MODELLING THE EFFECTS OF MAIZE/LABLAB INTERCROPPING ON SOIL WATER CONTENT AND NITROGEN DYNAMICS USING APSIM-MODEL

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DECLARATION

I, Rapholo Seroto Edith, declare that the research submitted for the degree of Master of Science (MSc.) in Agriculture (Soil Science) at the University of Venda is my original work and has not been submitted for any degree or examination at any other University. I further declare that all sources cited or quoted are indicated and acknowledged by means of a comprehensive list of references.

Signature: .... Date 26/06/2020

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
APSIM	Agricultural Production System Simulator
ARC	Agricultural Research Council
BD	Bulk Density
Ca	Calcium
CEC	Cations Exchange Capacity
CLL	Crop Lower Limit
cm	Centimeter
°C	Degrees Celsius
OC	Organic Carbon
DAP	Days after planting
DST	Department of Science and Technology
DUL	Drained Upper Limit
Fbiom	Microbial Biomass
Finert	Proportion of soil carbon assumed not to decompose
K	Potassium
Kg	Kilogram
Kg/ha	Kilogram per hectare
KL	Water extraction coefficient
LAN	Limestone Ammonium Nitrate
LER	Land Equivalent Ratio
LL	Lower Limit
LSD	Least Significant Difference
m	Meter
mm	Millimeter
Mg	Magnesium
mg kg^{-1}	Milligram per kilogram

N	Nitrogen
NH_4^+	Ammonium ion
NO_3^-	Nitrate ion
NRF	National Research Foundation
P	Phosphorus
RCBD	Randomized Complete Block Design
RMSE	Root mean square error
SAT	Saturation Volumetric water content
SWcon	Saturated flow
T_{min}	Minimum temperature
T_{max}	Maximum temperature
t ha^{-1}	Tonnes per hectare
XF	Root Exploration Factor

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I dedicate this work to my late brother Rathabe Michael Rapholo and sister Mosima Estrech Machete who supported and viewed education as the passport to the future.

ABSTRACT

Maize (*Zea mays L*.) is widely grown in the semi-arid regions of South Africa mainly for its grain that is used for direct human consumption, feed for animals and raw materials for the industries. The challenges of soil infertility, water supply, and availability of high yielding cultivars remain a major constraint for its production in this environment. These constraints are a major threat to sustainable crop production and food security. Maize/lablab *Zea mays L.\ L. purpureus)* intercropping system could thus become an option for food security among small scale maize producers in dry environments. Preliminary studies show the huge potential of maize/lablab intercropping in the semi-arid environments of the North-Eastern South Africa. Therefore, this study aimed to assess the effects of maize/lablab intercropping on soil water content, nitrogen dynamics and crop productivity based field experiments and crop simulation modeling using the model APSIM. The trials were conducted at two sites (Univen and Syferkuil) in Limpopo province, South Africa, for two seasons (2015/2016) and 2016/2017).

The treatments consisted of; (i) sole maize (ii) sole lablab (iii) maize and lablab planted at the same time (Maize+lablab-ST) and (iv) maize with lablab planted 28 days after maize (Maize+lablab-28).The treatments were laid out in an RCBD replicated 4 times, with individual plots size measuring 4.5 m × 4 m (18 m^2) and the layout of the field as consisting of 4 plots per block giving a total of 16 plots in 4 blocks. The following parameters were determined: soil water content, soil NO_3^--N and NH_4^+-N levels, dry matter and grain yield. The APSIM-model (version 7.7) was then used to simulate maize grain yield and dry matter production to assess risks associated with the production of maize/lablab intercropping.

The results obtained from this study showed that maize/lablab intercropping had significant effects on measured parameters (grain, biomass yield soil water content, and N-minerals). Maize+lablab-28 produced 46 % higher grain yield than sole cropping (24%) and maize+lablab-ST) (30%). The results also showed variation in soil water content at different depths among the treatments. The soil water content was increased with depth. The intercropped plots and lablab sole had significantly higher soil water content than the sole maize. At all depths, the highest soil water content was obtained under sole lablab followed by maize+lablab-ST and maize+lablab-28. It was notable however that maize/lablab intercropping showed a higher NO_3^--N and NH_4^+-N levels at all depths. At both sites, the soil NO_3^--N showed a sharp drop at V7 sampling time. The results showed the benefits of intercropping in comparison to sole cropping as demonstrated by positive land equivalent ratios of >1 for both cropping systems in both years and sites. Modelling exercises showed that APSIM was able to simulate the results sufficiently. In the simulation experiment, a stronger negative effect of planting lablab with maize simultaneously was found. Hence, delayed planting of lablab should be a standard practice

Keywords: *Zea mays L.*, *L. purpureus* , intercropping, APSIM-model, simulate, validate

CHAPTER 1: INTRODUCTION

1.1 Background information

Maize *(Zea mays L.)* is one of the most important staple grain in Africa when compared with rice and wheat (Dahmardeh *et al.,* 2009). It is a summer crop, mostly grown in semiarid regions of the country (Benhin, 2006). The crop originated from Mexico but its production spread fast around the world (Wrigley and Batey, 2010). Maize accounts for 30% of the total area under cereal production in Sub-Saharan Africa, 19% in West Africa, 61% in Central Africa, 21% in Eastern Africa and 65% in Southern Africa (FAO, 2010). The crop is a staple food for more than 200 million people living in developing countries (Nuss and Tanumihardjo, 2010), where it has a variety of uses ranging from direct human consumption, feed for animals (poultry, pigs, cattle), to raw material for the industries (agri-food, textile, pharmaceutical, etc.) (Khaliq *et al*, 2004). South African farmers produce both white (human consumption) and yellow (animal feed) maize. In South Africa, white maize is made into what is known locally as "pap", the main dietary source of energy for many households. Maize is a major crop produced by smallholder and commercial farmers in Limpopo Province. A large proportion of the population in Limpopo Province depends on maize as their primary staple food (Ayisi and Whitbread, 2004).

Maize can be grown as a sole crop or jointly with another crop (so called intercropping). Intercropping is an agricultural practice of planting two or more crops in the same piece of land within the same year to promote their interaction (Thobatsi, 2009). It is commonly practiced in Asia, Africa, and South America (Bhartnagar *et al*., 2015). Intercropping represents a viable agronomic practice by ensuring the effective utilization of resources in space and time (Lemlem, 2013). As a result, intercropping of cereal/legumes is being practiced in many areas of South Africa, including Limpopo Province, due to land scarcity and need to enhance food production (Odhiambo and Nemadodzi, 2007). Several researchers have clearly indicated the beneficial effects of maize and legume intercrop on weed control, crop growth, soil moisture content, and other soil resources (Ayisi and Mpangane, 2004; Maluleke *et al*., 2005; Bennet *et al.,* 2012; Oelbermann and Echarte 2011). Intercropping cereals with a legume is usually proposed in the farming system in Limpopo Province in order to enhance nitrogen nutrition in the system of which nitrogen is a major limiting plant nutrient in cereal production in smallholders (Ayisi and Mpangane, 2004). Maize can be intercropped with legume cover crops such as velvet bean, cowpea and lablab to maximize yield. In this study, maize was intercropped with lablab.

Lablab *(L. purpureus)* is a drought-tolerant legume crop with large seeds that are easy to handle (Whitbread *et al.,* 2004). The crop is grown in certain parts of Africa such as Kenya, Tanzania, Uganda, and Ethiopia, primarily as a food crop with both the grain and the immature pods being consumed. In more temperate climates, it is a more challenging plant and does not produce pods so well, but it can still be rewarding to grow it. Lablab is a forage legume which has a wide variety of uses in farming such as animal feed, soil fertility improvement through biological nitrogen fixation and green manuring, cover crop for management of weeds, water and pests and also as human food and its large above-ground biomass mulches the soil and conserves moisture for maize (Chigariro, 2004). There are two hundred types of lablab recognized, but only two cultivars, (Rongai and Highworth), are available commercially (Aganga and Tshwenyane 2003). Lablab has been found to be well adapted to the dry environment of Limpopo province and it has the potential to be intercropped with maize (Maluleke *et al*., 2004). When lablab is intercropped with maize, it fixes nitrogen which is used by the maize, supplies large quantities of good quality fodder for animals, conserves soil water content, and provides grain and leafy vegetables for human food, thus improving food security.

One of the main advantages of maize/lablab intercropping is the biological nitrogen fixation (BNF) by the lablab. Lablab can fix atmospheric nitrogen up to 120 to 200 kg N/ha depending on the climatic and soil conditions (Valenzuela and Smith, 2002; Lindemann and Glover, 2003). Nitrogen is of prime importance to maize growth. Maize can use nitrogen either in the cation form, ammonium, or the anion form, nitrate. Nitrogen is needed in large amount compared to other elements. Maize/lablab intercropping also can increase productive water use (transpiration) and reduces evaporation from the soil beneath crop canopy and hence soil water conservation (Maluleke *et al*., 2005). Therefore, maize/lablab intercropping can have economic, ecological and environmental benefits compared to mono-cropping according to the cited references.

The use of models to predict agricultural crop production over long periods under intercropping has matured over the years (Fosu-Mensah, 2012). These models are able to quantify the benefits and the risk of intercropping on parameters such as soil water content and nitrogen dynamics across the range of soil types and climate faced by small-scale farmers (Robertson *et al.,* 2005). The Agricultural Production System Simulator (APSIM) has been proven to be a useful tool for representing long-term productivity and environmental effects on cropping systems and extrapolating the experimental results in time and space (Muli *et al.,* 2015).

The use of crop system models to simulate crop yields results in greater understanding hence, improves prediction and reduces the risk of total crop loss or drastic low yield (Fosu-Mensah, 2012). Crop models help researchers to ascertain the relationship between the environment, management, and yield variability and also predicting the effects of weather, soil properties and plant characteristic on soil water (Muli *et al.,* 2015). The APSIM-model will be used in this study to assess the effects of maize/lablab intercropping on soil water content, nitrogen dynamics and production.

1.2 Objectives

1.2.1 Main objective

To assess the effects of maize/lablab intercropping on resource use efficiency and productivity in comparison to sole cropping

1.2.2 Specific Objectives

i. To determine the effects of maize/lablab intercropping on soil water content and mineral N levels (NH_4^+ and NO_3^-).

ii. To determine the effects of maize/lablab intercropping on maize/lablab dry matter production, grain yield and land equivalent ratio.

iii. To simulate maize/lablab intercropping biomass production and grain yield as influenced by climatic conditions using APSIM-model.

1.2 Hypotheses of the study

i. Maize/lablab intercropping conserve soil water content and provides additional soil mineral N levels (NH_4^+ and NO_3^-).

ii. Maize/lablab intercropping has a positive effect on maize dry matter, grain yield and land equivalent ratio.

iii. APSIM-model simulates with great accuracy the maize/lablab intercropping biomass production and grain yield as influenced by climatic conditions.

CHAPTER 2: LITERATURE REVIEW

2.1 Maize origin and utilization

Maize (*Zea Mays L*.) is one of the most important staple grain, occupying the third position next to wheat and rice in cereal production in South Africa. Maize is produced throughout the country under diverse environments with the Free State, Mpumalanga and KwaZulu-Natal provinces being the largest producers (FAOSTAT, 2012). Nuss and Tanumihardjo*,* (2010) reported that approximately 80 million tons of maize are produced in South Africa annually on approximately 3.1 million hectares of land. In the year 2011, 2.86 million hectares of farmland were allocated to maize production in South Africa (Department of Agriculture Forestry and Fisheries (DAFF), 2012).

Maize is consumed by more than half of the population of South African as a primary staple food (Makhaga *et al.,* 2011). It is a multipurpose crop that provides food for human, feed for animals such as poultry, pigs and cattle and raw materials for the industries, for example, agrifood, and pharmaceuticals (Khalig *et al.,* 2004). Maize has a high composition of carbohydrate (84%), protein (10%), fats (4.5%) and (1.3) minerals *(*Du Plessis*,* 2003)*.* Maize has been recognized as a common component in most intercropping systems and Intercropping has become one of the solutions to increase maize production among small scale farmers (Belel *et al.,* 2014)*.*

Maize can be grown on a wide variety of soils, but performs well in deep, well-drained and easily tilled soil. Maize can be grown successfully on soils with a pH of 5.0-7.0, but a moderately acid environment of pH 6.0 – 7.0 is optimum (FAOSTAT, 2012). The crop can be successfully grown in areas receiving rainfall in excess of 350 mm per annum

(Thobatsi, 2009). In a survey carried out in Vhembe district of Limpopo Province in 2004, inadequate rainfall (49%), weed infestation (23%) and low soil fertility (20%) were reported as the most important factors limiting the grain yields of maize (Nemutshili and Ogola, 2010). Alkpalu *et al,* (2009) reported that temperatures below 5°C and above 45°C results in poor growth and death of the maize plants. According to EcoAfrica (2015), 62% of Limpopo's maize area is attributed to smallholder farmers whose yields are constrained by drought stress, poor soil fertility, weeds and pests, and low input availability. Therefore, there is a need to develop a sustainable strategy that will improve maize yields to alleviate food insecurity and poverty in the province.

2.2 Lablab origin and utilization

Lablab (*L. purpureus*) is a legume that is presently grown in certain parts of Africa namely Kenya, Tanzania, Uganda, Botswana, and Ethiopia, primarily as a food crop with both the grain and the immature pods being consumed. There is a limited understanding of the origin and diversity of lablab bean due to little research and development, but it is believed that the crop is native to Asia or Africa (Pengelly and Maass, 2001; Robotham and Chapman, 2015). Lablab is not well known in South Africa but initial trials indicated that it can be successfully grown in the northern part of the country which is the Limpopo Province (Ayisi and Whitbread, 2004). Lablab is a twinning annual legume capable of producing large quantities of biomass, it is a large-seed hence easy to handle and established (Whitbread *et al*., 2004). The leaves are trifoliate, and the flowers are purple or white. Lablab is useful as a forage crop and as a cover crop that can add nitrogen to the soil through biological nitrogen fixation (Ayisi and Whitbread, 2004). Lablab can fix atmospheric nitrogen up to 120 to 200 kg N/ha when it is planted either as an intercrop or as a sole crop depending on the climatic and soil conditions (Lindemann and Glover, 2013). Following an initial study with smallholder farmers in rural communities, it was reported by (Whitbread *et al.,* 2004) that fresh or dried lablab leaves could be cooked and consumed as a leafy vegetable as well as being used as a grain legume.

Lablab can grow in a wide range of soil textures, from heavy clays to sandy soils. It tolerates acidic soils, growing well when soil pH is 4.5-6.5, it does well in low fertility soils and is a drought-tolerant legume (Valenzuela and Smith 2002). Njarui and Mureithi (2010) reported that lablab improves maize yield and it provides highly nutritious livestock feeds. Therefore, more studies should be done to raise the awareness of the potential and proper production of lablab intercropped with maize among the smallholder farmers.

2.3 Intercropping and its effects on soil

2.3.1 Intercropping

Intercropping is an agricultural practice of growing two or more crops in the same area. The practice increases production on a given piece of land by making efficient use of the available soil resources (Lemlem*,* 2013). It does not mean crops have to be planted at the same time together, but rather that two or more crops are together in one place, during their growing season or at least in the time frame (Mousavi and Eskandari, 2011). Intercropping legumes with maize is practiced to achieve many advantages, such as the utilization of environmental factors, soil protection and a variety of food resources (Bantie*,* 2014). Odhiambo and Nemadodzi (2007) found that because of the shortage of land only 39% of the farmers in Limpopo province practice intercropping.

