THE RESPONSE OF SELECTED SOIL HEALTH VARIABLES TO RAINFED AND IRRIGATED MAIZE-LEGUME INTERCROPPING SYSTEMS

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THE RESPONSE OF SELECTED SOIL HEALTH VARIABLES TO RAINFED AND IRRIGATED MAIZE-LEGUME INTERCROPPING SYSTEMS

BY

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DECLARATION

I declare that the mini-dissertation submitted to the University of Limpopo, for the degree of Master of Science in Agriculture (Soil Science) has not previously been submitted by me for a degree at this or any other University; that it is my work in design and in execution, and all material contained herein has been duly acknowledged.

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DEDICATION

This work is sincerely dedicated to both my parents,

(P.A and K.A Nong) for their support.

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ABSTRACT

Soil health support crop production and answer to its sustainability and renewability. This study involved the use of under explored legumes in South Africa, Limpopo under maize-legume intercropping systems as a strategy to mitigate soil quality deterioration. The study was conducted at University of Limpopo (Syferkuil) and University of Venda (UNIVEN) Experimental farms during 2020/2021. A split plot experiment, with the main factor comprised of water regimes (irrigation and rainfed) and second main factor included cropping systems (Intercropping and monocropping). Five treatments comprised of 3 monocrops (Maize, Chickpea, and Mungbean) and 2 intercrops (maize-chickpea and maize-mungbean) replicated three times. Data collected from the soil before planting and after maturity were pH, Electrical conductivity (EC), particle size, bulk density, aggregate stability, organic matter (OM), organic carbon (OC), phosphorus (P), ammonium (NH_4-N), nitrate (NO_3—N), soil active carbon (SAC), and potentially mineralizable nitrogen (PMN). Plant parameters collected during vegetative and flowering stage included plant height, chlorophyll content, plant vigour, and leaf area index. All data was subjected to descriptive statistics and analysis of variance using GenStat software. Significant effect ($p<0.05$) was observed between treatments on soil pH (KCl), OM, organic carbon (OC), and ammonium (NH_4) at Syferkuil Farm. Also, interaction between water regimes and cropping systems affected NH_4 and pH (KCl). Cropping systems had significant effect ($p<0.01$) on pH (H_2O), OM, OC, P, NH_4, and NO_3 at UNIVEN. Interaction between water regimes and cropping systems affected ($p<0.01$) pH (H_2O), P but no significant effect was observed on OC, NH_4, and NO_3. Cropping systems and interaction at both locations did not affect particle size, bulk density, aggregate stability, EC, SAC, and PMN. Pure stands of maize and legumes had greater plant height, plant vigour, and chlorophyll content whereas intercrops had greater LAI. The results at both locations revealed that legume intercropping systems improved soil health variables without posing negative feedbacks and hence can be used to boost soil functioning.

Keywords: Soil health, maize-legume intercropping, soil quality

CHAPTER 1

INTRODUCTION

1.1 Background

Globally, including Africa, crop production has been collectively affected by the consequences of rising human population, climate change, rapid urbanization, shrinking agricultural lands, and extensive agrochemical use (Rashid *et al*., 2016; Vimal *et al*., 2017). A rising population and cultivable land that is limited pose major challenges for food production (Qisong *et al*., 2018). Intercropping, a practice of planting two or more different crop species together in the same field in a beneficial manner has been extensively used to control and improve agricultural yields (Gomes and Gomez, 1983). The promising yield advantages of intercropping have been documented and play an important role in upholding farmland environment biodiversity and stability, improving resources efficacy by plants, and achieving stable yields (Zhang *et al*., 2012). Regardless of the intercropping yield advantages, some intercropping practices have shown yield disadvantages due to robust interspecific competition between the crops (Willey and Rao, 1980). Moreover, these interactions may influence soil physico-chemical properties as well as diversity, and population of soil microorganisms (Wang *et al*., 2014).

Most intercropping studies were focused on intercropping to make use of available environmental space and primarily to increase food production (Li *et al*., 2009; He *et al*., 2013; and Ojiem *et al*., 2014). However, little is done on belowground interactions between soil microbial diversity, population, physicochemical properties, and the cropping practice relative to yields. Intercropping advantages have been globally demonstrated, including higher yields of grains and greater N-rich residues which contribute to organic matter pools and soil fertility (Punyalue *et al*., 2018). Different crops in intercropping affect rhizosphere microbial population and soil physicochemical properties, the brought about changes in soil microbial population plays important roles in the paybacks of intercropping (Baudoin *et al*., 2003). Intensive land use affects soil microbial diversity and its population; consequently, affecting soil properties (Karlen *et al*., 1997). The inclusion of legume species in intercropping systems enriches soil biodiversity, improves soil health, upholds soil fertility, and develops microbial biomass (Mäder *et al*., 2002).

Intercropping is a cheap management practice of soil fertility and also possesses a massive soil mineral N replenishment through the ability of legumes to biologically fix atmospheric N (Dwivedi *et al*., 2015). Soil fertility indicators such as particulate organic matter (POM), that are susceptible to changes over a short period due to management, are crucial for agroecosystem functioning and its evaluation (Bukovsky-Reyes *et al*., 2019). Notably, legumes rely less on biological N2 fixation in soils with higher fertility levels due to the presence of available N while their performance is constrained at lower soil fertility levels due to nutrient limitation, particularly phosphorus (Schipanski *et al*., 2014; Bukovsky-Reyes *et al*., 2019). The practice of cereal-legume intercropping may not only increase the availability of deficient soil resources but also alleviate stressful environmental conditions (Bargaz *et al*., 2017). Despite documented growth and yield improvements in cereal-legume intercropping systems, more research is needed on the plant-soil-microbe continuum particularly under low soil nutrient availability conditions (Tang *et al*., 2014; Bargaz *et al*., 2017).

Plant roots besides absorbing water and nutrients, synthesize and transform trace substances to other tissues and hence serve as a site for belowground interspecific interactions (Wang *et al*., 2018). Cereal-legume intercropping offers greater room for minimizing adverse impacts of moisture and nutrient stress, hence improving soil health and productivity (Layek *et al*., 2018). Consequently, resource acquisition and adaptation to environmental restraints such as nutrient deficiency, e.g., P may be improved in cereal-legume intercropping by belowground interactions (Bargaz *et al*., 2017). Intercropping is reported to enhance root health through the stimulation of legume nodulation and root distribution which advantages both crops in the acquisition of resources such as water and P (Li *et al*., 2007).

Therefore, the ultimate goal of intercropping is to increase crop productivity without compromising the environment, soil fertility, and quality of food (Layek *et al*., 2018).

Certainly, soil health indicators include the degree of change in dynamic and inherent soil quality components such as soil physico-chemical properties and mostly biological activities (Morris and Garrity, 1993; Karlen *et al*., 1997). However, little is known about the behaviour of soil health indicators resulting from effects of maize-chickpea intercropping systems.

1.2 Problem statement

Over the decades, declined crop productions associated with loss of soil quality and biodiversity such as beneficial soil bacteria have been reported in agricultural plant productions (Li *et al*., 2014). These declines are strongly linked to cultural practices and cropping systems under cultivation. The adoption of a cropping system like intercropping was brought by the pressures to increase crop productivity (Betencourt *et al*., 2012). However, intercropping may contribute to soil health deterioration through its effects on the soil physicochemical properties driven by microorganism relationships with the surrounding environment (Bybee-Finley and Ryan, 2018). Intercropping systems also change the soil microenvironment in terms of properties and affect the structure of the microorganism community, with further effects on the root health and crop yields (Zhou *et al*., 2018). Apart from anthropogenic impacts on the environment, climate also affects the rate and extent of soil microbial activity. The destruction or loss of soil health and productivity in agroecosystems is a huge problem faced in sustainable agricultural productions and requires adequate attention. Although the effects of intercropping systems on relative yields of component crops and land equivalent ratios are well documented, there is a dearth of information on the effects of maize-chickpea and maize-mungbean species in row intercropping practice on soil physicochemical properties, root health, and functioning of soil microbes and consequently soil health, especially under different water regimes. Also, there is little information on the influence of soil types on these responses.

