpiration rate at 28 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.01584583	0.00528194	0.03	0.9917
Cultivar	2	1.10207500	0.55103750	3.42	0.0551
Error	18	2.89964167	0.16109120		
Total	23	4.01756250			

Appendix 4.22: Transpiration rate at 35 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.07431667	0.02477222	1.15	0.3568
Cultivar	2	0.29747500	0.14873750	6.89	0.0060
Error	18	0.38845833	0.02158102		
Total	23	0.7602500			

Appendix 4.23: Transpiration rate at 42 DAE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.00637917	0.00212639	0.03	0.9915
Cultivar	2	0.68957500	0.34478750	5.41	0.0145
Error	18	1.14770833	0.06376157		
Total	23	1.84366250			

Appendix 4.24: Number of nodules plant^{-1}

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	7.33333333	2.44444444	0.74	0.5433
Cultivar	2	72.33333333	36.16666667	10.91	0.0008
Error	18	59.6666667	3.3148148		
Total	23	139.3333333			

Appendix 4.25: Nodule dry weight

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	0.05864583	0.01954861	2.29	0.1126
Cultivar	2	1.57157500	0.78578750	92.18	<.0001
Error	18	0.15344167	0.00852454		
Total	23	1.78366250			

Appendix 4.26: Active nodules number

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Replication	3	6.83333333	2.27777778	1.38	0.2803
Cultivar	2	16.00000000	8.00000000	4.85	0.0206
Error	18	29.66666667	1.64814815		
Total	23	52.50000000			