One of the most important reasons for intercropping is to ensure that an increased and diverse productivity per unit area is obtained compared to sole cropping. Li *et al.,* (2015) mentioned that in many countries such as China, Egypt, and India, intercropping has played an important role in increasing crop production and farmers' income. There are different techniques farmers can choose to intercrop which need to be practiced to produce at optimal levels for both crops and to benefit the environment, especially with regard to soil fertility. These intercropping techniques are row-intercropping, mixed-cropping, strip-cropping and relay intercropping which are the most important (Sullivan, 2003 and Carlson, 2008).

2.3.2 Benefits of Intercropping to soil

Intercropping helps to maintain and improve soil fertility because legume crops such as cowpea, lablab, soybean and groundnuts accumulate from 80 to 350 kg nitrogen (N)/ha (Mobasser *et al.,* 2014). Successful crop mixtures such as maize/lablab combination extend the sharing of available resources over time and space and both crops benefit (Oljaca*,* 2000) which is the productive form of intercropping (Dolijanovic *et al*., 2013). Intercropping uses resources more efficiently than in the corresponding monoculture (Mobasser *et al.,* 2014). Intercropping conserves soil water by providing shade, reducing wind speed, increasing infiltration rate, improving soil structure (Mobasser *et al.,* 2014) and could help to increase soil organic matter content over time (Dolijanovic *et al.,* 2013). Intercropping has also been reported to increase light interception compared with sole cropping. Li *et al*., (2015) mentioned that intercropping largely improves nitrogen-use efficiency and land-use efficiency when compared with monoculture.

Maize is susceptible to many pests and diseases, and intercropping practice appears to decrease and control the spread of pests and diseases (Seran *et al.,* 2010). Trenbath (1993) cited by Ijoyah (2012) reported that pest and diseases were less in maize/tomato intercropping compared to tomato alone. Intercropping controls weeds as compared with mono-cropping (Seran *et al.,* 2010), and encourages efficient use of natural resources, thus decreasing the growth of weeds (Mobasser *et al.,* 2014).

2.3.3 Effect of intercropping on grain yield and dry matter of maize and lablab

Several authors reported that intercropping maize with legumes resulted in a decrease in yield. This was attributed to delayed planting of the cassava crop which was affected by interspecific crop competition. This is worsened by the early vigorously growing legumes which outperform the maize early growth (Rahman *et al*., 2017; Yang *et al.,* 2017; Hirpa, 2013; Gbaraneh *et al.,* 2004). Makgoga, (2013), reported that lablab had a greater leaf canopy than other legumes (chickpea, cowpea, and groundnut) and hence had a greater negative effect of on maize yield. Intercropping sustainably improves crop productivity and household income, nutrition and livelihood of the farmers.

Similarly, contrasting results on the effect of maize/lablab intercropping on yield and dry matter of maize and lablab have been reported. For example, intercropping maize and lablab increased the yield of maize but did not favor lablab yield improvement (Lemlem, 2013). Ennin and Dapaah (2008) revealed a positive legume yield in the maize-legume intercropping system. Also, intercropping reduced the number of soybean pods per plant in the first season and seed yield in the first and second seasons (Muoneke *et al.,* 2007). Intercropping with maize reduced the number of pods, seed weight and grain yield in soybean in two cropping seasons (Dapaah *et al.,* 2003). Soybean is a relatively long season crop compared to cowpea. The decrease in the grain yield of legumes was reported due to intercropping with maize (Eskandari and Ghanbari, 2009). It is clear from the foregoing that the effect of maize/lablab intercrops on the yield of component crops varies greatly. This variation may be due to a number of factors such as crop genotype, environment and planting time. Therefore, the importance of investigating the productivity of maize/lablab intercropping in diverse environments and varying management practices cannot be overemphasized.

2.3.4 Intercropping and land equivalent ratio (LER)

Land equivalent ratio is a tool that can be used to measure the degree of yield advantage in intercrops (Mohammed, 2012). Willey (1979) cited by Dwivedi *et al.,* (2015) reported that when the LER is greater than one (unity), the intercropping favours the growth and yield of the species, whereas when the LER is lower than one, the intercropping negatively affects the growth and yield of the plants grown in mixtures. (Lemlem, 2013) found higher LER for maize/cowpea intercrops (1.71) and maize/lablab (1.65) showing that intercropping of maize-lablab and maize-cowpea was advantageous in many instances rather than sole cropping. Land Equivalent Ratio shows the efficiency of the intercropping system in using environmental resources compared with sole cropping with the value of unity being the critical value (Lithourgidis *et al.,* 2011). Hirpa (2013) reported the highest partial LER value (1.16) for maize, when maize and black desi were simultaneously intercropped, which shows that 16% more grain yield than sole maize was obtained. Hirpa (2013) concluded that LER is probably the most useful term at present available for assessing the advantage of intercropping.

2.4 Effects of maize/lablab intercropping on soil water content.

Soil water content is the physical parameter used to characterize the availability of water for plants in the soil. The availability of water is one of the most important factors that determine production in cereal/legume intercropping systems (Walker and Ogindo, 2003). Intercropping may also be a way of saving water, mostly in situations of limited water resources as it conserves water due to high leaf area (Dolijanovic *et al.,* 2013 and Mobasser *et al.,* 2014). Li *et al*., (2015) reported that intercropping largely improve water-use efficiency when compared with monoculture. Mobasser *et al.,* (2014) also observed that intercropping maize/legume reduces water evaporation and improves conservation of the soil moisture when compared with sole maize. Dahmardeh and Rigi (2013) reported that the soil water content in the intercropping system is higher than those in the sole maize system. Ikerra *et al.,* (1999) found that gliricidia-maize intercropping depleted stored more soil water than sole maize during the dry season. Therefore, there is a need to investigate the effect of maize/lablab intercropping on soil water content.

2.5 Effects of maize/lablab intercropping on mineral N-levels (N-NO_3^- and N- NH_4^+)

Nitrogen is the most important plant nutrient and its availability can be improved by intercropping practice. It is taken up by the plants, mainly through its roots, as ammonium

(NH_4^+) or as nitrate (NO_3^-). Intercropping is a possible option to improve low inherent soil fertility status in order to enhance crop yields (Kebeney *et al.,* 2015). Lablab is among the nitrogen-fixing legumes intercropped with cereals. Maize obtain the bulk of their nitrogen requirements primarily as nitrate and ammonium from the soil (Nyambati, 2002). Kebeney *et al*., (2015) found that sorghum intercropped with soybean for two years resulted in high nitrate-nitrogen concentrations in the soil in all the treatments in both years. In addition, sorghum intercropped with soybean with nitrogen fertilizer applied at 40 kg N ha^{-1} reflected higher soil nitrate-nitrogen concentration in comparison to the other management options. Weber *et al.,* (1996) cited by Ikerra *et al*., (1999) obtained a highly significant relationship between maize grain yields and soil N-NO_3^- at two to eight weeks after planting. Dahmardeh and Rigi (2013) reported that mineral N-levels were significantly affected by cropping systems, the lowest N-levels were found at sole green gram and sole maize. Nitrogen deficiency could exert a particularly marked effect on maize crop yield as the plant would remain small and rapidly turn yellow if sufficient nitrogen is not available for the synthesis of protein and chlorophyll (Kogbe and Adediran, 2003).

2.6 Impact of climate variability on growth and yield of maize/lablab intercropping

Climate variability characterized by dry spells and frequent drought and flood is considered to be factors affecting agricultural production (Laux *et al.,* 2010). Most of the agricultural crops are naturally sensitive to climate conditions directly affecting agricultural production (Maponya, 2010). Climate change may have an impact on the phenology and development process of crops (Fosu-Mensah, 2012). Changes in temperature also affect photosynthesis and production (Maponya*,* 2010). For planting under dryland farming system, it is important for a farmer to check whether the rainfall will ensure adequate soil moisture during sowing and if moisture will be maintained in order to avoid total crop failure (Fosu-Mensah, 2012).

2.7 APSIM Model

The Agricultural Production System Simulator (APSIM) was developed by the agricultural system research unit in Australia in 1991. APSIM is an effective tool for simulating whole-farm systems, including crop and for considering strategic and tactical planning (Holzworth *et al.,* 2016). APSIM has been widely used to simulate the response of different crop management and soil conditions, including climate change. The system runs on a daily time step and requires daily climate data and a minimum set of soil data and crop variety information as inputs (Teixeira *et al.,* 2015). A simulation study conducted by Whitbread and Clem (2006) demonstrated that APSIM simulated sorghum biomass and grain yield with a high degree of accuracy. A study in Limpopo province by Ayisi and Whitbread (2004) positively simulated maize yield and biomass with a high degree of precision across a range of seasons using APSIM. The models are valuable for representing long-term productivity and environment effects on cropping systems and predict the effect of weather, soil properties and management practices (Muli *et al.,* 2015).

Crop simulation models are capable of using long-term weather records, soil characterization and information about management scenarios to quantify interactions among these variables (Muli *et al.,* 2015). In addition, drought stress can decrease the capability of legumes to fix nitrogen thus, reducing their soil fertility benefits. Crop simulation modelling can be used to investigate climate variability on crop yields by extending the results of field experiments based on long-term climate records (Ollenburger, 2012). A number of crop simulation models have been developed and widely used in other countries. For example, other models such as EPICphase, CROPwat have been used by Cavero *et al.,* (2000) to simulate maize yield under water stress.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study sites

The field trials were conducted at two locations in the Limpopo Province of South Africa namely, the University of Venda experimental farm (Univen) and the University of Limpopo experimental farm (Syferkuil). Univen is located in Thohoyandou, 70 km east of Louis Trichardt, situated at the latitude of 22° 58'49.9'' S and longitude 30° 26' 16.8'' E, 597 m above sea level. The area receives about 847 mm annual rainfall which is highly seasonal with 85% occurring between October and March. The average daily temperature ranges from 25^{0}C to 40^{0}C in October to March and 12^{0}C and 26^{0}C from April to September (FAO, 2009; M'marete, 2003). Syferkuil is located in Turfloop (Mankweng), 9 km north-west of the main campus situated at latitudes 23˚50' 01.5" S and longitude 29˚41' 34.4" E, 1226 above sea level. The area receives mean annual rainfall of 491 mm and the average daily temperature ranges from 18 to 35°C from October to March and 25^{o}C or lower from April to September (Shiringani, 2007; Mpangane *et al*., 2004).

Univen soil is predominantly deep (>150 cm), red and well-drained clays with an apedal structure (Mzezewa *et al,* 2010). Clay content is generally high (49 %) and soil reaction is acidic (pH 5.0). The soils are formed in situ and classified locally as Hutton form (Soil Classification Working Group, 1991) equivalent to Rhodic Ferralsol (WRB, 2006). Syferkuil soil is sandy clay loam, of the Hutton form (Soil Classification Working Group, 1991) equivalent to Chromic Luvisol, with pH ranging from 6.0-6.8 (Moshia, 2005).

3.2 Experimental design and management

The area was ploughed mechanically using a disc plough followed by demarcation and manual seed-bed preparation before planting. The experiment was set-up as a randomized complete block design (RCBD) with four replicates. The experiment consisted of four treatments; (i) sole maize (ii) sole lablab (iii) maize and lablab planted at the same time (Maize+lablab-ST) and (iv) maize with lablab planted 28 days after maize (Maize+lablab-28). This led to a total of 16 plots at each site measuring 4.5 m x 4 m (18 m^2) in size, with a maize plant density of three plants m^{-2}. The planting date for the first cropping season was 04 December 2015 at Univen and 29 November 2015 at Syferkuil. In the second cropping season, the planting date it was 24 October 2016 and 03 January 2017 at Univen and Syferkuil, respectively. Each plot comprised of six plant rows with the legume row established between the maize rows in the intercrop plots. The crop varieties used were maize variety PAN 6479 and lablab variety Rongai. Both crops (maize and lablab) were sown using the same inter-row spacing of 90 cm, with intra row spacing 44 cm for maize and lablab, respectively. Planting (sowing) was done manually by placing two seeds per hole and then thinned to one after emergence. Phosphorus (P) was applied on sole and intercropped maize rows at the rate of 30 kg P/ha in the form of superphosphate (10.5%P). Nitrogen (N) was applied at the rate of 40 kg N/ha in the form of Limestone Ammonium Nitrate (LAN) (28%N) along maize rows at planting. The trials were rainfed and weeding was done when necessary after planting.

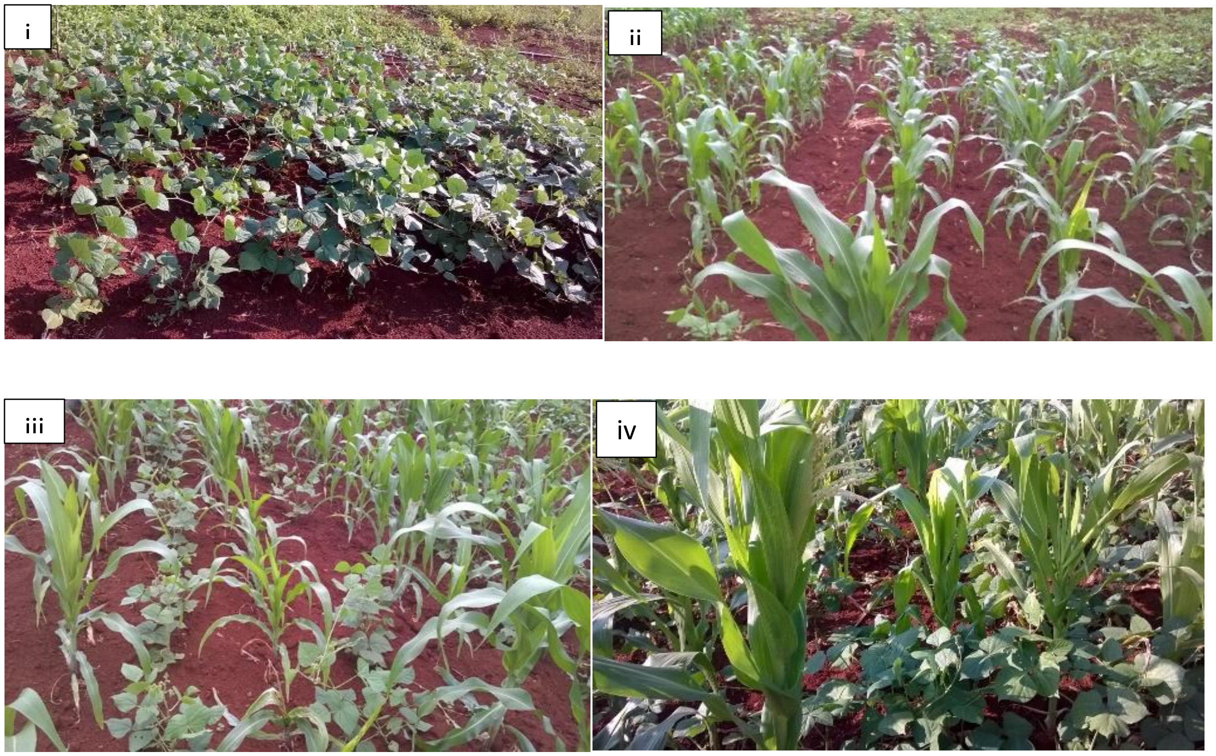

Figure 1: Treatments: (i) sole lablab, (ii) sole maize, (iii) Maize+lablab-ST, and (iv) Maize+lablab-28

3.3 Soil sampling to characterize the trial sites

Prior to the establishment of the trial, soil samples were collected from both trial sites to a depth of 30 cm. The soils were collected from several spots within each experimental area separately and bulked together to form a composite sample. A sub-sample was obtained from the composite sample and analyzed to determine selected soil physical and chemical properties. Soil pH was determined by using 1:1 (soil: water) ratio, electrical conductivity was determined by using soil water extract (1:1) and particle size distribution was determined by hydrometer method (Okalebo *et al.,* 2002). Organic carbon was determined using the Walkey Black method (Walkey Black, 1934) whereas the total nitrogen was determined by using Kjeldahl method. Bray 1 method was used to determine the amount of phosphorus in the soil (Bouyoucos, 1962). The exchangeable cations and CEC were determined using 1N Ammonium Acetate solution at pH 7 (Schollenberger, and Simon, 1945).