1.3 Rationale of the study

The use of intercropping systems and exploitation of soil resources and beneficial bacteria serves as an efficient way to overcome crop productivity losses and soil quality deterioration (Deepak *et al*., 2018). For example, maize-legume intercropping improves the accumulation of soil nitrogen and crop residues (Punyalue *et al*., 2018) and enhances soil properties and biodiversity that play a crucial role in organic matter decomposition, formation of soil aggregates, soil nutrients cycling, and suppression of soil-borne microorganisms (Zhang *et al*., 2012). However, conventional farming can suppress and exhaust soil properties, bacterial diversity, and activity which can lead to deterioration in soil health followed by productivity, root health, and yields (Li *et al*., 2014). The benefits of bacteria are well recognized; for decomposition of organic matter, cycling of nutrients, and detoxification of chemical elements, and hence they promote soil health and productivity (Rekha *et al*., 2017). Investigating the behaviour of physicochemical properties, diversity, and activity of beneficial bacteria under cropping practices and systems is always necessary to understand their interspecific interactions with the crop species to account for enhanced sustainable soil and crop productivity (Deepak *et al*., 2018). The main focus of this study was to determine the effects of maize-legume intercropping systems on soil physicochemical properties, root health and microbial activities, at climatically two different regions, and contrasting soil types, with water regimes. This study would be helpful to the farming sector and raise awareness on the upkeep and preservation of soil physicochemical properties under cropping and cultural practices to sustainably manage crop productions, reclaim soil health and quality in the current days of water scarcity.

1.4 Purpose of the study

1.4.1 Aim

The study aimed to investigate the responses of soil health variables to rainfed and irrigated maize-legume intercropping systems at two sites with contrasting soil types and climatic regions.

1.4.2 Objectives

The objectives of the study were:

i) To determine the effects of rainfed and irrigated maize-legume intercropping systems on selected soil health variables at Syferkuil (loamy sand soil) and Thohoyandou (clay soil).

ii) To determine the effects of rainfed and irrigated maize-legume intercropping systems on plant growth and yield parameters at Syferkuil (loamy sand soil) and Thohoyandou (clay soil).

1.5 Reliability, validity, and objectivity

Statistical levels of significance were derived through analysis of variance (ANOVA) and used to ensure reliability. Replications of samples during sampling and analysis for objectives 1 and 2 were made to achieve validity. The forms of subjectivity were eliminated by ensuring that findings were discussed based on empirical evidence to achieve objectivity.

1.6 Bias

Replications were made in all treatments to reduce experimental error and to minimize bias in all objectives.

1.7 Scientific significance of the study

The study was carried out to investigate the effects that arise from the maize-legume intercropping systems on soil physicochemical properties with the use of rainfed and irrigated water regimes. Furthermore, paying attention to such interactions to maintain soil productivity and fertility would benefit the farming industry in improving soil quality and health. Consequently, improving crop production levels that could meet the food demands of an ever-growing population.

1.8 Structure of the mini-dissertation

The mini-dissertation is made up of five chapters. Chapter 1 describes the details of the research problem; chapter 2 is the literature review outlining the work done and work not done on the research problem; chapter 3 and 4 are aligned with the work done to achieve objectives 1 and 2 respectively; and chapter 5 includes the summary of all research findings and their significance, the conclusion drawn from the study, and incorporation of all chapters to provide recommendations for future research. Harvard referencing style was followed in the mini-dissertation, author-alphabet in-text and reference list as approved by the University of Limpopo Senate.

CHAPTER 2

LITERATURE REVIEW

2.1 Work done on the research problem

2.1.1 Agronomic benefits of cereal-legume intercropping

The most popular intercropping technique is legume-cereal intercropping, which not only allows crops to absorb more nutrients than monoculture but also minimizes disease incidence (Liu *et al*., 2017). The main practice of intercropping is to cover for total crop failure against unpredictable incidences of pests or disease and weather (Ananthi *et al*., 2017). The component crops in intercropping have varied morphology and they can exploit edaphic and climatic conditions more efficiently compared to sole crops (Layek *et al*., 2012). Intercropping also offers the best utilization in terms of space, sunlight, moisture, and nutrients (Manasa *et al*., 2018). The mixture of two-component crops gives better coverage of soil and thus reducing weed growth, runoff, and loss of soil nutrients (Von Cossel *et al*., 2019). Furthermore, intercropping increases productivity per unit area by intensifying the land use, reducing the need of nitrogenous fertilizers, and herbicides (Bybee-Finley and Ryan, 2018). The crop performance and productivity in intercropping is higher whereas competition is minimized between crops of different species as against the same species (Layek *et al*., 2018). Legumes can increase legume-cereal intercropping productivity and sustainability by fixing atmospheric nitrogen, making P soluble, and adapting to adverse cropping systems or environmental conditions (Manasa *et al*., 2018).

According to Matusso *et al*. (2014), cereal-legume intercropping by smallholder farmers and agriculturalists was for adaptation and flexibility, risk minimization against complete crop failure, benefit intensification, soil conservation, integrated nutrient management, and weed control. Layek *et al*. (2018), reported that intercropping involving soybean and cereals may effectively increase yield stability and overall productivity while improving soil conditions, breakdown of pest cycle perpetuation, and weed problems. The foliage and greater leaf cover in intercropping save water to a great extent and thereby enhancing water use efficiency (WUE) (Mao *et al*., 2012). Aasha *et al*. (2017), found pearl millet and legume intercropping the most effective in terms of WUE and productivity. Su *et al*. (2014), also reported that in the mixed intercropping of taller and shorter crops, taller crops shield short-statured crops by acting as wind hindrances.

2.1.2 Efficiency of biological nitrogen fixation in legumes

The success of leguminous crops in nitrogen-deficient soils plays a crucial role in agricultural production and results from rhizobium bacteria contained in nodules which reduces atmospheric nitrogen (N_2) to ammonium (NH_4^+) (Vanlauwe *et al*., 2019). Rhizobium bacteria form symbiotic relationships with plants by using sunlight energy collected by plants for photosynthesis (Vanlauwe *et al*., 2019). The significance of rhizobium-legume symbiosis raised awareness in many agricultural fields and prompted farmers to contemplate enhancing symbiotic N_2 fixation in legumes (Phillips, 1980). Nitrogen (N) nutrition of associated cereals in cereal-legume intercropping is improved through a transfer of biologically fixed N from legumes (Meena *et al*., 2015). Though, a certain amount of N got by cereal might not be adequate for its optimal performance (Layek *et al*., 2018). The benefits of biological nitrogen fixation (BNF) are well documented, nevertheless it can be lowered by constraints such as low soil pH which hampers rhizobium growth by making soil P and some micronutrients unavailable (Bakari *et al*., 2020).

Savci (2012), stated that the inclusion of legumes in intercropping with cereals forms an essential component of integrated plant nutrient supply (IPNS) which aims to improve soil health by conserving natural resources and agricultural sustainability. Since legumes can fix nitrogen, they are frequently used in crop rotations (Uzoh *et al*., 2019). Ojiem *et al*. (2014), highlighted that legumes play an important part in achieving beneficial food security systems, and legume rotations help to diversify crop production systems while also improving soil fertility.

2.1.3 Crop descriptions: maize, chickpea, and mungbean

<u>Maize</u>

Maize (*Zea mays* L.) is the most important grain crop in South Africa, and it is grown in a range of diverse environmental conditions throughout the nation (Tandzi *et al*., 2020). Maize (*Zea mays* L) is a member of the grass family and one of the main cereals which constitute staple food to continents such as Africa (FAO, 2012). The crop is cultivable in frost-free climates ranging from temperate to tropic where mean daily temperatures between 19 °C and 32 ºC are required (DAFF, 2012). The best soil for maize has a good effective depth, strong internal drainage, an ideal moisture regime, enough and balanced plant nutrients, and chemical properties (DAFF, 2012). Morphologically, the plant has a fine, well-branched root system. The correct variety selection is critical to successful cultivation and the adaptability of varieties to different climates varies widely. Great commercial grain production is normally increased when irrigation is used (DAFF, 2012). The yields of maize plants in each agro-climatic region are impacted by various factors related to agronomic or cultural practices utilized (Tandzi and Mutengwa, 2020).

Chickpea

Chickpea (*Cicer arietinum* L.) is one of the leguminous crops that are not commonly grown in South Africa, but few parts of provinces such as Limpopo and Mpumalanga (Ogola *et al*., 2015). Chickpeas are often cultivated as a winter crop between late April and early May. The plant prefers fertile, sandy-loam soil with adequate internal drainage, and it is waterlogging intolerant. Chickpeas require a soil pH range from 6.0 to 7.0 and require soil with a high residual moisture content or storage capacity (DAFF, 2012). Temperatures between 5 and 15 °C are ideal for germination, whereas temperatures over 29 °C and frost might be detrimental during flowering and pod development (DAFF, 2012). Chickpea is drought resistant due to its deep taproot, which can draw moisture from deep layers of the soil profile, but its productivity is decreased by the recurring terminal droughts. Ogola *et al*. (2015), reported Chickpea to be a recently introduced legume crop in NE Southern Africa, lack of nodulation has been a recurring problem across regions with varying soil conditions. However, the productivity of chickpea can be improved by soil amendments such as biochar and biofertilizers (Ogola *et al*., 2021).

Mungbean

Mungbean (*Vigna radiata*) is an annual crop that is typically grown in rotation with cereals. Limpopo and Mpumalanga are the primary producing areas in South Africa, where it is mostly consumed (DAFF, 2012). Growth requires an optimal temperature between 27 °C and 30 °C and this means that the crop is usually grown during summer (DAFF, 2012). Mung beans thrive on fertile, sandy loam slightly acidic soils with adequate internal drainage and a pH between 6.3 and 7.2 (QDPIF, 2006). Mung beans are commonly cultivated under irrigation and are susceptible to waterlogging. Mungbean, like the other legumes (field bean and cowpea) produced as the main crop on the field, should be sown between late November and early December (DAFF, 2012).

2.1.4 The role of cereal-legume on improving soil fertility

Soil quality encompasses optimum soil organic matter, pH, macro-and micronutrients, physical properties (bulk density, aggregate stability, etc.), and biological properties (Ozturkmen *et al*., 2020). Legumes are known for their ability to restore soil fertility (Dhakal *et al*., 2016). The morphological deep rooting, lead shedding ability, nitrogen fixation, and mobilization of insoluble nutrients allow pulses to improve soil properties and check the declining productivity trends of continuous cereal monocropping (Layek *et al*., 2018). Legumes improve soil quality by enhancing carbon and nitrogen sequestration in typical intercropping settings (Cong *et al*., 2015; Duchene *et al*., 2017). The availability of nutrients for plants in the rhizosphere is also influenced by soil microbes (Mimmo *et al*., 2014). The supply of either biologically fixed N or roots excretion by associated legume crop in the intercropping can enhance soil fertility and reduces dependence on synthetic fertilizers (Cong *et al*., 2015). Well-nodulated legumes seldomly respond to N fertilizer additions, but soybean may occasionally respond to N fertilizer applications presumably due to N fixation decline in the nodules (Layek *et al*., 2018).

In resource-limited agricultural areas, intercropping contributes to sustainable agriculture through species complementarity by increasing productivity, nutrient availability (Li *et al*., 2014), effective weed management (Weerarathne *et al*., 2017), and insect control (Lopes *et al*., 2016). The results of maize-legume rotation effects showed that growing velvet bean in the same year as maize in rotation with maize boosted maize yield and improved some soil fertility indices more effectively than growing maize following maize in the same area (Uzoh *et al*., 2019). A recent study's findings suggest that intercropping barley-pea or triticale-vetch can support agricultural productivity, soil quality, and sustainability in semi-arid areas (Ozturkmen *et al*., 2020).

2.1.5 Intercropping on soil nutrient use efficiency (NUE) and replenishment

The production of maize and other staple crops is principally restricted by low fertility across South African soils (Fischer *et al*., 2015). Since small-holder maize producers are restrained by the expensive nitrogen fertilizers, this results in poor nutrient management and soil fertility deterioration under monocropping (Chen *et al*., 2017). However, intercropping systems of cereal-legume are the cheapest source of nitrogen and a technique to improve poor nutrient soils (Fischer *et al*., 2015). Compared to sole crops, cereal-legume intercropping systems minimize the quantity of nutrients taken from the soil (Jensen *et al*., 2020). Deep-rooted legumes, such as pigeon pea, also take up nutrients from subsoil and minimize competition for nutrient uptake with cereals, allowing cereals in the upper layers to absorb more nutrients (Aslam *et al*., 2018).

One of the most significant elements of cereal-legume intercropping is nutrient use efficiency. Crop selection has been shown to play a role in boosting NUE in cereal-legume intercropping systems (Rodriguez *et al*., 2020). Healthy forage crop development enhances phosphorus and potassium absorption by roots and maximizes nutrient availability in soils (Ozturkmen *et al*., 2020). Woliy *et al*. (2019) postulated that the proportions of nitrogen fixed by various legumes range from 5 to 300 kgN/ha/year, with an average of around 100 kgN/ha/year. On the other hand, Masvaya *et al*. (2017), reported 40, 30, and 30 kgN/ha quantities of N: P: K respectively generated in maize-cowpea intercropping.

2.1.6 Effects of cereal-legume intercropping on soil physical, chemical, and biological properties

System productivity enhancement has been reported with cereal-legume intercropping by improving the physical, chemical, and biological properties of the soil environment (Layek *et al*., 2018). Due to interspecific variations and interactions in the rhizosphere, intercropping systems have a considerable positive impact on the physicochemical and biochemical aspects of soil and the microbial population (Dai *et al*., 2019). The exploitation of biological nitrogen fixation by leguminous crops is a need at some point in time to reduce the dependency on synthetic fertilizers for yield improvements (Rosenblueth *et al*., 2018). Soil organic matter (SOM) improves soil physicochemical and biological properties which in turn decrease soil deterioration and increase water and nutrient accessibility (Dhakal *et al*., 2016). The ability of legumes to fix atmospheric N in soil reduces the depletion of limited soil nutrients and thereby improving soil fertility (Meena *et al*., 2015). Ozturkmen *et al*. (2020), stated that soil organic matter (SOM) can be enriched by intercropping cereals and leguminous forage crops.

Soil organic matter promotes soil fertility by enhancing soil physical and chemical characteristics (Ozturkmen *et al*., 2020). Manasa *et al*. (2018), reported that land where intercropping with legumes is practiced can sequester carbon (C), store N, and enrich biodiversity. Dai *et al*. (2019), studied the benefits of maize-peanut intercropping on iron (Fe) nutrition and stated that peanut-maize intercropping system can be used as a case approach to better understand the molecular mechanisms through which intercropping promotes non-graminaceous Fe nutrition.

Soil physical properties

Cereal-legume intercropping is a common practice among smallholder farmers due to the strong ability of legumes to adapt to soil disintegration and health deterioration (Vanlauwe *et al*., 2019). Intercropping of diversified crops protects the soil surface from being directly hit by precipitation drops due to greater canopy cover that acts as a seal for surface pores, thus reducing runoff volume and increasing water infiltration (Nyawade *et al*., 2019). Grain legumes are true component crops for soil physicochemical and biological properties (Layek *et al*., 2018). Soil aggregates are balanced by soil organic matter (SOM) which is enhanced by legumes, consequently making soil easily cultivable by increasing water holding capacity, aeration, buffering limits (Yadev *et al*., 2017). Penetrative resistance is strongly connected to soil pore size distribution, and a compacted layer has few big holes, less pore volume, and consequently leads to a higher density (Liu *et al*., 2019). As opposed to pure barley cultivation, the barley-cereal blend resulted in a substantial increase in porosity and aggregate stability, which presumably enhanced the available soil water (Ozturkmen *et al*., 2020). Liu *et al*. (2019), discovered a positive link between aggregate stability, organic matter, and soil clay content.

Aggregate stability and biomass yield had a strong positive connection, whereas penetration resistance and biomass yield had a significant negative relationship in triticale-pea intercropping (Ozturkmen *et al*., 2020). Liu *et al*. (2019), reported that cowpea reduced soil breakdown from raindrops when used as the best cover crop in maize-cowpea intercropping than a maize-bean intercropping framework. Yadev *et al*. (2017), reported that SOM forms better soil aggregation by physically and chemically chelating soil, stabilizing and resisting soil from disintegration. Furthermore, SOM impacts soil aggregation and lessens bulk density through legume residues with narrow C:N ratios that are quickly decomposed to improve SOM. Salahin *et al*. (2017), found that mung bean stover incorporation in rice-wheat-mung bean intercropping sequence resulted in lower soil bulk density and hydraulic conductivity. Similarly, mixed crop stands (barley+pea) had a favourable effect on soil porosity and other soil physical characteristics (Ozturkmen *et al*., 2020). In contrast to the strong positive connection found between aggregate stability and biomass production, a significant negative link was discovered between penetration resistance and biomass yield (Salahin *et al*., 2017).