3.4 Determination of Soil water content

The soil water content was determined up to 60 cm depth at both experimental sites. The determination was done before planting (BP) and at four maize growth stages which were; vegetative leaf V1, V7, R1 and R6. The soil samples were collected at the depth of 0-15, 15-30 and 30-60 cm between the rows in each plot using an auger. Soil samples were put inside plastic bags during the collection at the field to avoid moisture loss from soil samples. The gravimetric water content (GWC) method was used to determine water content. Each porcelain tin was weight and recorded and tared before putting soil inside. Samples were oven-dried at 105°C for 24 hours. The samples were returned to the oven to dry for several hours until there was no difference between any two consecutive measurements of the weight of dry soil + tare.

%GWC = (Weight of wet soil + tare) – (Weight of dry soil + tare) / (Weight of dry soil + tare) – (tare) x100……………………………………………….….. (1) (Black *et al.,* 1965).

3.5 Determination of ammonium and nitrate (NH_4^+ and NO_3^-)

Soil samples were collected before planting (BP) and at four maize growth stages which were; vegetative leaf V1, V7, R1 and R6. The soil samples were collected at depths of

0-15 cm, 15-30 cm and 30-60 cm between the rows of sole maize, maize/lablab-ST and maize/lablab-28 plots and stored immediately in a refrigerator until the day of analyses. NH_4^+ and NO_3^- were determined by colorimetric method procedures outlined by Okalebo *et al*., 2002.

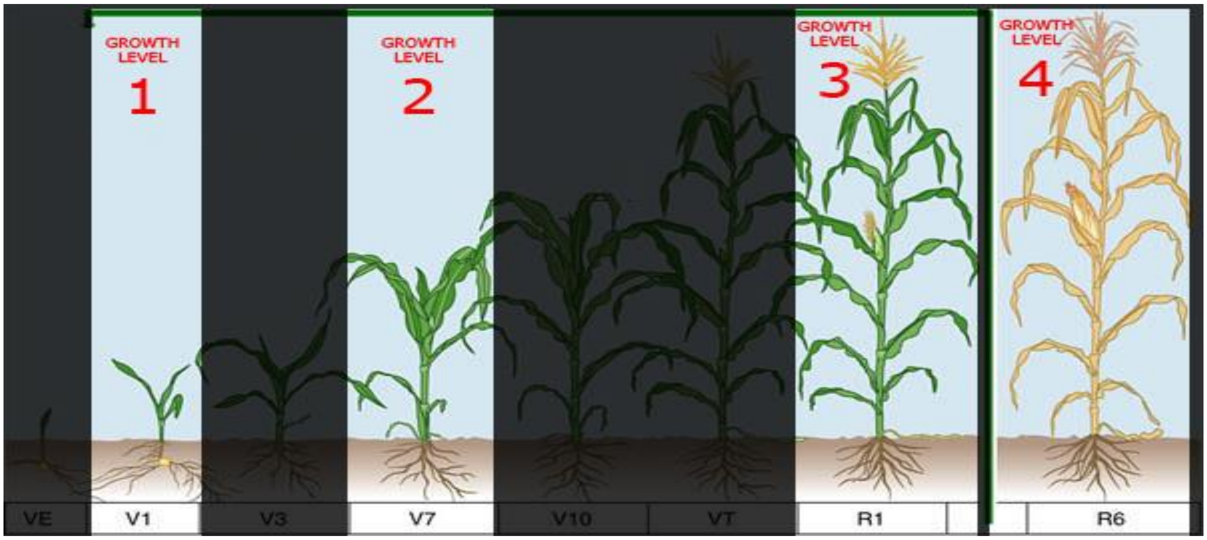

Figure 2: Five maize growth levels (FAO, 2003)

3.6 Maize dry matter, yield and harvest index

Maize dry matter accumulation was determined by weighing aboveground biomass at flowering and at harvest. At flowering, the dry matter was determined by harvesting 4 stalks of the plants while at physiological harvest maturity, 10 stalks from each plot were harvested. The stalks were chopped, weighed and dried at 70 ^{o}C until a constant weight was attained. The grain yield was determined by removing the ears from the 10 harvested maize stalks using a sharp knife. The cobs were air-dried, hand shelled and the grain yield weighed using the weighing balance. Harvest index (HI) was determined by using the ratio of grain yield to biomass using equation 2 below:

HI (%) = seed dry weight (kg)/total above-ground biomass (kg) x100.............................(2)

(Pypers *et al*., 2011)

3.7 Lablab dry matter, yield and Harvest index

Lablab dry matter accumulation was determined by weighing aboveground biomass at flowering and harvesting time. The dry matter was determined by harvesting 4 plants at flowering and 10 plants from each plot at physiological maturity. The plants were chopped, weighed and dried at 70 ^{o}C until a constant weight was attained. The grain yield was determined by removing the pods from the 10 harvested lablab plants using a hand. The pods were air-dried, hand shelled and the grain yield weighed using the weighing balance. The harvest index was determined using the formula number (2) above.

3.8 Land Equivalent Ratio (LER) of maize and lablab

A method for assessing the efficiency of intercropping over sole cropping is to use a ratio, such as LER (Willey, 1979). This is the area under sole cropping compared to the area under intercropping required to yield equal amounts at the same level of management (the sum of the fractions of the intercropped yields divided by sole crop yields). The LER is a common approach to assess the land use advantage of intercropping (Rao and Willey, 1980):

LER=LERa+LERb=La/Ya+Lb/Yb…………………………………………...……….. (3)

Where: La and Lb are the yields for each crop in the intercrop system, and Ya and Yb are the yields for each of the sole crops. LERa and LERb are the partial LER values for each species. If LER >1 it means that intercropping is more productive than sole cropping; LER < 1 indicates sole cropping was more productive, while LER = 1 shows no significant difference between intercropping and sole cropping (Legese and Gobeze, 2013).

3.9 Weather data

Weather stations at or near the sites provided daily weather data. Due to periodic malfunctioning at stations on both sites, alternative stations, or sources were used to complete the climatic information. For Univen, the on-site weather station was used for 2015/16, and Makwarela station (six kilometers from a site) during 2016/2017. The Syferkuil weather station was used in 2015/2016, which was complemented with the Prediction of Worldwide Energy Resource dataset from the National Aeronautics and Space Administration (NASA, 2017). This source has been satisfactorily tested against measured data (Van Wart et al., 2015). We used this data and trained a simple linear regression model for solar radiation, maximum and minimum temperature on the days where we had actual measured data. This database contains 12 years (2005 to 2017) of daily hydro-climatological data such as daily rainfall, minimum and maximum temperatures, solar radiation and reference evapotranspiration. These parameters are meteorological parameters required to run the APSIM model.

3.10 APSIM evaluation

Crop (APSIM-maize), SoilWat (soil water) and residue modules were linked with APSIM 7.9 for simulations. Also included were manager and weather (met) modules. The manager folder deals with crop management module information such as when to plant. The met module contains inputs of daily weather data for the study area and was used for both model calibration and validation. It is a key input parameter as all processes are driven by weather variables. Data includes for a given site (incl. latitude) rainfall, maximum temperature, minimum temperature and solar radiation.

Data on soil water, nitrogen levels, 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:

Root mean square error (RMSE)

$$RMSE=[n^{-1}\Sigma(yield_{sim}–yield_{obs})^2]^{0.5} \ldots\ldots (4)$$

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

3.11 Simulation set-up

The climatic records obtained from Univen and Syferkuil weather stations were used. With the use of soil data, management data such as sowing date, sowing depth, fertilizer application rates, fertilizer application methods, and weather data were all entered in the manager window in the APSIM-model. The initial water content and initial nitrogen were set into the APSIM data. Simulation runs were made and model-predicted data were generated.

3.12 Statistical analysis

All data gathered from the experiments sites were recorded and processed in the Microsoft office excel 2010. The effect of maize/lablab intercropping on soil water content and nitrogen dynamics, and yield were examined by two- way analysis of variance (ANOVA) using Genstat 17th edition. Where significant difference was observed, the least significant difference was used to compare the treatments means at $P < 0.05$.

CHAPTER 4: RESULTS

4.1. Physico-chemical properties of the soil at the trial site

The initial physico-chemical properties of the soil at the Univen and Syferkuil trial sites are presented in Table 1. At Univen, the soil is clay with slightly acid pH (5.08) and has a moderate CEC, adequate amounts of exchangeable Ca^{2+}, Mg^{2+}, and K^{+} and low soil available phosphorus. At Syferkuil, the soil is sandy clay loam with slightly acid pH (6.61) and has a moderate CEC, adequate amounts of exchangeable Ca^{2+}, Mg^{2+}, and K^{+} and adequate soil available phosphorus.

4.2 Crop simulation

Soil modules were also input mainly with measured data from experimental sites. The drained upper limit (DUL), lower limit (LL), Bulk density (BD) and saturation (SAT) for the sites were estimated. The results for soil water parameters are indicated in Table 2.

Table 1: Physico-chemical properties of the soil at the experimental sites

Soil properties	Experimental sites	
	Univen	Syferkuil
Physical properties		
Sand (%)	24	61
Silt (%)	16	31
Clay (%)	60	9
Textural class	Clay	Sandy clay loam
Chemical properties		
pH (H_2O)	5.08	6.61
EC (mS m^{-1})	29.90	8.05
SOC (%)	2.39	0.70
P (mg kg^{-1})	10.10	31.00
Exchangeable cations		
K	67	130
Na	140	68
Mg	265	325
Ca	798	508
CEC ($cmol_{(+)}$ kg^{-1})	23.04	18.80

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

Site	Depth (cm)	BD (gm^{-3})	LL (mm/m)	DUL (mm)	OC (%)	SAT (mm)	XF (0-1)	KL (/day)
Univen	0-15	1.100	0.120	0.260	0.230	0.490	1.0	0.06
	15-30	1.200	0.130	0.290	1.000	0.490	1.0	0.06
	30-60	1.200	0.130	0.320	0.400	0.490	1.0	0.05
	60-90	1.200	0.130	0.320	0.400	0.490	1.0	0.05
Syferkuil	0-15	1.450	0.054	0.150	0.870	0.403	1.0	0.06
	15-30	1.450	0.072	0.156	0.870	0.403	1.0	0.06
	30-60	1.450	0.110	0.157	0.700	0.403	1.0	0.06
	30-90	1.450	0.11	0.157	0.600	0.403	1.0	0.04

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

4.3 Temperature and solar radiation

At Univen, the cropping season 2015/2016 was characterized by high temperature for 25% of all days during that period, the maximum daily temperature was above 35 °C

(Figure 3). During five days of the season, the maximum temperature was above 40 °C, the average temperature was 24.7 °C. The 2016/2017 season was cooler, with an average of 23.7 °C, only 9% of all days experienced a maximum temperature above 35 °C. cropping seasonal average daily solar radiation was 19.0 MJ m^{-2} in 2015/2016 and 15.6 MJ m^{-2} in 2016/2017. At Syferkuil, in 2015/2016 cropping season it was cooler and drier (Figure 4). The average daily temperature was 21.2°C for 2015/2016 and 19.5 °C for 2016/2017 with eleven and four days above 35 °C, respectively. Solar radiation was high in both seasons with a daily average of 21.3 MJ m^{-2} in 2015/2016 and 19.3 MJ m^{-2} in 2016/2017.

4.5 Rainfall

At Univen, the cropping season 2015/2016 was characterized by low rainfall of 716 mm from 01 October to 31 May (Figure 3). The cropping season 2016/2017 was a high rainfall year with 1434 mm for the maize cropping period. Generally, heavy rainfall days with more than 40 mm of rain occurred nine times in 2016/2017 and four times in 2015/2016. An extreme rainfall event took place in March 2016 with > 180 mm of rain per day (Figure 3). In 2016/2017 cropping season, it rained on almost 35 % of all days from October to April, which was an extremely wet season for that region. In 2015/2016, it only rained on 18.6 % of all days. At Syferkuil, in general, rainfall was low in 2015/2016 (442 mm) and 2016/2017 (393 mm) for the period between October to May (Figure 4). In contrast to Univen, 2016/2017 was drier in Syferkuil. However, the number of rain days was higher in 2016/2017. In 2016/2017 season, it rained on 21 % of all days, while in 2015/2016 it rained on 15 % of all days (Figure 4).

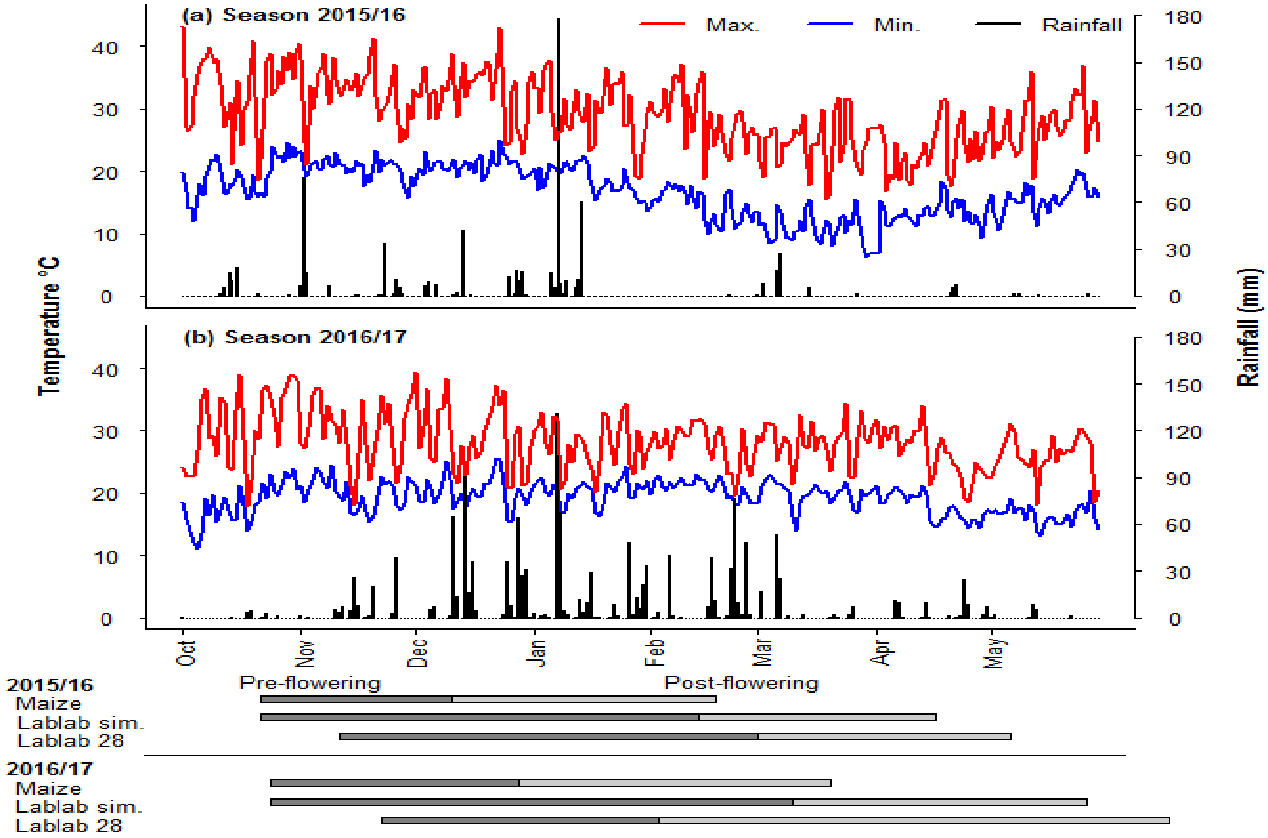

Figure 3: Average daily maximum and minimum temperature and rainfall for season 2015/2016 and 2016/2017 at Univen. Horizontal bars filled in dark grey bars (below the plot) represent the time from germination to the completion of the flowering of both crops. The light grey bars represent the grain/pod filling to final harvest stage

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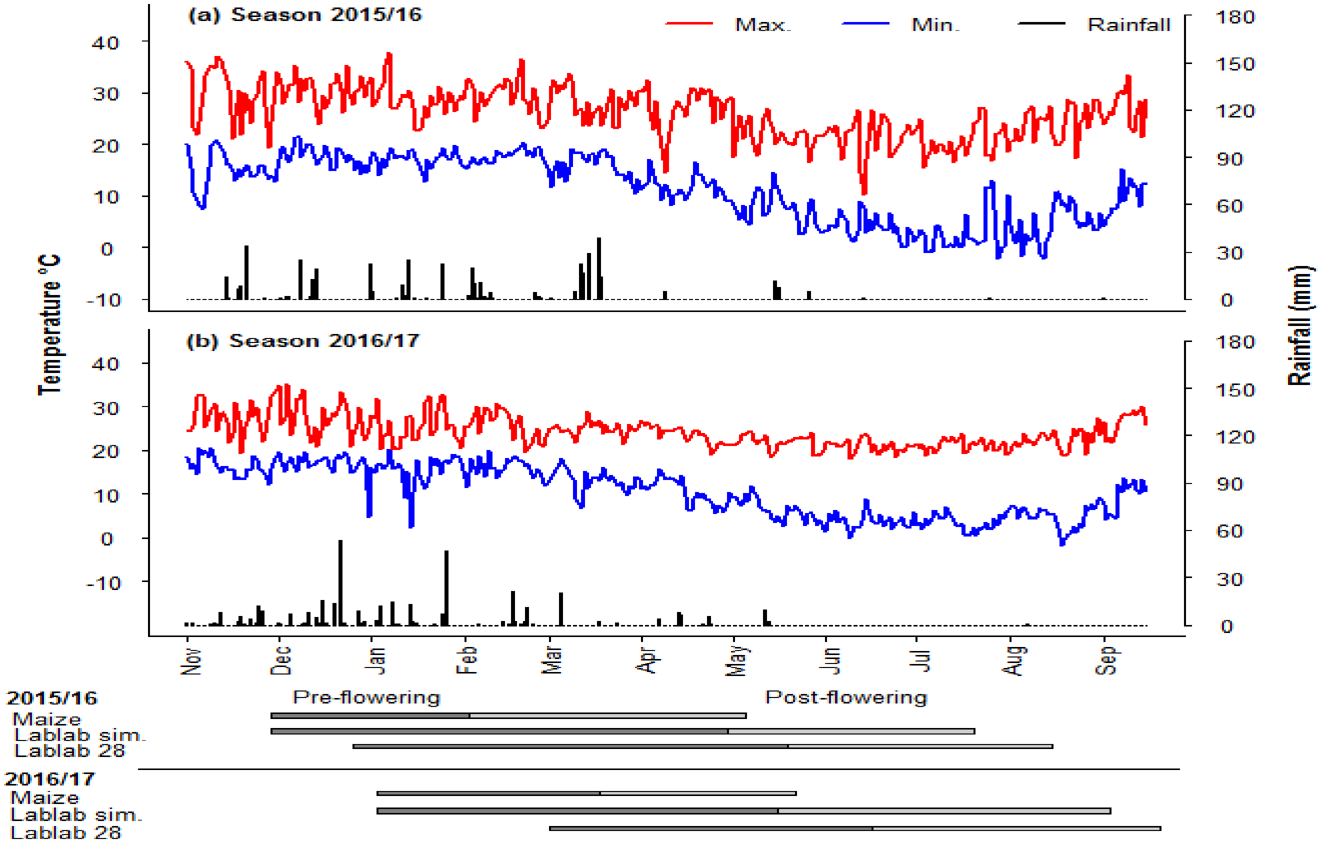

Figure 4: Average daily maximum and minimum temperature and rainfall for season 2015/2016 and 2016/2017 at Syferkuil. Horizontal bars filled in dark grey bars (below the plot) represent the time from germination to the completion of the flowering of both crops. The light grey bars represent the grain/pod filling to final harvest stage

4.6 Effects of maize/lablab intercropping on maize/lablab dry matter production, grain yield, and land equivalent ratio

4.6.1 Maize dry matter production and grain yield at Univen site

Maize/lablab intercropping had no significant effect on maize dry matter production at flowering in 2015/2016 at Univen, but had a significant effect (P<0.05) in 2016/2017 (Table 3). At flowering in 2016/2017 season, sole maize produced the highest dry matter of 2633 kg/ha followed by maize+lablab-28 (2442 kg/ha) and maize+lablab-ST (1962 kg/ha). Maize sole dry matter was 25.5% higher than maize+lablab-ST and 7.2% higher than maize+lablab-28 at flowering. At harvest, maize/lablab intercropping had no significant effect on maize dry matter production in the both seasons. Maize/lablab intercropping had a significant effect on cob weight in 2015/2016 and 2016/2017 seasons. Maize+lablab-28 produced the highest cob weight (3658 kg/ha in 2015/2017 and 5167 kg/ha in 2016/2016) followed by sole maize (2499 kg/ha in 2015/2016 and 3759 kg/ha in 2016/2017) and maize+lablab-ST (2065 kg/ha in 2015/2016 & 3378 kg/ha in 2016/2017). Maize+lablab-28 produced 46.4% and 37.5% higher cob weight than maize+lablab-ST and sole maize in 2015/2016 and 2016/2017, respectively. Maize/lablab intercropping had a significant effect (P<0.05) on grain yield in both 2015/2016 and 2016/2017 seasons, where the highest grain yield was obtained from maize+lablab-28 (2206 kg/ha in 2015/2016 & 3742 kg/ha in 2016/2017).

4.6.2 Maize dry matter production and grain yield at Syferkuil site

Intercropping maize/lablab had no significant effect on dry matter production at flowering and harvesting (Table 4) in both 2015/2016 and 2016/2017 cropping seasons. Intercropping had a significant effect ($P<0.05$) on cob weight in 2015/2016, but had no significant effect in 2016/2017. Maize+lablab-28 produced the highest cob weight in 2015/2016 (3896 kg/ha) followed by sole maize (3329 kg/ha) and maize+lablab-ST (2540 kg/ha). Maize+lablab-28 produced 24% more cob weight while maize+lablab-ST produced 17% less cob weight as compared to sole maize. Similarly, maize/lablab had a significant effect ($P<0.05$) on grain yield in 2015/2016, but had no effect in 2016/2017. Maize+lablab-28 produced the highest grain yield (2770 kg/ha) in 2015/2016 followed by sole maize(2234 kg/ha) and maize+lablab-ST (1810 kg/ha) (Table 4). Maize+lablab-28 produced 24% more grain yield while maize+lablab-ST produced 19% less grain yield as compared to the sole maize.

4.6.3 Lablab biomass production and grain yield at Univen site

Maize/lablab intercropping had no significant effect on lablab dry matter production at flowering in 2015/2016, but had a significant effect ($P<0.05$) in 2016/2017 (Table 5). Sole lablab produced the highest dry matter of 3503 kg/ha in 2016/2017 followed by maize+lablab-ST (2817 kg/ha) and maize+lablab-28 (2699 kg/ha). Sole lablab had 23% more dry matter at flowering than maize+lablab-ST and maize+lablab-28. Maize/lablab intercropping had no significant effect on dry matter production at harvest in both 2015/2016 and 2016/2017 seasons. Maize/lablab intercropping had a significant effect ($P<0.05$) on pod weight in 2015/2016 but had no significant effect in 2016/2017.

Maize+lablab-28 produced the highest pod weight in 2015/2016 (1472 kg/ha). Lablab grain yield was not affected by maize/lablab intercropping in both 2015/2016 and 2016/2017 cropping seasons (Table 5). However, yield in 2016/2017 was more than yield in 2015/2016.

4.6.4 Lablab dry matter production and grain yield at Syferkuil site

Intercropping maize/lablab had no significant effect on lablab dry matter production at flowering in both 2015/2016 and 2016/2017 seasons. At harvest, maize/lablab intercropping had a significant effect (P<0.05) on dry matter production in 2015/2016, but had no effect in 2016/2017 (Table 6). Sole lablab produced the highest dry matter production in 2015/2016 (2851 kg/ha) followed by maize+lablab-28 (2532 kg/ha) and maize+lablab-ST (2414 kg/ha). Sole lablab produced 15% more dry matter at flowering than maize+lablab-ST and maize+lablab-28. Maize/lablab intercropping had no significant effect on pod weight in both seasons. Similarly, maize/lablab intercropping had no effect on grain yield in both2015/2016 and 2016/2017 seasons (Table 6).

4.6.5 Harvest index (%)

Harvest index was significantly affected by maize/lablab intercropping on maize crop in 2015/2016 but not in 2016/2017 at Univen. The highest harvest index was from maize+lablab-28 followed by maize+lablab-ST (Table 3). Harvest index was significantly (p<0.05) less for sole maize compare to maize+lablab-ST and maize+lablab-28 in both sites and planting seasons (Table 3 and 4). Lablab harvest index was not affected by the maize/lablab intercropping at both sites and planting seasons(Table 5 and 6). Harvest index for lablab sole was not significantly different to maize+lablab-ST and maize+lablab-28 in both planting season. Maize harvest index in 2016/2017 was slightly high than in 2015/2016 for both sites. Lablab harvest index in 2016/2017 was more than in 2015/2016 at Syferkuil, however at Univen lablab harvest index in 2016/2017 was less than in 2015/2016 (Tables 3,4, 5 and 6).

Table 3: The effects of maize/lablab intercropping on maize dry matter production (kg/ha) and grain yield (kg/ha) at Univen

SEASON	TREATMENT	DMF (kg/ha)	DMH (kg/ha)	CW (kg/ha)	GY (kg/ha)	HI (%)
2015/2016	Sole maize	1410	3307	2499b	1038a	19a
	Maize+lablab-ST	1241	3301	2065a	1273a	21a
	Maize+lablab-28	2076	4446	3658c	2206b	26b
	LSD	808.76	1092.74	407.32	480.94	27
	F-test probability	ns	ns	**	*	*
	CV (%)	13.4	8.3	10	6.1	11
2016/2017	Sole maize	2633b	5943	3759a	2712a	23
	Maize+lablab-ST	1962a	5088	3378a	2548a	25
	Maize+lablab-28	2442ab	6526	5167b	3742b	26
	LSD	489.2	1705.4	1088.8	910.6	29
	F-test probability	*	ns	*	*	ns
	CV (%)	9.4	10.4	8.4	14.9	13

DMF= dry matter at flowering, DMH = dry matter at harvest, CW = cob weight, GY = grain yield, HI = harvest index, LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, ** Highly Significant at P≤0.01, * significant at P≤0.05

Table 4: The effects of maize/lablab intercropping on maize dry matter production (kg/ha) and grain yield (kg/ha) at Syferkuil in 2015/2016 and 2016/2017 seasons.

SEASON	TREATMENT	DMF (kg/ha)	DMH (kg/ha)	CW (kg/ha)	GY (kg/ha)	HI (%)
2015/2016	Sole maize	2003	3332	3329b	2234a	25
	Maize+lablab-ST	1822	2792	2540a	1810a	26
	Maize+lablab-28	1918	3376	3896b	2770b	28
	LSD	580.2	1069.3	781.6	486.6	24
	F-test probability	ns	ns	*	*	ns
	CV (%)	12.4	22.9	10.3	16	15
2016/2017	Sole maize	2957	2780	4824	3460	31
	Maize+lablab-ST	2475	4132	4710	3758	34
	Maize+lablab-28	3040	5207	5761	4576	33
	LSD	1320.36	1941.5	1131.9	892.1	22.9
	F-test probability	ns	ns	ns	ns	ns
	CV (%)	11.8	20.7	12.1	10.4	13

DMF= dry matter at flowering, DMH = dry matter at harvest, CW= cob weight, GY = grain yield, HI = harvest index, LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, ** Highly Significant at P≤0.01, * significant at P≤0.05

Table 5: The effects of maize/lablab intercropping on lablab dry matter production (kg/ha) and grain yield (kg/ha) at Univen in 2015/2016 and 2016/2017 seasons.

SEASON	TREATMENT	DMF (kg/ha)	DMH (kg/ha)	PW (kg/ha)	GY (kg/ha)	HI (%)
2015/2016	Sole lablab	1902	2789	1066ab	555	10
	Maize+lablab-ST	1662	2344	977a	496	11
	Maize+lablab-28	1581	2390	1472b	645	12
	LSD	358.8	753	412.7	260.7	34
	F-test probability	ns	ns	*	ns	ns
	CV (%)	9.4	9	7.2	5.3	10
2016/2017	Sole lablab	3503b	4089	795.5	632	8
	Maize+lablab-ST	2817a	3609	693.4	524	8
	Maize+lablab-28	2699a	4140	980.9	793	10
	LSD	593.2	1934.2	244.2	225.5	15
	F-test probability	*	ns	ns	ns	ns
	CV (%)	3.3	3.8	6.5	8.3	7

DMF= dry matter at flowering, DMH = dry matter at harvest, PW= pod weight, GY = grain yield, HI = harvest index, LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, ** Highly Significant at P≤0.01, * significant at P≤0.05

Table 6: The effects of maize/lablab intercropping on lablab dry matter production (kg/ha) and grain yield at Syferkuil in 2015/2016 and 2016/2017 seasons.