<u>Soil chemical properties</u>

Expanded nutrient uptake from soil can happen over time and space in intercropping systems (Layek *et al*., 2018). The expansion of root mass can benefit spatial nutrient uptake while temporal nutrient uptake happens when there is no nutrient demand synchronization by component crops (Aslam *et al*., 2018). The disintegration of soil organic matter (SOM) releases important nutrients made available for plant absorption (Yadev *et al*., 2017). Legume crops have a robust ability to make nutrients accessible to cereals by modifying soil pH in the rhizosphere (Dhakal *et al*., 2016). Legumes acquire most of their N requirement from atmospheric diatomic N than soil and the net effect lowers the soil pH (Duchene *et al*., 2017). Legumes supply N to the intercrop through nitrogen sparing path since some portion of N requirements is fulfilled by N-fixation, subsequently conserving some of inorganic N to the intercrop cereal (Duchene *et al*., 2017).

According to Jani *et al*. (2015), chickpea mostly reduces the soil pH compared to pea, pigeon pea, and other legumes. Bakari *et al*. (2020), found maize-cowpea intercropping more suited under N-deficient soils compared to maize sole cropping due to improvement of N, K, and P availability. Similarly, Uzoh *et al*. (2019), observed significant boosts of cation exchange capacity (CEC), total soil N, exchangeable potassium (K), and magnesium (Mg) in each of the years under cereal-legume rotations. Dai *et al*. (2019), reported that rhizosphere interactions can improve Fe bioavailability by phytosiderophores. Furthermore, Crop Fe nutrition may also be aided by enriched microbes (Dai *et al*., 2019).

The increased biomass output aboveground is reflected belowground (Layek *et al*., 2018; Cong *et al*., 2014), and a recent research has shown that intercropping enhances soil organic carbon (C) stocks (Cong *et al*., 2014), but the rise in C stocks after 7 years of maize/faba-bean intercropping (4%) was less than the projected increases in annual root litter intake in intercrops versus monocrops (23 %) (Cong *et al*., 2014). Soil organic matter is composed of a variety of plant and animal remains that are at various stages of decomposition and have varying levels of resistance to further breakdown (Cong *et al*., 2014). Yadev *et al*. (2017), attributed the higher SOM breakdown rate to increased soil C inputs caused by enhanced biomass output in species-diverse plots. Increased litter input rejuvenates SOM stock by increasing the fraction of relatively young, labile C in total soil C, lowering overall SOM resistance and speeding SOM decomposition (Yadev *et al*., 2017). When compared to monoculture corn, intercropping systems enhanced soil nitrogen availability but had no effect on total nitrogen or organic carbon content (Dhakal *et al*., 2016). Maize intercropped with P. maxima enhanced soil microbial biomass nitrogen and microbial nitrogen quotient, as well as microbial biomass carbon in the surface soil layer, as compared to corn intercropped with *U. humidicola* (Dhakal *et al*., 2016).

Soil biological properties

Legumes are known to improve the soil environment for the growth and development of soil microorganisms, also releasing unused nitrate to the soil through symbiotic nitrogen fixation (Meena *et al*., 2015). The active portion of the soil known as soil microbial biomass incorporates viable microorganisms (Ozturkmen *et al*., 2020) which interacts with legumes to improve soil N through N fixation from the atmosphere by the method of biological nitrogen fixation (Beukes *et al*., 2013). The biological efficiency of intercropping is generally reported higher compared to sole cropping and it explores greater soil mass than the latter (Savci, 2012). Furthermore, intercropping boosts agroecosystem biodiversity (Layek *et al*., 2014), through the provision of suitable habitat by component crop for soil macro and micro-animals which may otherwise be not present under sole cropping situation (Kumar *et al*., 2016). Legumes are known to improve the soil by providing N within the soil through N fixation from the atmosphere by the method of biological nitrogen fixation (BNF) particularly when N fertilizer is confined.

Microorganisms in the soil break down organic materials and convert nutrients into plant-available forms (Ozturkmen *et al*., 2020). Masvaya *et al*., (2017), observed around 41 kg N ha^{-1} added to the soil by cowpea through BNF in a maize-cowpea intercropping framework, while Huang *et al.* (2014), recorded a sorghum yield of 20% higher in soils with available N within the sorghum-soybean intercropping framework. Sorghum depended mostly on added fertilizer and available N in soil, while soybean depended on BNF. Ozturkmen *et al*. (2020), reported that organic compounds released to the soil as exudates serve as substrates to soil microorganisms for population build-up. He *et al*. (2013), reported that the presence of legumes in an intercropping boosts the activity and reactions of enzymes such as urease, phosphatase, protease, dehydrogenase, and β-glucosidase. Enzymatic activities and reactions within the soil are generally the products of intracellular or free mixes from the soil microbial populace (He *et al*., 2013).

Odhiambo *et al*. (2015), demonstrated a significantly greater potential mineralizable nitrogen (PMN) during short rainy season compared to long rainy season and fallow period in maize-faba bean intercropping. However, it was further demonstrated that mineralization negatively impacted annual soil organic matter (SOM) renewal as indicated by low total carbon (C) and nitrogen (N) in the soil (Odhiambo *et al*., 2015). Measurements of compounds such as PMN, carbon dioxide (CO_2), and Nitrous oxide (N_2O) that are biogenically produced by soil microbes serves a great interest for indication of belowground C and N retention (Simunji *et al*., 2019). Hence, soil labile N estimates coupled with fluxes of greenhouse gas (GHG) are indices of soil nutrient status and response to soil disturbance to indicate the health and resilience of agroecosystems (Odhiambo *et al*., 2015).

2.1.7 The influence of intercropping on roots health

The rooting patterns of cereal and legumes differ significantly, their intercropping not only increases water uptake and transpiration but also reduces loss of water through evaporation or percolation (Nyawade *et al*., 2019). The diverse rooting and growth patterns, nutrients requirements, and crop span tend to impart them to a certain extent of ability to allow them to grow under stressful conditions (Layek *et al*., 2014). Unlike intercropping, all roots rival each other under sole cropping due to their comparative architecture and surface profundity (Nyawade *et al*., 2019). The rhizosphere microbiome can be shaped by root exudates involving primary metabolites (sugars, amino acids, and organic acids) and subsequently, the related microbes can have an impact on plant health and growth (Huang *et al*., 2014). Correspondingly, rhizobia act as plant growth-promoting rhizobacteria (PGPR) which help plants to assimilate a higher sum of essential macro and micronutrients from a bigger volume of soil (Gao *et al*., 2014). A new study suggests that root behavior may play an important role in soil-borne disease control by being a key site for detecting signals from surrounding plants in the soil (Backer *et al*., 2018). The disease severity was also affected by the planting distance between soybean and maize plants, as seen by the lowest disease incidence and index happening when soybean was cultivated close to maize (Gao *et al*., 2014).

2.1.8 Effects of cereal-legume on crop growth and yield

The aim of legume-based intercropping is to make optimum use of available resources that could not be utilized by a single crop, improving land equivalent ratio (LER) and thereby producing higher yields (Kumar et *al*., 2016). The availability and supply of adequate N aid speedy development and growth of roots and shoot dry weight, encouraging a strong positive correlation with crop productivity (Dhakal *et al*., 2015). Intercropping may assist in making legume cultivation alluring by promoting stability in productivity and profitability (Manasa *et al*., 2018). Layek *et al*. (2014), reported that small-statured legumes such as soybean and groundnut in the intercropping system are likely vulnerable to a shortage of solar radiation, competition of nutrients, and moisture, unlike cereals. Hence, the possible growth of intercropped soybean or groundnut may be hampered leading to reduced productivity and impaired quality. The system of cereal-legume intercropping possesses a huge potential to improve land equivalent ratio (LER) and food production in developing countries from marginal and degraded land in light of changing climate (Kumar *et al*., 2016).

Plant development and crop yields are inevitably aided significantly by proper coordination of the two intercrops (Yang *et al*., 2018). Several researchers such as Matusso *et al*. (2014), Meena *et al*. (2017), and Salama and Abdel-Moneim (2021), reported that compared to pure stands, intercropping increased soybean plant height, but reduced production of vegetative biomass and pods. However, nitrogen application in the cereal-soybean intercropping had a very limited impact on the dry matter production of intercrops. The dry matter yield of intercropped soybean was 89% of the pure stand, while intercropped maize had 104% of its pure stand and LER was improved (Kim *et al*., 2018). In a similar experiment, Astiko *et al*. (2021), reported that massive growth of cereals by inorganic fertilizer (N) in an intercropping system significantly reduced the growth and yield of soybean.

In an intercropping system, competition to soybean by associated cereal (pearl millet and sorghum) was reported to reduce the growth and yield parameters of soybean compared to its sole crop (Layek *et al*., 2012). However, Salama and Abdel-Moneim (2021), documented a higher number of full pods per plant in soybeans under intercropping with sesame compared to its monoculture. Liu *et al*. (2018), reported that soybean plants intercropped in a 4:2 ratio with maize received more radiation than plants in a 2:2 ratio. Compared to soybean sole crops, the chlorophyll content of Soy leaves was significantly reduced in a ratio of 2:2, and the decrease was less in a ratio of 4:2. Liu *et al*. (2017), conducted a maize-soybean intercropping experiment and reported that the light interception by soybean was affected by maize, not *vice versa*.

2.2 Work not yet done on the research problem

Soil researches of the last centuries were mostly focused on intercropping for yield maximization, with relative neglect of soil quality (Zhou *et al*., 2018). Previous studies were focused more on the yield potentials in both irrigated and rainfed crop production systems (Nwite *et al*., 2017; He *et al*., 2013; and Lüneberg *et al*., 2018). Little attention has been paid to intercropping systems with newly introduced legumes in South Africa (chickpea and mungbean) on soil physicochemical properties and subsequent crop yields. Less work in South Africa has been done on the post effects of intercropping with chickpea and mungbean on soil physicochemical properties in different soils and climates. Furthermore, there is limited information on how and to which extent cereal to legume intercropping systems can be used to enhance and sustain soil fertility and health by understanding interactions of underground micro-biomes. Hence, it is important to investigate responses of soil physiochemical properties to maize-legume in rainfed and irrigated intercropping systems relative to crop yields at different ecological regions. This study attempts to meet these knowledge gaps and will be helpful by contributing to the literature on soil properties response to underlying belowground interactions of the maize-legume intercropping system.

CHAPTER 3

THE RESPONSE OF SELECTED SOIL HEALTH VARIABLES TO RAINFED AND IRRIGATED MAIZE-LEGUME INTERCROPPING SYSTEMS

3.1 Introduction

Soil health has existed as an integrative feature that displays the ability of soil to react to agricultural interference, such that it constantly supports both agricultural production and the provision of other ecosystem services (Subhadip *et al*., 2019). Soil health can be improved by organic carbon which also helps to mitigate climate change (Chan, 2008). Intercropping is a potential approach for improving soil health and ensuring sustainable crop production (Muhammad *et al*., 2019). Intercropping can promote crop growth and productivity by making better use of both above and below ground resources (Muhammad *et al*., 2019).

Thus, to maintain soil fertility and intensive cropping, soil should be cultivated with a variety of crops that both improve soil and sustain optimum production (Acosta-Martínez and Cotton, 2017). Soil health functions comprise of biological processes provided by soil organisms which dictates soil health assessment and management (Acosta-Martínez and Cotton, 2017). However, different cropping systems are used in different agro-climatic areas depending on resource availability (Muhammad *et al*., 2019). Cropping system diversification is necessary to increase yield and return while conserving soil health. Hence, not only is the number of crops essential, but so is the type of crops included in the cropping sequence (Li *et al*., 2013). The increase in aboveground biomass following intercropping has been shown to have a substantial positive relationship with belowground soil health indices (He *et al*., 2013). However, studies on effect of maize-legume intercropping systems under different watering regimes are not well researched and elucidated. Therefore, this chapter investigates the responses of soil health variables to rainfed and irrigated maize-legume intercropping systems at two sites with contrasting soil types and climatic regions.

3.2 Materials and methods

3.1.1 Description of the study sites

The study was conducted at the University of Limpopo's Syferkuil (23°50'42.86" S; 29°42'44.3" E) Farm and the University of Venda's Experimental Farm, Thohoyandou (22°58'.08" S and 30°26'.4" E). Syferkuil is in Polokwane municipality in the Capricorn district, South Africa. The climate of the area was classified as semi-arid with mean annual precipitations of about 405 to 500 mm occurring mostly in the summer months of October to March (Weather SA, 2019). The mean annual temperatures estimated were about 25°C (max) and 10°C (min) for winter and summer respectively. The farm is dominated by Hutton and Glenrosa soil forms and soils are moderately shallow to deep sandy loam with a pH ranging from 5-6 (Soil Classification Working Group, 1991).

Thohoyandou is located in Thulamela municipality of Vhembe district, Limpopo Province, South Africa. The climate of the area is semi-arid (mean annual aridity = 0.52) receiving annual precipitations of about 781 mm (Weather SA, 2019). The mean annual temperatures range about 30ºC (max) to about 20 ºC (min) (Weather SA, 2019). The soil form dominating the farm is Hutton and at the site, soil is characterized by well drained clay soil with slightly acidic average pH of around 5.17 (Soil Classification Working Group, 1991). Hence, UNIVEN and Syferkuil regions are chosen for the study because of their contrasting climates and soils.

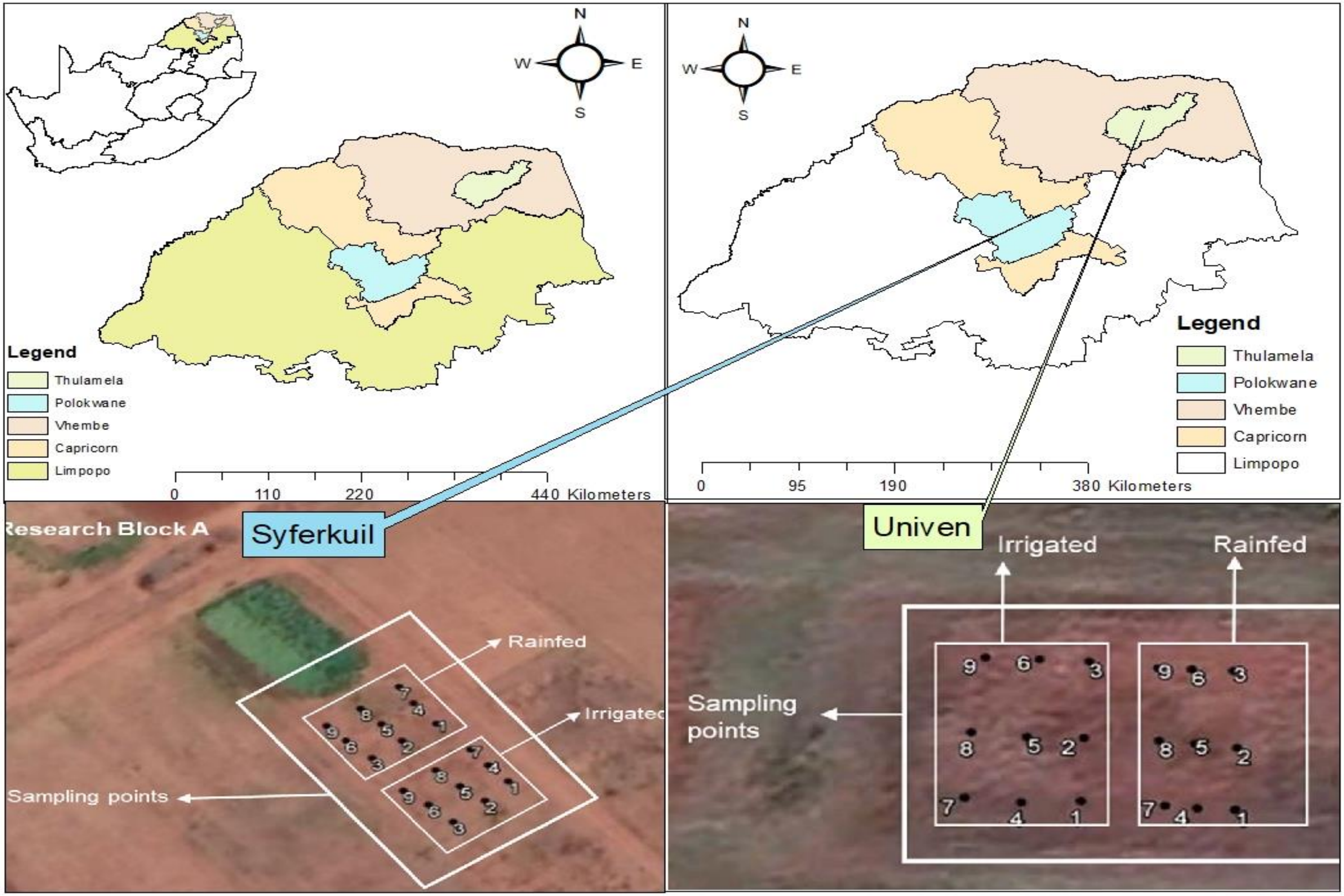

Figure 3.1 Map of the study sites showing Syferkuil and UNIVEN experimental fields

3.2.2 Treatments and research design

Maize-legume field experiment layout

The maize-legume field trial study was laid out in a split plot design comprised of two watering regimes treated as two separate experiments, one under irrigation and other under rainfed. Five (5) treatments which were replicated three (3) times included cropping systems: sole maize (SM), sole chickpea (SC), sole mungbean (SMB), maize/chickpea row intercropping (MC), and maize/mungbean intercropping. Site sampling points coordinates before planting were collected with GPS and mapped using ArcMap 10.6 software (Figure 3.1).