SEASON	TREATMENT	DMF (kg/ha)	DMH (kg/ha)	PW (kg/ha)	GY (kg/ha)	HI (%)
2015/2016	Sole lablab	2748	2851b	894.9	486.6	8
	Maize+lablab-ST	1969	2414a	848.9	411.2	8
	Maize+lablab-28	2406	2532ab	941.9	456.6	10
	LSD	801.7	333.5	217.2	146.3	18
	F-test probability	ns	*	ns	ns	ns
	CV (%)	14.4	8	7	9.9	11
2016/2017	Sole lablab	1687	2387	427	387	9
	Maize+lablab-ST	1411	1411	431	311	10
	Maize+lablab-28	1857	1457	437	357	11
	LSD	593.2	1934.2	244.2	205.5	10
	F-test probability	ns	ns	ns	ns	ns
	CV (%)	3.3	3.8	6.5	8.3	6

DMF= dry matter at flowering, DMH = dry matter at harvest, PW= pod weight, GY = grain yield, HI = harvest index, LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, ** Highly Significant at P≤0.01, * significant at P≤0.05

4.6.6 Land equivalent ratio

The overall Land Equivalent Ratio (LER) was greater when maize was intercropped with lablab for both sites and seasons. The highest LER was recorded at maize/lablab(28)

(3.29 and 2.63) at Univen and (2.17 and 2.46) at Syferkuil as compared to maize/lablab(sim) (2.12 and 1.76) at Univen and (1.65 and 1.76) at Syferkuil respectively, in both cropping seasons. The individual yield for maize was higher at maize/lablab(28) as compared to sole cropping at both sites. The overall LER was greater at maize/lablab(28) in 2015/2016 at Univen. The highest partial LER was obtained at maize/lablab(28) (2.13) as compared to maize/lablab(sim) in 2015/2016 (Table 7).

Table 7: Effects of maize/lablab intercropping on land equivalent ratio of maize-lablab intercrop at Univen and Syferkuil in 2015/2016 and 2016/2017 seasons.

	SEASON	2015/2016			2016/2017		
SITE	TREATMENT	PLER $_a$	PLER $_b$	TOTAL LER	PLER $_a$	PLER $_b$	TOTAL LER
Univen	Maize+lablab-ST	1.23	0.89	2.12	0.94	0.83	1.76
	Maize+lablab-28	2.13	1.16	3.29	1.38	1.26	2.63
Syferkuil	Maize+lablab-ST	0.81	0.85	1.65	1.09	0.68	1.76
	Maize+lablab-28	1.24	0.94	2.17	1.32	1.15	2.46

LER = total land equivalent ratio, PLER $_a$ = Partial land equivalent ratio for individual maize, PLER$_b$ = land equivalent ratio for individual lablab.

4.3 Effects of maize/lablab intercropping on soil water content and mineral N (NH_4^+ and NO_3) levels.

4.7.1 Soil water content at Univen site.

The effects of sampling time and treatment on soil water content are shown in Table 8. There was an interaction between sampling time and treatments on soil water content at 0-15 cm and 30-60 cm soil depths in 2015/2016 (Table 8). At 0-15 cm, soil water content was higher under sole lablab compared to maize+lablab-28, sole maize and maize+lablab-ST at all sampling times (Figure 5). Sampling time R1 had the highest soil water content, but not significantly different for all treatments as compared to the other sampling times. At 30-60 cm soil depth, soil water content increased with increased sampling times from BP, V1, V7, and R1 and decreased at sampling time R6 (Figure 6).

In 2015/2016 season, at 0-15 cm soil depth, sampling time had no significant effect on soil water content, but the treatment had a significant effect. Sole lablab had significantly higher soil water content compared to maize+lablab-ST, maize+lablab-28 and sole maize.

At soil depth 15-30 cm, sampling time had a significant effect on soil water content. Soil water content was higher at sampling time BP, V7, R1, R6 compared to sampling time V1. At 30-60 cm both treatments and sampling times had a significant effect on soil water content. The highest soil water content was recorded under sole lablab followed by sole maize, maize+lablab-ST and maize+lablab-28. Soil water content was significantly higher at sampling time BP, while significantly lower at sampling time V7.

In 2016/2017, at 0-15 cm soil depth, soil water content at sampling time V7 was significantly higher than at all other sampling times. Significantly lower soil water content was recorded at sampling time V1 and R6, while no difference was observed in soil water content at sampling times BP and R1 (Table 8).

At 15-30 cm soil depth, significantly higher soil water content was observed at sampling time R1 compared to all other sampling times, while significantly lower soil water content was observed at sampling times V1 and V6. At 30-60 cm depth, significantly higher soil water content was recorded at sampling time R1, while significantly lower soil water content was recorded at sampling time R6. There was no difference in soil water content observed at sampling times BP and V1 (Table 8).

There was no interaction observed between sampling time and treatments on soil water content (Table 9). Sampling time resulted in a significant increase in soil water content at all soil depths in 2015/2016 and 2016/2017 seasons (Table 9). In 2015/2016, soil water content was increasing with sampling time at all soil depths. At all soil depths, soil water content was significantly higher at sampling time R6, while significantly lower at sampling time BP. At 0-15 cm and 15-30 cm soil depth, soil water content was significantly higher at sole lablab, while significantly lower at sole maize (Table 9). At 30-60cm depth, there was difference in soil water content observed between treatments.

In 2016/2017, soil water content was increased with increasing soil depths at all sampling times. There was no difference in soil water content observed between the treatments. At soil depth 0-15 cm, soil water content was significantly higher at sampling time BP, and significantly lower at sampling time V7 and R6. At 15-30 cm depth, soil water content was significantly higher at sampling time R1, while significantly lower at sampling time R6. At depth 30-60 cm, soil water content was significantly higher at sampling time R1, while was significantly lower at sampling time R6.

Table 8: The effects of maize/lablab intercropping on soil water content at Univen in 2015/2016 and 2016/2017 seasons.

Year	2015/2016			2016/2017		
Depths	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
Treatments (TRT)						
Sole lablab	25.36a	25.11a	28.77a	23.45	28.75	31.20
Sole maize	24.27b	24.90a	26.07b	23.85	29.10	31.25
Maize+lablab-ST	24.45b	24.83a	25.70b	23.75	29.30	30.30
Maize+lablab-28	24.53b	25.18a	25.36b	24.30	29.15	30.65
Sampling Time (ST)						
BP	24.88	25.34	27.93a	25.77b	27.50c	28.69c
V1	24.26	24.52	26.72b	17.38c	22.50d	27.13c
V7	24.39	25.00	25.72c	36.00a	32.50b	31.00b
R1	24.95	25.75	26.62b	24.25b	39.75a	43.38a
R6	24.76	25.49	26.57b	16.18c	22.50d	24.06d
LSD	0.72	0.74	0.75	1.36	1.28	1.57
F-test probability						
ST	ns	ns	*	**	**	**
TRT	*	*	*	ns	ns	ns
ST*TRT	**	ns	**	ns	ns	ns
CV (%)	4.15	4.17	3.98	8.06	6.29	7.21

(sim)= simultaneously, (28) = 28 days afterwards, LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, ** Highly Significant at P≤0.01, * significant at P≤0.05, ST=Sampling Time, TRT= Treatments

Table 9: The effects of maize/lablab intercropping on soil water content at Syferkuil in 2015/2016 and 2016/2017 seasons

Year	2015/2016			2016/2017		
Depths	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
Treatments (TRT)						
Sole lablab	23.21a	24.99a	25.12	23.30	29.85	32.40
Sole maize	22.46b	24.17ab	24.89	23.60	30.25	32.55
Maize+lablab-ST	22.68ab	24.13ab	24.61	23.10	30.25	31.95
Maize+lablab-28	22.67ab	24.37b	24.95	22.50	30.40	31.85
Sampling Time (ST)						
BP	24.14c	24.35a	25.70d	31.50a	32.56b	34.68b
V1	24.44d	24.89b	26.56c	22.85d	28.07c	29.37d
V7	24.43d	25.00b	26.72c	20.56c	32.25b	31.00c
R1	25.38a	26.24a	27.02b	24.25b	39.75a	43.81a
R6	25.79a	26.56a	27.40a	20.56c	27.50d	26.06e
LSD	0.73	0.52	0.67	1.29	0.99	1.42
F-test probability						
ST	**	*	**	**	**	**
TRT	*	*	ns	ns	ns	ns
ST*TRT	ns	ns	ns	ns	ns	ns
CV %)	4.57	3.07	3.81	4.57	3.07	3.81

(sim)= simultaneously, (28) = 28 days afterwards, LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, ** Highly Significant at P≤0.01, * significant at P≤0.05, ST=Sampling Time, TRT= Treatments

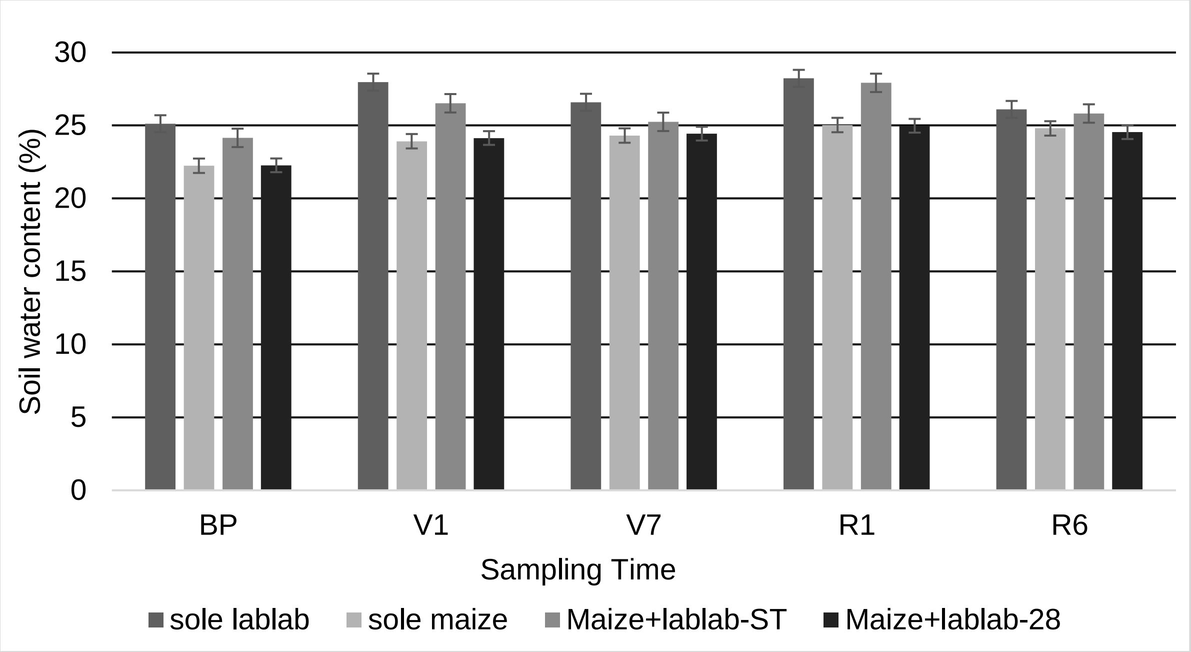

Figure 5: The effects of sampling time and treatment interaction on soil water content at 0-15 cm in 2015/2016 cropping season.

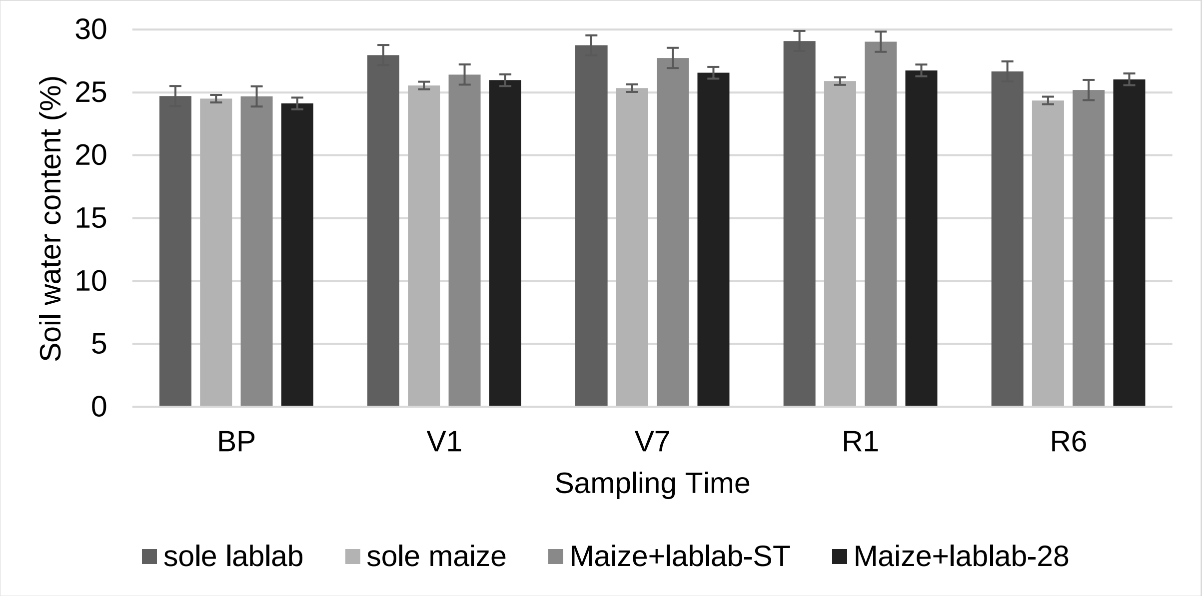

Figure 6: The effects of sampling time and treatment interaction on soil water content at 30-60 cm in 2015/2016 cropping season

4.7.3 Soil nitrate (NO_3^--N) and ammonium (NH_4^+-N) levels.

4.7.3.1 Soil nitrate (NO_3^--N) and ammonium (NH_4^+-N) levels at Univen site.

There was no interaction between sampling time and treatment on soil NO_3^--N and NH_4^+-N levels in 2015/2016 and 2016/2017 seasons at all soil depths. Treatments also had no effect on soil NO_3^--N and NH_4^+-N levels in 2015/2016 and 2016/2017 seasons for all soil depths, but sampling time had a significant effect in both seasons for all depths (Table 10).

In 2015/2016 at all the depths, soil NO_3^--N increased with sampling time from BP to R1 and decreased at the last sampling time R6. At soil depth 0-15 cm, soil NO_3^--N was higher by 39.18%, 33.19%, 15.10% and 5.78% at sampling time R1, R6, V7, and V1, respectively, compared to the sampling time BP. At 15-30 cm, soil NO_3^--N was higher by 39.49%, 36.70%, 13.71% and 5.59 at sampling time R1, R6, V7 and V1, respectively, compared to the sampling time BP. At 30-60 cm, soil NO_3^--N was higher by 25.06%, 16.13%, 15,04% and lower by -2.81% at sampling time V1, V7, R1, and R6, respectively, compared to the sampling time BP.

In 2016/2017, at soil depth 0-15 cm, soil NO_3^--N was lower by -55.73%, -47.92%, -2,05 and higher by 0.25% at sampling time V1, R6, V7, and R1, respectively, compared to the sampling time BP. At 15-30 cm NO_3^--N was lower by -294.76%, -181.96%, -6.51%, and -158.13% at R6, R1, V1, and V7 respectively, compared to the sampling time BP. At 30-60 cm, soil NO_3^--N was higher by 2.6%, at sampling time V1, and lower by -213.54%, -168.97% and -20,61 at R1, V7, and R6, respectively, compared to the sampling time BP.

In 2015/2016, at soil depth 0-15 cm soil NH_4^+-N was higher at sampling time V7, by 23.66% and lower at R6, R1, and V1 by -56.16%, -47.05% and -3.85%, respectively, compared to the sampling time BP. At 15-30 cm soil NH_4^+-N was lower at sampling time R6, V7, V1, and R1, by -48.52%, 28.37%, 28.11%, 25.34%, respectively, compared to the sampling time BP. At 30-60 cm, soil NH_4^+-N was lower by -33.37%, -27.39%, 8.48%, 5.63% at sampling time R6, R1, V7, and V1, respectively, compared to the sampling time BP.