Soil sampling for physicochemical properties and cations

Soil samples were randomly collected at each field before planting and randomly collected in plastic bags from irrigated and rainfed subplots after harvesting using auger at a depth of 0–20 cm.

Soil sampling for biological activities

Soil samples for biological properties before and after planting were collected in small zip-bags at 0 – 20 cm depth. Samples were transported in a cooler box with ice at a temperature of about -4 °C and were stored in a fridge then taken to the laboratory for analysis.

3.2.4 Data collection

Physical properties

Preceding pre-and post-soil analyses, particle size distribution from soil samples was determined using hydrometer method (Bouyoncos, 1962). Bulk density was determined using the cylindrical core method (Campbell and Henshall, 1991). Soil aggregate stability was determined by separating air-dried soil aggregates through wet sieving of three sieve sizes using a method by Elliot (1986).

Chemical properties

Soil pH was determined in a 1:2.5 solution ratio in both deionized water and 1M KCl suspension using a glass electrode (Reeuwijk, 2002). Electrical conductivity (EC) was determined using the electrode method where glass EC meter was suspended in glass beakers (Rhoades, 1982). Soil organic matter (SOM) and soil organic carbon (SOC) was determined using Ignition method through combustion of samples in the furnace (Davies, 1974). Phosphorus (P) was determined through bray 1 extraction method from liquid converted samples and absorbances read using T60 UV spectrophotometer at 882 nm (Bray and Kurtz, 1945). Ammonium (NH_4^+-N) and nitrate (NO_3^-) were determined using Colorimetric method through liquid converted samples and absorbances read using T60 UV spectrophotometer at 655 nm and 419 nm respectively (Bremmer and Mulvaney, 1982).

Biological activities

Soil active carbon (SAC) was determined using a method described by Weil *et al*. (2003) through oxidization of carbon in soil samples with permanganate. Potentially Mineralizable Nitrogen (PMN) was determined through a method proposed by Stanford and smith (1972) through incubation of samples for a period of 7 days.

Root health rating

For the root health assessment, soil samples from each field were put in 200 ml cone-tubes as treatments, with one garden bean seed seeded in each (Gugino *et al*., 2009). Treatments were organized in a randomized full block design with three replications, and the tubes were placed on the greenhouse bench. Plants were irrigated with 25 ml tapwater every other day. At four weeks after emergence, plants were removed from containers, with roots washed under running tapwater and then scored for root health rating on a 1 to 9 scale (Table 4.1).

Figure 3.2: Root health treatments as laid out in the greenhouse.

Table 3.1: Root health rating numbers and description (Gugino *et al*., 2009).

Rating number	Description
1	White and coarse textured hypocotyl and roots; healthy.
2	Light discoloration and lesions less than 10% of hypocotyl and root tissue.
3	Light discoloration and lesions covering up to a maximum of 10% of hypocotyl and root tissues
4	Approximately 10-20% of hypocotyl and root tissue have lesions, but the tissues remain firm.
5	Approximately 25% of hypocotyl and root tissue have lesions, but the tissues remain firm.
6	There is little decay or damage to the root system.
7-9	50 to ≥ 75% of hypocotyl and roots severely symptomatic and at advanced stages of decay.

3.2.5 Data analysis

Data were summarized using descriptive statistics and subjected to split-plot analysis of variance (ANOVA) through GenStat 20th Edition software. Mean separation for significant soil health variables was determined at probability level of 5% confidence interval using Waller Duncan's Multiple Range Test.

3.3 Results

3.3.1 Selected soil health variables prior trial establishment

Soil health variables quantified before planting are outlined in Table 3.2 for both study sites. UNIVEN had higher clay % (9.14) and lower bulk density (1.23) compared to Syferkuil. UNIVEN was slightly acidic (5.46) and had greater organic matter (5.63), phosphorus (5.72), and ammonium (1.12) than Syferkuil which was slightly alkaline (7.46).

Table 3.2: Selected soil health variables prior trial establishment

Soil physicochemical properties	Syferkuil	UNIVEN
%Clay	2.40	9.14
%Silt	20.49	3.60
%Sand	77.11	87.27
BD (g/cm^3)	1.70	1.23
Aggregate stability	0.11	0.13
pH (H_2O)	8.40	6.52
pH (KCl)	7.46	5.46
EC (µS/cm)	68.27	69.83
OM	3.87	5.63
OC (%)	0.86	0.58
P (mg/kg)	3.01	5.72
NH_4^+-N (mg/kg)	0.44	1.12
NO_3^- -N(mg/kg)	0.09	0.06
AC (mg POXC/kg)	635.74	347.32
PMN (µg N/g)	0.15	0.14

BD-bulk density, MWD-mean weight diameter (aggregate stability), pH- potential hydrogen, EC-electrical conductivity, OM-organic matter, OC-organic carbon, P-phosphorus, NH_4^+-N-ammonium nitrogen, NO_3^--N-nitrate nitrogen, AC-active carbon, PMN-potentially mineralizable nitrogen.

3.3.3 Interactive effects of water regimes and maize-legume intercropping systems on selected physical indicators of soil health.

Selected soil physical properties (Bulk density and Aggregate stability)

The interaction between water regimes and cropping systems had no significance difference ($p>0.05$) on studied soil physical properties; bulk density and aggregate stability at both locations, Syferkuil and UNIVEN. Water regimes also did not show significant effect on bulk density and aggregate stability at Syferkuil (Appendix 3.1 and 3.3) but showed significant effect on aggregate stability at UNIVEN (Appendix 3.2 and 3.4) while no significance was shown at Syferkuil. At both locations, cropping systems did not show any significant effect on soil bulk density and aggregate stability. Bulk density from irrigated treatments at Syferkuil ranged from a minimum of 7.22 to a maximum of 7.54; and 6.98 to 8.13 for rainfed plot. On the other hand, irrigated and rainfed plots ranged from 5.59 to 6.14 and 6.05 to 7.28 respectively at UNIVEN (Table 3.3). For aggregate stability at Syferkuil, irrigated plot ranged from 20 to 23 and that of rainfed ranged from 0.18 to 21. UNIVEN had a range of 0.15 to 0.21 for irrigated plot and 0.14 to 0.17 (Table 3.4).

Table 3.3: The effects of maize-legume and water regimes on Bulk density (BD)

Treatments	BD (g/cm^3)					
	Syferkuil			UNIVEN		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	7.51^a	8.12^a	7.81^A	6.06^b	7.28^a	6.69^A
SC	7.22^a	7.00^a	7.11^A	5.99^b	6.50^{ab}	6.24^A
SMB	7.54^a	6.98^a	7.26^A	6.57^{ab}	6.23^b	6.40^A
MC	7.52^a	7.18^a	7.35^A	6.14^b	6.05^b	6.10^A
MMB	7.43^a	8.13^a	7.78^A	5.59^b	6.43^{ab}	6.01^A
Means	7.44^A	7.48^A		6.07^B	6.50^A	
P (f-test)						
WR		0.83			0.02	
CS		0.31			0.38	
WR x CS		0.41			0.20	
CV (%)		9.20			9.57	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, MC-maize chickpea, and MMB-maize mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test. Response** (ns-not significant, ***-significant).