In 2016/2017, soil NH_4^+-N at soil depth 0-15 cm was significantly higher at sampling time V7 and V1, by 21.24% and 18.93%, respectively and lower at R1 and R6, by -9.50% and 3.28%, respectively, compared to the sampling time BP. At 15-30 cm, soil NH_4^+-N was lower at R6 by -2.75%, however, it was higher at V7, V1, and R1 by 33.59%, 32.38%, and 4.62%, respectively, compared to the sampling time BP. At 30-60 cm soil NH_4^+-N was lower at R6 by -16.45% and higher by 31.95%, 28.39% and 7.92% at V7, V1 and R1, respectively, compared to the sampling time BP.

4.7.3.2 Soil nitrate (NO_3^--N) and ammonium (NH_4^+-N) levels at Syferkuil site.

There was no interaction between sampling time and treatment on soil NO_3^--N and NH_4^+-N levels in 2015/2016 and 2016/2017 seasons at all soil depths. Treatments also had no effect on soil NO_3^--N and NH_4^+-N levels in 2015/2016 and 2016/2017 seasons for all soil depths, but sampling time had a significant effect in both seasons for all depths (Table 11).

In 2015/2016 at soil depth 0-15 cm, soil NO_3^--N was lower at R6, R1, and V1 by -19.30%, -7.38%, and -2.24%, respectively and it was higher by 21.98% at sampling time V7. At 15-30 cm, soil NO_3^--N was lower at V1, V7, and R1 by -22.31%, -13.86% and -6.59%, respectively and higher by 6.44% at R6. At 30-60 cm, soil NO_3^--N was higher at V7, R1 and R6 by 13.46%, 4.88% and 1,08%, respectively and lower at V1 by -16.41%.

In 2016/2017, at all soil depths, soil NO_3^--N decreased over time. At 0-15 cm, soil NO_3^--N decreased by -104.91%, -55.86%, -46.08% and -32.90% at R6, R1, V7, and V1, respectively as compared. At 15-30 cm, soil NO_3^--N decreased by -127.10%, -88.18%, -46.73%, and -38.31% at sampling time R6, R1, V7, and V1, respectively. At 30-60 cm, soil NO_3^--N decreased by -108.19%, -60.14%, -18.51% and -17.81% at R6, R1, V7, and V1, respectively as compared to sampling time BP (Table 11).

In 2015/2016, at soil depth 0-15 cm soil NH_4^+-N was increasing with the increasing sampling time by 19.38%, 20.17%, 39.13%, and 43.49% at sampling time V1, V7, R1 and R6, respectively. At 15-30 cm, soil NH_4^+-N was higher at R6, R1, V1, and V7 by 48.38%, 44.76%, 34.34%, and 18.55%, respectively. At 30-60 cm, soil NH_4^+-N was higher at R1 and V1 by 27.88% and 5.45%, however, it was lower by -18.71% and -17.38 % for sampling time V7 and R6, respectively, as compared to sampling time BP (Table 11).

In 2016/2017, at soil depth 0-15 cm soil NH_4^+-N was higher at R6 and V7 and R1, by 11.50%, 11.11%, and 4.49% and was lower by -17.47% at V1, respectively. At 15-30 cm, soil NH_4^+-N was higher at V7 and R1 by 2.43% and 1.87 %, and it was lower by -103,49% and -7.11% at V1 and R6, respectively. At 30-60 cm, soil NH_4^+-N increased with the increasing sampling time by 2.19%, 13.89%, 18.43%, and 19.15% at sampling time V1, V7, R1 and R6, respectively, as compared to sampling time BP (Table 11).

Table 10: The effects of maize/lablab intercropping on NO_3^--N and NH_4^+-N at Univen site in 2015/2016 and 2016/2017 seasons

	NO_3^--N						NH_4^+-N					
	2015/2016			2016/2017			2015/2016			2016/2017		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
Treatments (TRT)												
Sole maize	32.40	36.72	31.36	27.38	22.85	37.65	8.85	9.03	18.10	33.23	37.61	29.76
Maize+lablab-ST	34.51	29.49	32.94	31.17	20.50	27.89	6.93	8.65	20.88	34.62	32.51	30.32
Maize+lablab-28	28.60	27.26	34.14	26.11	25.58	33.79	8.86	9.84	19.23	33.87	33.89	33.22
Sampling Time (ST)												
BP	16.30a	22.28b	28.80c	34.54a	32.37a	33.11a	27.00b	18.55a	20.46a	28.00b	23.54b	23.36b
V1	17.30a	23.60b	38.43a	22.18c	30.39a	34.00a	26.00b	14.48b	19.37a	34.54a	34.8a	32.62a
V7	19.20b	25.82b	34.34b	27.44b	12.54b	12.31c	35.37a	14.45b	18.86ab	35.55a	35.45a	34.33a
R1	26.80a	36.82a	33.90b	34.63a	11.48b	10.56c	18.36c	14.80b	16.06b	25.57a	24.68b	25.37b
R6	24.40a	35.20a	22.48d	23.35c	8.20b	27.45b	17.29c	12.49b	15.30b	27.11b	22.91b	20.06c
LSD	19.28	22.84	24.22	24.75	18.89	21.12	6.14	4.64	8.22	21.8	15.8	17.09
TRT	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
ST	*	*	**	**	*	**	**	*	*	*	**	**
TRT X ST	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV%	11.8	6.1	10.1	16.7		15.6	10.8	10.4	5.76	5.2	6.1	5.7

LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, *** Highly Significant at P≤0.01, ** significant at P≤0.05, ST= Sampling Time, TRT= Treatments

Table 11: The effects of maize/lablab intercropping on NO_3^--N and NH_4^+-N at Syferkuil site in 2015/2016 and 2016/2017 season.

	NO_3^--N						NH_4^+-N					
	2015/2016			2016/2017			2015/2016			2016/2017		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
Treatments (TRT)												
Sole maize	17.31	27.04	33.45	25.26	32.97	37.98	5.86a	9.52	16.96	35.26	39.97	37.98
Maize+lablab-ST	20.83	29.55	31.36	31.66	31.37	36.93	7.62b	11.63	19.87	31.66	38.37	36.93
Maize+lablab-28	21.58	30.90	35.48	39.19	31.61	36.97	6.56ab	10.56	17.67	33.19	36.61	36.97
Sampling Time (ST)												
BP	29.67b	34.43ab	30.00b	15.43a	15.92a	14.22a	5.99b	6.06a	18.91b	30.79d	36.16a	30.23c
V1	29.02b	28.15c	25.77c	11.61b	11.51b	12.07b	7.43b	9.23b	20.00b	26.21a	17.77b	30.91c
V7	38.03a	30.24bc	34.64a	10.46b	10.85b	12.00b	7.53b	7.44a	15.93c	34.64b	37.06a	35.11b
R1	27.63b	32.30b	31.54b	9.90b	8.46c	8.88c	9.84a	10.97b	26.22a	32.24c	36.85a	37.17a
R6	24.87c	36.80a	30.33b	7.53c	7.01c	6.83c	10.60a	11.74b	16.11c	34.76a	33.76a	37.39a
LSD	15.28	11.63	16.77	27.27	18.21	25.52	1.83	5.34	5.46	27.27	18.21	25.52
TRT	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
ST	**	**	**	**	*	*	*	*	**	*	*	**
TRT X ST	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV%	13.0	8.3	3.1	8.2	13.7	6.6	7.0	12.3	10.0	8.2	13.7	6.6

LSD=Least Significant Difference, CV= coefficient of variation, ns=non-significant, *** Highly Significant at P≤0.01, ** significant at P≤0.05, ST= Sampling Time, TRT= Treatments.

4.8 Simulation for biomass and grain yield

4.8.1 Observed and simulated grain yield and dry matter at Univen site

The comparison between the simulated and the observed grain yield are presented in Table 12. In general, grain yield was well simulated by the model in 2016/2017 season for both crops with an overall coefficient of determination (R^2) of 0.90 and not well simulated in 2015/2016 with an overall coefficient of determination (R^2) of 0.44 for both crops. The APSIM model overestimated grain yield of lablab with an overall RMSE of 425.51 and 782.20 kg/ha, respectively, in 2015/2016 and 2016/2017 planting seasons. The model underestimated maize grain yield with an overall RMSE of 852.54 kg/ha in 2016/2017 planting season and in 2015/2016, maize grain yield was only underestimated at maize/lablab(sim) with an overall RMSE of 739.71 kg/ha.

The results of observed and simulated dry matter yield are shown in Table 13. The APSIM model simulated dry matter yield well in 2015/2016 with an overall coefficient of determination (R^2) of 0.97 for both crops than in 2016/2017 coefficient of determination (R^2) of 0.41. The model overestimated lablab dry matter yield in both 2015/2016 and 2016/2017 planting seasons for all treatments with an RMSE of 844.20 and 185.56 kg/ha in 2015/2016 and 2016/2017, respectively. Maize dry matter yield was overestimated in 2015/2016 except for maize+lablab-ST and underestimated in 2016/2017 with an RMSE of 829.68 and 985 kg/ha in 2015/2016 and 2016/2017, respectively.

Table 12: Comparison of simulated and observed grain yield at Univen site.

		MAIZE			LABLAB		
		Sim	Obs	∆diff	Sim	Obs	∆diff
SEASON	TREATMENT	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
2015/2016	Sole	2436.3	1336	1100.3	1450.2	788.6	661.6
	Maize+lablab-ST	1300	1499	-199	869.5	611.8	257.7
	Maize+lablab-28	3126.5	2501	625.5	1000	802.4	197.6
	RMSE	739.71			425.51		
	R^2	0.49			0.39		
2016/2017	Sole	2345.2	2971	-625.8	1386.8	821.8	565
	Maize+lablab-ST	2100	2804	-704	1117.5	702.1	415.4
	Maize+lablab-28	2848.8	3986	-1137.2	2071.1	911.9	1159.2
	RMSE	852.54			782.20		
	R^2	0.96			0.89		

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

Table 13: Comparison of simulated and observed dry matter at Univen site.

		MAIZE			LABLAB		
SEASON	TREATMENT	Sim (kg/ha)	Obs (kg/ha)	∆diff (kg/ha)	Sim (kg/ha)	Obs (kg/ha)	∆diff (kg/ha)
2015/2016	Sole	3768.9	3307	461.9	4251.2	2789	1462.2
	Maize+lablab-ST	3155.6	3301	-145.4	3245.6	2344	901.6
	Maize+lablab-28	5799	4446	1353	3489.3	2390	1099.3
	RMSE	829.68			844.20		
	R^2	0.95			0.98		
2016/2017	Sole	5522.5	5943	-420.5	4410.4	4089	321.4
	Maize+lablab-ST	4176.4	5088	-911.6	5504.5	3609	1895.5
	Maize+lablab-28	5145.5	6526	-1380.5	5413.4	4140	1273.4
	RMSE	985			185.56		
	R^2	0.59			0.23		

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

4.8.2 Observed and predicted grain yield and dry matter at Syferkuil site

The APSIM model simulated grain yield and there was a good agreement with observed data collected in 2016/2017 planting season for both crops with an overall coefficient of determination R^2 of 0.80 and 0.97 for maize and lablab. In 2016/2017, there was a disagreement between the simulated and observed data with an overall coefficient of determination R^2 of 0.36 and 0.55 for maize and lablab grain yield. In 2015/2016 and 2016/2017 planting seasons, maize grain yield was underestimated with an RMSE of 931.40 and 745.50 kg/ha, respectively. Lablab grain yield was overestimated with an

RMSE of 195.38 and 354.82 kg/ha in 2015/2016 and 2016/2017 planting seasons (Table 14).

The was a good relationship between simulated and observed maize dry matter yield in 2015/2016 and 2016/2017 planting seasons with an overall coefficient of determination R^2 of 0.99 and 0.95, respectively. The model overestimated the maize dry matter in 2015/2016 with an RMSE of 583.60 kg/ha in 2015/2016 and underestimated maize dry matter yield with an RMSE of 609.42 kg/ha. Lablab dry matter yield was also well simulated with an overall coefficient of determination R^2 of 0.85 in 2015/2016 but no well simulated in 2016/2017 with a coefficient of determination R^2 of 0.51. In 2015/2016, the data was underestimated with an RMSE of 156.73 kg/ha and overestimated in 2016/2017 with an RMSE of 1191.10 kg/ha (Table 15).

Table 14: Comparison of simulated and observed grain yield at Syferkuil site.

		MAIZE			LABLAB		
		Sim	Obs	∆diff	Sim	Obs	∆diff
SEASON	TREATMENT	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
2015/2016	Sole	1265	2455	-1190	701.1	597.3	103.8
	Maize+lablab-ST	1600	2020	-420	618.8	532.4	86.4
	Maize+lablab-28	2000	3005	-1005	910.5	600.2	310.3
	RMSE	931.40			195.38		
	R^2	0.36			0.55		
2016/2017	Sole	3360	3681	-321	887	501	386
	Maize+lablab-ST	3258	3925	-667	611	450	161
	Maize+lablab-28	3676	4734	-1058	987	536.7	450.3
	RMSE	745.50			354.82		
	R^2	0.8			0.97		

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

Table 15: Comparison of simulated and observed dry matter at Syferkuil site.

		MAIZE			LABLAB		
SEASON	TREATMENT	Sim (kg/ha)	Obs (kg/ha)	∆diff (kg/ha)	Sim (kg/ha)	Obs (kg/ha)	∆diff (kg/ha)
2015/2016	Sole	3587.1	3332	255.1	2793.7	2851	-57.3
	Maize+lablab-ST	2867.7	2792	1324.3	2594.1	2414	180.1
	Maize+lablab-28	3528.4	3376	152.4	2717.1	2532	185.1
	RMSE	583.60			152.73		
	R^2	0.99			0.85		
2016/2017	Sole	2035.4	2780	-744.6	3406.2	2387	1019.2
	Maize+lablab-ST	3438.9	4132	-693.1	2149.8	1411	738.8
	Maize+lablab-28	5196.2	5207	689.2	3102.4	1457	1645.4
	RMSE	609.42			1196.10		
	R^2	0.95			0.51		

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

CHAPTER 5: DISCUSSION

Maize/lablab intercropping had a significant effect on maize grain yield in 2015/2016 and 2016/2017 planting season. The trials showed higher productivity of the maize+lablab-28 treatment in comparison to the sole systems. A similar observation was made by Gbaraneh et al (2004) who reported that planting lablab four weeks after planting maize resulted in high grain yield of maize. The lablab grain yield and dry matter simply added to the maize dry matter and did not reduce the latter (Tables 5 and 6). This might be related to more spatially efficient use of soil water (Tables 8 and 9). Interestingly, maize grain yields were reduced in the 2015/2016 season, but lablab dry matter and yield were not affected (Table 3, 4, 5 and 6). This suggests that lablab is indeed a drought-tolerant legume, as was also found by Sennhenn et al. (2017) in comparison to cowpea and common bean in field experiments in Kenya.

Delayed planting resulted in improved performance for the intercropping systems, reflecting common knowledge that planting the crops at the same time leads to increased competition between crops. The soil water content did not differ between sole and mixed systems, indicating complementary water use. Both hypotheses of this study were confirmed. From an agronomic perspective, this cropping system appears promising, although further investigation is required, in particular, with regard to the micro-climatic effects of these systems, and on how to best upscale the results from field to farm, region and beyond, as well as for future climatic conditions.