Table 3.4: The effects of maize-legume and water regimes on aggregate stability (AS)

Treatments	AS					
	Syferkuil			UNIVEN		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	0.20^{a}	0.19^{a}	0.19^{A}	0.21^{a}	0.15^{b}	0.18^{A}
SC	0.21^{b}	0.18^{a}	0.20^{A}	0.16^{b}	0.14^{b}	0.15^{A}
SMB	0.23^{a}	0.21^{a}	0.22^{A}	0.17^{b}	0.17^{b}	0.17^{A}
MC	0.20^{a}	0.20^{a}	0.21^{A}	0.15^{b}	0.15^{b}	0.15^{A}
MMB	0.20^{a}	0.20^{a}	0.21^{A}	0.17^{b}	0.14^{b}	0.16^{A}
Means	0.21^{A}	0.20^{A}		48.37^{A}	50.53^{A}	
P (f-test)						
WR		0.39			0.04	
CS		0.20			0.17	
WR x CS		0.48			0.16	
CV (%)		10.22			14.27	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, MC-maize chickpea, and MMB-maize mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test. Response** (ns-not significant, ***-significant).

3.3.4 Interactive effects of water regimes and maize-legume intercropping systems on selected chemical indicators of soil health

Soil pH (H_2O)

The interaction of water regimes and maize-legume intercropping systems had no significant effect (p>0.05) on soil pH (H_2O) at Syferkuil, but a highly significant effect (p>0.01) was observed at UNIVEN. Water regimes did not show any significant effect on soil pH at Syferkuil, but a highly significant effect was observed at UNIVEN. Like the interaction and Water regimes, cropping systems did not show significant effect on soil pH at Syferkuil while a highly significant effect was observed at UNIVEN (Appendix 3.7 and 3.8). The soil pH among the treatments at an irrigated plot from Syferkuil ranged from a minimum of 8.94 to 9.04 and 8.90 to 9.08 for rainfed. For treatments at UNIVEN, soil pH under irrigated plot ranged from 7.13 to 7.41 and 6.96 to 7.16 for rainfed plot (Table 3.5).

Soil pH (KCl)

There was a highly significant effect ($p<0.01$) observed on soil pH at Syferkuil under the interaction of irrigation and maize-legume intercropping systems on soil pH, while no significant effect was observed at UNIVEN ($p>0.05$). A highly significant effect was observed from water regimes at Syferkuil while at UNIVEN significant effect was also observed on soil pH. cropping systems showed a significant effect on soil pH at Syferkuil as there was no significant effect observed among the treatments at UNIVEN (Appendix 3.5 and 3.6). Soil pH under irrigated plot at Syferkuil ranged from a minimum of 7.64 to maximum of 7.88 while rainfed plot ranged from 7.22 to 7.83. At UNIVEN, soil pH minimum and maximum values were 5.50 and 5.83 respectively while the rainfed plot ranged from 5.35 to 5.61 (Table 3.5).

Table 3.5: The effects of maize-legume and water regimes on soil pH (KCl and H_2O) at Syferkuil and UNIVEN

Treatments	Syferkuil						UNIVEN					
	pH (KCl)			pH (H_2O)			pH (KCl)			pH (H_2O)		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	7.86^{a}	7.57^{cd}	7.72^{AB}	9.00^{a}	9.02^{a}	9.01^{A}	5.83^{a}	5.50^{bc}	5.66^{A}	7.41^{a}	7.13^{c}	7.27^{A}
SC	7.64^{bcd}	7.63^{bcd}	7.63^{AB}	8.96^{a}	9.08^{a}	9.02^{A}	5.62^{abc}	5.56^{abc}	5.59^{A}	7.21^{bc}	7.16^{bc}	7.19^{AB}
SMB	7.84^{ab}	7.56^{d}	7.70^{AB}	8.94^{a}	8.95^{a}	8.94^{A}	5.67^{ab}	5.35^{c}	5.51^{A}	7.25^{b}	6.96^{d}	7.10^{B}
MC	7.88^{a}	7.22^{e}	7.55^{B}	9.04^{a}	8.90^{a}	8.97^{A}	5.50^{bc}	5.61^{abc}	5.55^{A}	7.13^{c}	7.14^{bc}	7.14^{B}
MMB	7.78^{abc}	7.83^{ab}	7.81^{A}	9.04^{a}	8.94^{a}	8.99^{A}	5.56^{abc}	5.43^{bc}	5.50^{A}	7.15^{bc}	7.14^{bc}	7.15^{B}
Means	7.80^{A}	7.56^{B}		8.99^{A}	8.97^{A}		5.64^{A}	5.49^{A}		7.23^{A}	7.11^{B}	
P (f-test)												
WR	0.02			0.75			0.10			0.02		
CS	0.04			0.84			0.42			0.01		
WR x CS	0			0.50			0.14			0.00		
CV (%)	1.71			1.49			2.87			0.93		

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, MC-maize chickpea, and MMB-maize mungbean. Column means followed by the same letter were not different ($p<0.05$)) according to Duncan Multiple Range Test. Response** (ns-not significant, ***-significant).

Electrical conductivity (EC)

There was no significant effect observed (p>0.05) under the interaction of water regimes and cropping systems on soil electrical conductivity at both Syferkuil and UNIVEN regions. Water regimes showed significance among the treatments at Syferkuil whereas no significance was observed at UNIVEN on electrical conductivity. Like the interaction, cropping systems at both Syferkuil and UNIVEN did not show significant effect on soil electrical conductivity among the treatments (Appendix 3.9 and 3.10). However, electrical conductivity under irrigated plot ranged from 70.40 to 104.57 and 69.12 to 75.91 for rainfed at Syferkuil. Range of irrigated plot had a minimum of 46.25 and maximum of 50.18 while minimum was 44.86 and maximum was 61.43 under rainfed plot at UNIVEN (Table 3.6).

Table 3.6: The effects of maize-legume and water regimes on electrical conductivity

Treatments	EC (µS/cm)					
	Syferkuil			UNIVEN		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	87.92^{ab}	75.91^{b}	81.92^{A}	50.18^{a}	47.93^{a}	49.06^{A}
SC	77.13^{b}	70.99^{b}	74.06^{A}	47.34^{a}	52.20^{a}	49.77^{A}
SMB	104.57^{a}	70.70^{b}	87.63^{A}	46.25^{a}	44.86^{a}	45.56^{A}
MC	70.40^{b}	69.12^{b}	69.76^{A}	49.90^{a}	46.22^{a}	48.06^{A}
MMB	85.11^{ab}	74.05^{b}	79.58^{A}	48.19^{a}	61.43^{a}	54.81^{A}
Means	85.03^{A}	72.16^{A}		48.37^{A}	50.53^{A}	
P (f-test)						
WR		0.07			0.59	
CS		0.21			0.64	
WR x CS		0.30			0.61	
CV (%)		16.90			20.94	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, MC-maize chickpea, and MMB-maize mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test. Response** (ns-not significant, ***-significant).

Soil organic carbon (OC)

There was no significant effect (p>0.05) observed under the interaction of water regimes and cropping systems on soil organic carbon at both Syferkuil and UNIVEN regions. A significant effect (p<0.05) observed on organic carbon was exerted by Water regimes at Syferkuil and no significant effect was observed at UNIVEN by Water regimes. Higher significant effect (p<0.01) was observed from Cropping systems at Syferkuil which also showed significant effect at UNIVEN (Appendix 3.11 and 3.12). The range of soil organic carbon under irrigated plot at Syferkuil had a minimum of 0.75 and maximum of 1.58 while rainfed plot had a minimum of 0.95 and maximum of 2.34. UNIVEN irrigated plot ranged from 1.78 to 6.49 and rainfed plot from 1.56 to 6.65 in terms of organic carbon (Table 3.7).

Table 3.7: The effects of maize-legume and water regimes on organic carbon (OC)

Treatments	OC (%)					
	Syferkuil			UNIVEN		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	0.75^{d}	0.95^{cd}	0.85^{C}	1.78^{d}	1.56^{d}	1.67^{C}
SC	1.44^{bcd}	2.34^{a}	1.88^{A}	6.49^{a}	6.65^{a}	6.57^{A}
SMB	1.58^{bc}	1.46^{bc}	1.52^{A}	5.99^{ab}	6.36^{a}	6.17^{A}
MC	1.06^{bcd}	1.71^{ab}	1.38^{B}	4.76^{c}	5.16^{bc}	4.96^{B}
MMB	1.20^{bcd}	1.66^{ab}	1.43^{AB}	4.42^{c}	5.31^{bc}	4.87^{B}
Means	1.21^{A}	1.62^{A}		4.69^{A}	5.01^{A}	
P (f-test)						
WR		0.30			0.51	
CS		0			0	
WR x CS		0.09			0.38	
CV (%)		22.36			9.70	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, MC-maize chickpea, and MMB-maize mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test. Response** (ns-not significant, ***-significant).