The result of this study showed that maize grain yields and dry matter were the same for maize+lablab-28 as they were for sole maize across years and sites (Table 3 and 4).

Hence, the dry matter of lablab can be regarded as an additional benefit, which can be used for forage or high-quality residue material. Grain yields of lablab were low and may be of less interest. Other lablab planting material, which could potentially produce more grain (Pengelly and Maass, 2001) could be considered depending on the interest of the producer.

Exploring the reasons for this favorable result requires careful observation in terms of the season and site, where high maize grain yields and lablab dry matter were obtained (Tables 3, 4, 5, and 6). As expected in the 2015/2016 season, the maize grain yields and DM values were significantly lower at both sites in comparison to the season of 2016/2017. This can be linked to water availability and higher temperatures (Figures 3 and 4).

Nevertheless, there was also a significant effect of site on maize grain yields, i.e. higher yields in Syferkuil as opposed to Univen. At Univen in 2015/2016, the total rainfall was 700 mm lower during the maize growth period than in the following season (586 vs 1315 mm) (Figure 3). The lower water supply was reflected in the soil water content across the season 2015/2016. This site has a clay soil, which provides a relatively good water holding capacity, but also has the potential to keep the water in the topsoil - the water in this layer is more prone to evaporation. In 2015/2016, temperatures were average, although there were some extremely hot days around maize anthesis (> 40 °C). The higher temperature may cause a reduction in water supply due to higher evaporation demand, and the extreme events might have resulted in less grain development (Wilhelm et al., 1999). This is supported by the low HI percentage of 19 and 10 for maize and lablab, respectively in Univen in 2015/2016 (Tables 3 and 5).

When comparing the two sites, temperatures at Syferkuil were much lower (Figure 4) and there were notably no days with temperatures of 40 °C or above. The season 2015/2016 was warmer than 2016/2017. At Syferkuil, the HI was higher in both years with a value of around 25 % and above for maize crop (Table 4). Interestingly, the dry matter at flowering and at maturity was generally comparable between both sites.

It is important to note that although there was less rain at Syferkuil, it was more equally distributed over the season. This is indicated by the higher number of heavy rainfall days at Univen at days 4 and 9 in 2015/2016 and 2016/2017, respectively, with > 40 mm rain/day in comparison to 0 and 2 days at Syferkuil. In 2015/2016, which was a dry year at Univen, there was one extreme event with > 180 mm/day. In addition, there may have been less evaporation due to deeper infiltration of the water (less water in the topsoil) and lower evapotranspiration demand (lower temperatures) at Syferkuil. This is underlined by the fact that the soil water content at Syferkuil was higher compared with that of Univen (Tables 8 and 9). Solar radiation was higher at Syferkuil, which may additionally contribute to higher grain yields at Syferkuil.

This comparison between the sites makes it plausible that the extreme temperatures at Univen played an important role in the yield formation of maize. This would also explain why the maize/lablab intercropping system was not severely affected by the different water supplies. The high total yield (combined lablab and maize yields) and LER suggested complementary water use by the maize/lablab intercropping (Table 7). Maize/lablab intercropping showed the advantage of efficient utilization of resources as compared to sole cropping the results are comparable to the earlier findings of Dwivedi et al., (2015), Nndwambi et al., (2016), Osman et al., (2011). In this study, maize/lablab intercropping did not reduce but raised maize yield. Kutu and Asiwe (2010) and Tsubo et al., (2004) found similar results that maize intercropping increased LER in different intercrop systems. The partial LER for maize in both planting seasons at both sites was higher as compared to lablab and this is in agreement with results obtained by Sebetha et al., (2010) who reported that partial LER of maize in both planting seasons at 3 sites was higher as compared to cowpea. These results suggest that maize/lablab intercropping is a viable option even in seemingly marginal rainfall environment. This might be related to the relatively low planting density of three plants/m^2 in the maize system. Between row spacing of 90 cm leaves a significant area of bare soil until canopy closure occurs. During this period, the water in the topsoil could be highly prone to evaporation. In addition, this wide spacing may result in sub-optimal spatial exploitation of the water content in the soil. Maize roots grow vertically deeper before starting to grow horizontally (Ahmed et al., 2016). The lablab crop with a more horizontal aboveground growth pattern than the erect growing maize covered the soil quickly and hardly left any soil bare. It could be argued that soil water was more efficiently exploited in the intercropping system.

The low planting density typically used by smallholder farmers - as also used in the field trials - is an adaptation to the high climate variability from season to season through the avoidance of spending too much money on expensive maize seeds. Such a risk aversion strategy, which results in lower gains than attainable in favorable years, helps to minimize the financial losses in years with adverse climate conditions (Hoffmann et al., 2018). This behavior might be difficult to change and could also be beneficial depending on the socio-economic situation in which the smallholder operates for maize cropping. Despite this, the additional lablab could work to supplement this system. Lablab is a drought-resistant and robust crop, as also seen in this trial, where season hardly had an effect. Provided lablab seeds can be sold to farmers at a reasonable price, it could be a risk management strategy to provide additional biomass to overcome the trade-off between soil fertility maintenance and fodder availability during the dry season for cattle.

Soil nitrate and ammonium were not significantly affected by maize/lablab intercropping treatments, but were significantly affected by sampling time which was before planting, vegetative leaf-level V1, V7, R1, and R6. There was no interaction between treatment and sampling time (Tables 10 and 11). Sampling time significantly affects soil NO_3^--N. Soil NO_3^--N and NH_4^+-N are highly dynamic and are influenced by soil particle distribution, soil depth, soil sampling stage, precipitation amount and distribution during crop growth and development. It was notable however that maize/lablab intercropping showed a higher NO_3^--N and NH_4^+-N levels at all depths. The results showed that sole maize has negative implications on soil fertility improvement and management as shown by the amounts of NO_3^--N and NH_4^+-N recorded. At both sites, the soil NO_3^--N showed a sharp drop at V7 sampling time (Tables 10 and 11). This was attributed to the amount of precipitation that was received in the month of February and March that probably resulted in leaching of NO_3^--N and NH_4^+-N to lower soil depths. This is in agreement with the findings of Xue et al., (2013), who pointed out the influence of the environmental factors on nitrogen dynamics. The other possible reason for the sharp drop at sampling stage V7 could be that as the crop growth and development continued in the growing season, the demand for NO_3^--N and NH_4^+-N increased and thus reduced the concentration of the nutrient in the soil.

APSIM-model simulation for grain and pod yield at Univen was in agreement with the observed grain and pod yield. Furthermore, grain yield in maize/lablab(sim) treatment was undersimulated, with a lower gap (between simulated and observed). There was a strong relationship between the simulated and the observed grain and pod yield in 2016/2017 planting season for both crops at both sites. At Syferkuil, the APSIM over simulated the dry matter for both crops, and this could be attributed to the fact that field experimentation is exposed to various conditions such as delayed growth, overflowing of water, crusting and natural enemies that the model does not take into consideration. Chivenge et al., (2004) reported similar results where there was a serious over simulation of data by APSIM. The over stimulated was also obtained in the study by Whitbread et al., (2004), where APSIM-model over simulated the grain and dry matter yield production.

There was a significant difference between the simulated and observed grain and dry matter yield in all treatments, planting seasons and sites. Maize/lablab(sim) produced the lowest simulated grain and dry matter yield at all planting seasons and sites. However, the results showed a good performance of APSIM- model under the given set of conditions.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

This study demonstrated that maize/lablab intercropping provides additional biomass production in comparison to commonly cultivated sole maize cropping in the smallholder systems of the Limpopo province, South Africa. This finding, as indicated by total DM and yield output, as well as LER, was consistent across years and two contrasting sites. The analysis suggested that high temperatures in addition to water limitations play an important role for final maize yield in this region. Further research is needed to better understand the link between micro-climate differences between sole and intercropping systems, and in upscaling the results to farm and regional levels. Finally, the study highlighted potential opportunities through using local, underutilized crops, such as lablab for the sustainable intensification of smallholder systems.

Maize achieved the highest biomass and grain yield when maize was planted with lablab 28 days afterward at both sites and planting seasons. This indicated that maize had a lesser competition for growth resources such as nutrients, water, and light. The overall results show that the manipulation of the delayed planting of lablab to maize has a high potential in improving the productivity of maize. Lablab produced higher biomass and yield when planted solely at both sites and planting seasons. Furthermore, the highest biomass and yield was obtained when maize was planted with lablab 28 days afterward as compared to maize planted with lablab simultaneously at both sites and planting seasons. This is probably due to competition for light and other growth resources in intercropping as compared to sole cropping.

Maize/lablab intercropping increased the overall productivity of maize. Lablab did not reduce grain yield of maize. The results obtained showed that lablab should be introduced to maize 28 days afterward to improve the yield of maize.

APSIM-model has proved to be an applicable tool in simulating grain/pod and dry matter yields. In general, the model provided acceptable results for both seasons and sites. The simulation results showed the best performance of intercropping than sole cropping at both sites. However there’s need for investigations on how specific soil and climate conditions affect maize/lablab intercropping.

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APPENDICES

Appendix 1: Univen APSIM-model summary file (2015/2016)

```
                    Soil Profile Properties
   ---------------------------------------------------------------------
         Depth  Air_Dry  LL15   Dul    Sat     Sw     BD   Runoff  SWCON
           mm     mm/mm  mm/mm  mm/mm  mm/mm  mm/mm  g/cc    wf
   ---------------------------------------------------------------------
       0.-  150.  0.060  0.120  0.260  0.490  0.260  1.100  0.762  0.500
     150.-  300.  0.080  0.130  0.290  0.490  0.290  1.200  0.190  0.500
     300.-  450.  0.130  0.130  0.290  0.490  0.290  1.200  0.048  0.700
     450.-  600.  0.130  0.130  0.320  0.490  0.320  1.200  0.000  0.700
     600.-  750.  0.130  0.130  0.320  0.490  0.320  1.200  0.000  0.700
     750.-  900.  0.130  0.130  0.320  0.490  0.320  1.200  0.000  0.700
   ---------------------------------------------------------------------



                 Soil Water Holding Capacity
     ---------------------------------------------------------
         Depth    Unavailable Available  Max Avail.  Drainable
                     (LL15)   (SW-LL15)  (DUL-LL15)  (SAT-DUL)
                       mm        mm          mm         mm
     ---------------------------------------------------------
       0.-  150.      18.00      21.00      21.00      34.50
     150.-  300.      19.50      24.00      24.00      30.00
     300.-  450.      19.50      24.00      24.00      30.00
     450.-  600.      19.50      28.50      28.50      25.50
     600.-  750.      19.50      28.50      28.50      25.50
     750.-  900.      19.50      28.50      28.50      25.50
     ---------------------------------------------------------
          Totals      115.50     154.50     154.50     171.00
     ---------------------------------------------------------



                 Initial Soil Parameters
     ---------------------------------------------------------
            Insoil        Salb     Dif_Con   Dif_Slope
     ---------------------------------------------------------
              0.00        0.13       88.00       35.00
     -------------------------------------------------------

                 Runoff is predicted using scs curve number:
               Cn2   Cn_Red   Cn_Cov   H_Eff_Depth mm
     ---------------------------------------------------------
         73.00    20.00     0.80   450.00
     ---------------------------------------------------------



                        Initial Surface Organic Matter Data
    ----------------------------------------------------------------------
       Name    Type          Dry matter    C         N         P    Cover  Standing_fr
                              (kg/ha)   (kg/ha)   (kg/ha)   (kg/ha) (0-1)     (0-1)
    ----------------------------------------------------------------------
     maize      lablab          500.0    200.0       2.5      0.0   0.095      0.0
    ----------------------------------------------------------------------

                 Effective Cover from Surface Materials =   0.1
```

```
            Soil Profile Properties
     ---------------------------------------------------
      Layer     pH     OC      NO3      NH4     Urea
                      (%)  (kg/ha)  (kg/ha)  (kg/ha)
     ---------------------------------------------------
        1      5.70   1.23    48.96     9.54     0.00
        2      5.50   1.00    61.90    11.95     0.00
        3      5.40   0.40   184.79    32.54     0.00
        4      5.30   0.40     0.02     0.02     0.00
        5      5.30   0.40     0.02     0.02     0.00
        6      5.30   0.40     0.02     0.02     0.00
     ---------------------------------------------------
      Totals                 295.70    54.09     0.00
     ---------------------------------------------------



        Initial Soil Organic Matter Status
     ------------------------------------------------------------
      Layer      Hum-C   Hum-N  Biom-C  Biom-N   FOM-C   FOM-N
               (kg/ha) (kg/ha) (kg/ha) (kg/ha) (kg/ha) (kg/ha)
     ------------------------------------------------------------
        1      19999.4  1666.6   295.6    36.9   165.6     4.1
        2      17894.1  1491.2   105.9    13.2   100.5     2.5
        3       7157.6   596.5    42.4     5.3    60.9     1.5
        4       7192.9   599.4     7.1     0.9    37.0     0.9
        5       7192.9   599.4     7.1     0.9    22.4     0.6
        6       7192.9   599.4     7.1     0.9    13.6     0.3
     ------------------------------------------------------------
      Totals   66629.8  5552.5   465.2    58.1   400.0    10.0
     ------------------------------------------------------------



                Root Profile
    ---------------------------------------------------
      Layer       Kl       Lower Exploration
      Depth                limit    Factor
      (mm)        ()       (mm/mm)    ()
    ---------------------------------------------------
     150.000     0.060     0.120     1.000
     150.000     0.060     0.130     1.000
     150.000     0.060     0.150     1.000
     150.000     0.050     0.150     1.000
     150.000     0.050     0.150     1.000
     150.000     0.050     0.150     1.000
     ---------------------------------------------------
```

Appendix 2: Syferkuil APSIM-model summary file (2015/2016)

```
                   Soil Profile Properties
   ---------------------------------------------------------------------
         Depth  Air_Dry  LL15   Dul    Sat     Sw     BD   Runoff  SWCON
           mm     mm/mm  mm/mm  mm/mm  mm/mm  mm/mm  g/cc    wf
   ---------------------------------------------------------------------
       0.-  150.  0.030  0.054  0.150  0.403  0.150  1.450  0.762  0.700
     150.-  300.  0.030  0.072  0.156  0.403  0.156  1.450  0.190  0.700
     300.-  600.  0.110  0.110  0.157  0.403  0.157  1.450  0.048  0.700
     600.-  900.  0.110  0.110  0.157  0.403  0.157  1.450  0.000  0.700
     900.- 1200.  0.110  0.110  0.157  0.403  0.157  1.450  0.000  0.700
    1200.- 1500.  0.110  0.110  0.157  0.403  0.157  1.450  0.000  0.700
    1500.- 1800.  0.110  0.110  0.157  0.403  0.157  1.450  0.000  0.700
   ---------------------------------------------------------------------



               Soil Water Holding Capacity
     ---------------------------------------------------------
         Depth    Unavailable Available  Max Avail.  Drainable
                     (LL15)   (SW-LL15)  (DUL-LL15)  (SAT-DUL)
                       mm        mm          mm         mm
     ---------------------------------------------------------
       0.-  150.       8.10     14.40       14.40      37.95
     150.-  300.      10.80     12.60       12.60      37.05
     300.-  600.      33.00     14.10       14.10      73.80
     600.-  900.      33.00     14.10       14.10      73.80
     900.- 1200.      33.00     14.10       14.10      73.80
    1200.- 1500.      33.00     14.10       14.10      73.80
    1500.- 1800.      33.00     14.10       14.10      73.80
     ---------------------------------------------------------
          Totals     183.90     97.50       97.50     444.00
     ---------------------------------------------------------



               Initial Soil Parameters
     ---------------------------------------------------------
            Insoil        Salb     Dif_Con   Dif_Slope
     ---------------------------------------------------------
              0.00        0.13       88.00       35.40
     ---------------------------------------------------------



               Runoff is predicted using scs curve number:
             Cn2  Cn_Red  Cn_Cov   H_Eff_Depth
                                        mm
     ---------------------------------------------------------
           80.00   20.00    0.80  450.00
     ---------------------------------------------------------



                      Initial Surface Organic Matter Data
    ----------------------------------------------------------------------
       Name   Type          Dry matter   C        N        P    Cover  Standing_fr
```

```
                       (kg/ha)  (kg/ha)  (kg/ha)  (kg/ha) (0-1)     (0-1)
----------------------------------------------------------------------
 maize     lablab         500.0   200.0     2.5     0.0   0.095     0.0
----------------------------------------------------------------------

             Effective Cover from Surface Materials =   0.1



             Soil Profile Properties
 ------------------------------------------------
  Layer    pH    OC     NO3     NH4    Urea
                (%) (kg/ha) (kg/ha) (kg/ha)
 ------------------------------------------------
    1     6.60  0.87   22.47    9.87    0.00
    2     7.00  0.87   33.32   13.64    0.00
    3     6.90  0.70   75.56   68.82    0.00
    4     6.90  0.60    0.04    0.04    0.00
    5     6.90  0.50    0.04    0.04    0.00
    6     6.90  0.40    0.04    0.04    0.00
    7     6.90  0.40    0.04    0.04    0.00
 ------------------------------------------------
  Totals              131.52   92.50    0.00
 ------------------------------------------------




         Initial Soil Organic Matter Status
 ---------------------------------------------------------
  Layer      Hum-C   Hum-N  Biom-C  Biom-N   FOM-C   FOM-N
           (kg/ha) (kg/ha) (kg/ha) (kg/ha) (kg/ha) (kg/ha)
 ---------------------------------------------------------
    1      18646.9  1286.0   275.6    34.4    55.5     1.2
    2      18737.0  1292.2   185.5    23.2    43.3     1.0
    3      30211.2  2083.5   238.8    29.9    26.2     0.6
    4      26022.5  1794.7    77.5     9.7    15.9     0.4
    5      21750.0  1500.0     0.0     0.0     9.7     0.2
    6      17400.0  1200.0     0.0     0.0     5.9     0.1
    7      17400.0  1200.0     0.0     0.0     3.6     0.1
 ---------------------------------------------------------
  Totals  150167.6 10356.4   777.4    97.2   160.0     3.6
 ---------------------------------------------------------



                Initial Surface Organic Matter Data
----------------------------------------------------------------------
   Name   Type        Dry matter   C        N        P    Cover  Standing_fr
                       (kg/ha)  (kg/ha)  (kg/ha)  (kg/ha) (0-1)     (0-1)
----------------------------------------------------------------------
 maize     lablab         500.0   200.0     2.5     0.0   0.095     0.0
----------------------------------------------------------------------

             Effective Cover from Surface Materials =   0.1



             Crop Sowing Data
```

```
    -------------------------------------------------------
    Sowing   Depth  Plants Spacing Skiprow Cultivar    FTN
    Day no     mm     m^2    m     code     name       no
    -------------------------------------------------------
       344   30.0    2.7    0.9    0.0   sc501         0.00
    -------------------------------------------------------

   - Reading root profile parameters
Uptake of NO3 and water calculated by maize



                    Root Profile
    ------------------------------------------------
      Layer      Kl       Lower Exploration
      Depth               limit   Factor
      (mm)       ()      (mm/mm)    ()
    ------------------------------------------------
     150.000    0.060    0.054    1.000
     150.000    0.060    0.072    1.000
     300.000    0.060    0.110    1.000
     300.000    0.040    0.110    1.000
     300.000    0.040    0.110    0.000
     300.000    0.020    0.110    0.000
     300.000    0.010    0.110    0.000
     ------------------------------------------------
```

Appendix 3: Univen APSIM-model summary file (2016/2017)

```
Soil Profile Properties
      ---------------------------------------------------------------------
            Depth  Air_Dry  LL15   Dul    Sat     Sw     BD   Runoff  SWCON
              mm    mm/mm  mm/mm  mm/mm  mm/mm  mm/mm  g/cc    wf
      ---------------------------------------------------------------------
          0.-  150.  0.060  0.120  0.260  0.490  0.260  1.100  0.762  0.500
        150.-  300.  0.080  0.130  0.290  0.490  0.290  1.200  0.190  0.500
        300.-  450.  0.130  0.130  0.290  0.490  0.290  1.200  0.048  0.700
        450.-  600.  0.130  0.130  0.320  0.490  0.320  1.200  0.000  0.700
        600.-  750.  0.130  0.130  0.320  0.490  0.320  1.200  0.000  0.700
        750.-  900.  0.130  0.130  0.320  0.490  0.320  1.200  0.000  0.700
      ---------------------------------------------------------------------



                Soil Water Holding Capacity
        ---------------------------------------------------------
            Depth    Unavailable Available  Max Avail.  Drainable
                        (LL15)   (SW-LL15)  (DUL-LL15)  (SAT-DUL)
                          mm        mm          mm          mm
        ---------------------------------------------------------
          0.-  150.      18.00      21.00      21.00      34.50
        150.-  300.      19.50      24.00      24.00      30.00
        300.-  450.      19.50      24.00      24.00      30.00
        450.-  600.      19.50      28.50      28.50      25.50
        600.-  750.      19.50      28.50      28.50      25.50
        750.-  900.      19.50      28.50      28.50      25.50
        ---------------------------------------------------------
             Totals     115.50     154.50     154.50     171.00
        ---------------------------------------------------------
```

```
         Initial Soil Parameters
 ---------------------------------------------------------
        Insoil        Salb     Dif_Con   Dif_Slope
 ---------------------------------------------------------
          0.00        0.13       88.00       35.00
 ---------------------------------------------------------



         Runoff is predicted using scs curve number:
       Cn2  Cn_Red  Cn_Cov   H_Eff_Depth
                                  mm
 ---------------------------------------------------------
     73.00   20.00    0.80  450.00
 ---------------------------------------------------------



                Initial Surface Organic Matter Data
 ----------------------------------------------------------------------
   Name   Type        Dry matter   C        N        P    Cover  Standing_fr
                       (kg/ha)  (kg/ha)  (kg/ha)  (kg/ha) (0-1)     (0-1)
 ----------------------------------------------------------------------
 maize     lablab         500.0   200.0     2.5     0.0   0.095     0.0
 ----------------------------------------------------------------------

             Effective Cover from Surface Materials =   0.1



             Soil Profile Properties
 ------------------------------------------------
  Layer    pH    OC     NO3     NH4    Urea
                (%) (kg/ha) (kg/ha) (kg/ha)
 ------------------------------------------------
    1     5.70  1.23   48.96    9.54    0.00
    2     5.50  1.00   61.90   11.95    0.00
    3     5.40  0.40  184.79   32.54    0.00
    4     5.30  0.40    0.02    0.02    0.00
    5     5.30  0.40    0.02    0.02    0.00
    6     5.30  0.40    0.02    0.02    0.00
 ------------------------------------------------
  Totals              295.70   54.09    0.00
 ------------------------------------------------



         Initial Soil Organic Matter Status
```

```
     ---------------------------------------------------------
      Layer      Hum-C   Hum-N  Biom-C  Biom-N   FOM-C   FOM-N
               (kg/ha) (kg/ha) (kg/ha) (kg/ha) (kg/ha) (kg/ha)
     ---------------------------------------------------------
        1      19999.4  1666.6   295.6    36.9   165.6     4.1
        2      17894.1  1491.2   105.9    13.2   100.5     2.5
        3       7157.6   596.5    42.4     5.3    60.9     1.5
        4       7192.9   599.4     7.1     0.9    37.0     0.9
        5       7192.9   599.4     7.1     0.9    22.4     0.6
        6       7192.9   599.4     7.1     0.9    13.6     0.3
     ---------------------------------------------------------
      Totals   66629.8  5552.5   465.2    58.1   400.0    10.0
     ---------------------------------------------------------

                    Initial Surface Organic Matter Data
    ----------------------------------------------------------------------
       Name   Type         Dry matter   C        N        P    Cover  Standing_fr
                            (kg/ha)  (kg/ha)  (kg/ha)  (kg/ha) (0-1)     (0-1)
    ----------------------------------------------------------------------
     maize     lablab          500.0   200.0      2.5      0.0  0.095      0.0
    ----------------------------------------------------------------------

                 Effective Cover from Surface Materials =   0.1



                 Crop Sowing Data
    -------------------------------------------------------
    Sowing   Depth Plants Spacing Skiprow Cultivar     FTN
    Day no    mm     m^2     m     code     name        no
    -------------------------------------------------------
       326   30.0    2.7    0.9    0.0   sc501         0.00
    -------------------------------------------------------

      - Reading root profile parameters
   Uptake of NO3 and water calculated by maize



                    Root Profile
    ------------------------------------------------
      Layer      Kl       Lower Exploration
      Depth               limit   Factor
      (mm)       ()      (mm/mm)    ()
    ------------------------------------------------
     150.000    0.060    0.120    1.000
     150.000    0.060    0.130    1.000
     150.000    0.060    0.150    1.000
     150.000    0.050    0.150    1.000
     150.000    0.050    0.150    1.000
     150.000    0.050    0.150    1.000
     ------------------------------------------------
```

Appendix 4: Syferkuil APSIM-model summary file (2016/2017)

```
                      Soil Profile Properties
         ---------------------------------------------------------------------
               Depth  Air_Dry  LL15   Dul    Sat     Sw     BD   Runoff  SWCON
                 mm     mm/mm  mm/mm  mm/mm  mm/mm  mm/mm  g/cc    wf
         ---------------------------------------------------------------------
             0.-  150.  0.030  0.054  0.150  0.403  0.150  1.450  0.762  0.700
           150.-  300.  0.030  0.072  0.156  0.403  0.156  1.450  0.190  0.700
           300.-  600.  0.110  0.110  0.157  0.403  0.157  1.450  0.048  0.700
           600.-  900.  0.110  0.110  0.157  0.403  0.157  1.450  0.000  0.700
           900.- 1200.  0.110  0.110  0.157  0.403  0.157  1.450  0.000  0.700
          1200.- 1500.  0.110  0.110  0.157  0.403  0.157  1.450  0.000  0.700
          1500.- 1800.  0.110  0.110  0.157  0.403  0.157  1.450  0.000  0.700
         ---------------------------------------------------------------------



                  Soil Water Holding Capacity
           ---------------------------------------------------------
               Depth    Unavailable Available  Max Avail.  Drainable
                           (LL15)   (SW-LL15)  (DUL-LL15)  (SAT-DUL)
                            mm         mm          mm          mm
           ---------------------------------------------------------
             0.-  150.       8.10      14.40       14.40       37.95
           150.-  300.      10.80      12.60       12.60       37.05
           300.-  600.      33.00      14.10       14.10       73.80
           600.-  900.      33.00      14.10       14.10       73.80
           900.- 1200.      33.00      14.10       14.10       73.80
          1200.- 1500.      33.00      14.10       14.10       73.80
          1500.- 1800.      33.00      14.10       14.10       73.80
           ---------------------------------------------------------
                Totals     183.90      97.50       97.50      444.00
           ---------------------------------------------------------



                  Initial Soil Parameters
           ---------------------------------------------------------
                  Insoil        Salb     Dif_Con   Dif_Slope
           ---------------------------------------------------------
                    0.00        0.13       88.00       35.40
           ---------------------------------------------------------



                  Runoff is predicted using scs curve number:
                Cn2  Cn_Red  Cn_Cov   H_Eff_Depth
                                           mm
           ---------------------------------------------------------
               80.00   20.00    0.80  450.00
           ---------------------------------------------------------



                         Initial Surface Organic Matter Data
          ----------------------------------------------------------------------
```

```
   Name   Type        Dry matter   C        N        P    Cover  Standing_fr
                       (kg/ha)  (kg/ha)  (kg/ha)  (kg/ha) (0-1)     (0-1)
----------------------------------------------------------------------
 maize     lablab         500.0   200.0     2.5      0.0   0.095     0.0
----------------------------------------------------------------------

             Effective Cover from Surface Materials =   0.1



             Soil Profile Properties
 ------------------------------------------------
  Layer    pH   OC    NO3     NH4    Urea
                (%) (kg/ha) (kg/ha) (kg/ha)
 ------------------------------------------------
    1     6.60  0.87   20.16   89.00    0.00
    2     7.00  0.87   33.43  103.29    0.00
    3     6.90  0.70   74.04  236.21    0.00
    4     6.90  0.60    0.04    0.04    0.00
    5     6.90  0.50    0.04    0.04    0.00
    6     6.90  0.40    0.04    0.04    0.00
    7     6.90  0.40    0.04    0.04    0.00
 ------------------------------------------------
  Totals              127.80  428.67    0.00
 ------------------------------------------------




         Initial Soil Organic Matter Status
 ---------------------------------------------------------
  Layer      Hum-C   Hum-N  Biom-C  Biom-N   FOM-C   FOM-N
           (kg/ha) (kg/ha) (kg/ha) (kg/ha) (kg/ha) (kg/ha)
 ---------------------------------------------------------
    1      18646.9  1286.0   275.6    34.4    55.5     1.2
    2      18737.0  1292.2   185.5    23.2    43.3     1.0
    3      30211.2  2083.5   238.8    29.9    26.2     0.6
    4      26022.5  1794.7    77.5     9.7    15.9     0.4
    5      21750.0  1500.0     0.0     0.0     9.7     0.2
    6      17400.0  1200.0     0.0     0.0     5.9     0.1
    7      17400.0  1200.0     0.0     0.0     3.6     0.1
 ---------------------------------------------------------
  Totals   150167.6 10356.4   777.4    97.2   160.0     3.6
 ---------------------------------------------------------

                Initial Surface Organic Matter Data
----------------------------------------------------------------------
   Name   Type        Dry matter   C        N        P    Cover  Standing_fr
                       (kg/ha)  (kg/ha)  (kg/ha)  (kg/ha) (0-1)     (0-1)
----------------------------------------------------------------------
 maize     lablab         500.0   200.0     2.5      0.0   0.095     0.0
----------------------------------------------------------------------

             Effective Cover from Surface Materials =   0.1



             Crop Sowing Data
-------------------------------------------------------
```

```
    Sowing   Depth  Plants Spacing Skiprow Cultivar    FTN
    Day no    mm      m^2    m      code      name       no
    -------------------------------------------------------
         5   30.0    2.7    0.9    0.0   sc501         0.00
    -------------------------------------------------------

   - Reading root profile parameters
Uptake of NO3 and water calculated by maize



                    Root Profile
    ------------------------------------------------
      Layer      Kl       Lower Exploration
      Depth               limit   Factor
      (mm)       ()      (mm/mm)     ()
    ------------------------------------------------
     150.000    0.060    0.054    1.000
     150.000    0.060    0.072    1.000
     300.000    0.060    0.110    1.000
     300.000    0.040    0.110    1.000
     300.000    0.040    0.110    0.000
     300.000    0.020    0.110    0.000
     300.000    0.010    0.110    0.000
     ------------------------------------------------
```