Soil phosphorus (P)

There was no significance difference ($p>0.05$) observed under the interaction of water regimes and cropping systems on soil phosphorus at Syferkuil while a highly significant effect ($p<0.01$) was observed at UNIVEN. Water regimes did not show any significant effect on phosphorus at Syferkuil and UNIVEN. Like Water regimes, cropping systems did not show significant effect on phosphorus at Syferkuil while a highly significant effect was observed at UNIVEN (Appendix 3.15 and 3.16). Irrigated and rainfed plots ranged from 2.18 to 2.64 and 2.10 to 2.89 respectively at Syferkuil. The range at UNIVEN had a minimum value of 2.24 and maximum of 7.52 for irrigated plot whereas rainfed plot had a range of 2.76 minimum to 8.40 maximum (Table 3.8).

Table 3.8: The effects of maize-legume and water regimes on phosphorus

Treatments	P (mg/kg)					
	Syferkuil			UNIVEN		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	2.18^{a}	2.61^{a}	2.40^{AB}	2.24^{g}	2.76^{f}	2.50^{E}
SC	2.28^{a}	2.26^{a}	2.27^{AB}	6.44^{c}	6.43^{a}	6.44^{B}
SMB	2.64^{a}	2.89^{a}	2.77^{A}	7.52^{b}	8.40^{a}	7.96^{A}
MC	2.19^{a}	2.10^{a}	2.14^{B}	5.65^{d}	5.15^{e}	5.40^{D}
MMB	2.33^{a}	2.31^{a}	2.32^{AB}	6.03^{cd}	5.94^{d}	5.94^{C}
Means	2.32^{A}	2.43^{A}		5.58^{A}	5.72^{A}	
P (f-test)						
WR		0.62			0.15	
CS		0.32			0	
WR x CS		0.88			0	
CV (%)		21.43			4.59	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, MC-maize chickpea, and MMB-maize mungbean. Column means followed by the same letter were not different ($p<0.05$)) according to Duncan Multiple Range Test. Response** (ns-not significant, ***-significant).

Ammonium nitrogen (NH_4^+ - N)

There was significant effect ($p<0.05$) observed under the interaction of water regimes and cropping systems on soil ammonium at Syferkuil while interaction at UNIVEN did not show a significant effect ($p>0.05$). Water regimes at Syferkuil did not show significant effect on soil ammonium but significance was observed at UNIVEN. A highly significant effect ($p<0.01$) was observed on soil ammonium from Cropping systems at both Syferkuil and UNIVEN regions (Appendix 3.17 and 3.18). The range of ammonium among the irrigated treatments at Syferkuil had a minimum value of 4.13 and 12.19 while rainfed treatments had a minimum of 2.52 and maximum of 9.05. UNIVEN treatments had a range of 3.50 to 13.09 for irrigated plot and 2.53 to 13.68 for rainfed plot (Table 3.9).

Table 3.9: The effects of maize-legume and water regimes on ammonium (NH_4^+ - N)

Treatments	NH_4^+ - N (mg/kg)					
	Syferkuil			UNIVEN		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	12.19^{a}	5.96^{bcde}	9.08^{A}	3.50^{f}	2.53^{f}	3.02^{D}
SC	6.78^{bcd}	9.05^{ab}	7.91^{A}	6.87^{e}	8.21^{cde}	7.54^{C}
SMB	4.13^{de}	2.52^{e}	3.33^{B}	13.09^{a}	13.68^{a}	13.39^{A}
MC	4.26^{cde}	8.32^{abc}	6.29^{AB}	7.19^{de}	8.78^{cd}	7.99^{C}
MMB	6.46^{bcde}	5.51^{bcde}	5.98^{AB}	9.54^{bc}	11.19^{b}	10.36^{B}
Means	6.76^{A}	6.27^{A}		5.58^{A}	5.72^{A}	
P (f-test)						
WR		0.62			0.07	
CS		0.01			0	
WR x CS		0.02			0.27	
CV (%)		37.28			13.30	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, MC-maize chickpea, and MMB-maize mungbean. Column means followed by the same letter were not different ($p<0.05$)) according to Duncan Multiple Range Test. Response** (ns-not significant, ***-significant).

Nitrate nitrogen (NO_3^- -N)

There was no significant effect ($p>0.05$) observed on soil nitrate under the interaction of water regimes and cropping systems at both Syferkuil and UNIVEN regions. Water regimes at Syferkuil and UNIVEN also did not show significant effect in soil nitrate. Unlike interaction and Water regimes, cropping systems at UNIVEN showed a highly significant effect ($p<0.01$) in nitrate whereas it showed no significance in Syferkuil (Appendix 3.19 and 3.20). The range of nitrate observed in Syferkuil under irrigated plot was 0.01 to 0.60 and 0.10 to 50 under rainfed plots. The minimum and maximum values for nitrate under irrigated plot at UNIVEN were 0.34 and 1.37 respectively, and 0.33 and 1.42 respectively (Table 3.10).

Table 3.10: The effects of maize-legume and water regimes on nitrate (NO_3^- -N)

Treatments	NO_3^- -N (mg/kg)					
	Syferkuil			UNIVEN		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	0.60^{a}	0.12^{a}	0.36^{A}	0.34^{e}	0.33^{e}	0.34^{D}
SC	0.01^{b}	0.50^{ab}	0.26^{A}	0.93^{bc}	0.80^{cd}	0.87^{B}
SMB	0.02^{ab}	0.36^{ab}	0.19^{A}	1.37^{a}	1.42^{a}	1.40^{A}
MC	0.01^{b}	0.10^{ab}	0.05^{A}	0.75^{cd}	0.68^{d}	0.71^{C}
MMB	0.01^{b}	0.38^{ab}	0.19^{A}	1.08^{a}	0.91^{bc}	0.99^{B}
Means	0.13^{A}	0.29^{A}		0.89^{A}	0.83^{A}	
P (f-test)						
WR		0.38			0.32	
CS		0.62			0	
WR x CS		0.14			0.40	
CV (%)		158.56			12.50	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, MC-maize chickpea, and MMB-maize mungbean. Column means followed by the same letter were not different ($p<0.05$)) according to Duncan Multiple Range Test. Response** (ns-not significant, ***-significant).

3.3.5 Interactive effects of water regimes and maize-legume intercropping systems on selected biological activities indicators of soil health

Soil organic matter (SOM)

There was no significant effect (p>0.05) observed under the interaction of water regimes and cropping systems on soil organic matter at both Syferkuil and UNIVEN regions. A highly significant effect (p<0.01) was observed from Water regimes on soil organic matter at Syferkuil while no significance was observed among the treatments at UNIVEN. At both locations, cropping systems showed a highly significant effect on soil organic matter (Appendix 3.13 and 3.14). The soil organic matter range had a minimum value of 1.60 and maximum of 4.37 under irrigated plot at Syferkuil whereas rainfed plot had 2.56 for minimum and 5.98 for maximum. Organic matter at UNIVEN ranged from 3.89 to 9.43 under irrigated plot and 3.25 to 9.71 under rainfed plot (Table 3.11).

Table 3.11: The effects of maize-legume and water regimes on organic matter (OM)

Treatments	OM (mg/kg)					
	Syferkuil			UNIVEN		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	1.60^{h}	2.56^{g}	2.08^{C}	3.89^{d}	3.25^{d}	3.57^{C}
SC	3.88^{ef}	5.67^{ab}	4.77^{A}	7.53^{abc}	8.83^{ab}	8.18^{AB}
SMB	4.37^{de}	5.98^{a}	5.18^{A}	9.43^{a}	9.71^{a}	9.57^{A}
MC	3.36^{f}	5.03^{bc}	4.20^{B}	8.63^{abc}	7.14^{bc}	7.88^{B}
MMB	3.34^{f}	4.81^{cd}	4.07^{B}	6.59^{c}	7.93^{abc}	7.26^{B}
Means	3.31^{B}	4.81^{A}		7.22^{A}	7.37^{A}	
P (f-test)						
WR		0.02			0.02	
CS		0			0	
WR x CS		0.30			0.29	
CV (%)		8.50			8.50	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, MC-maize chickpea, and MMB-maize mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test. Response** (ns-not significant, ***-significant).

Soil Active Carbon (SAC)

There was no significant effect (p>0.05) observed under the interaction of water regimes and cropping systems on soil active carbon at both Syferkuil and UNIVEN regions. Water regimes as well did not show significance on active carbon at both locations. Like interaction and Water regimes, no significant effect was observed under Cropping systems at both locations (Appendix 3.21 and 3.22). Despite no significance among the treatments, soil active carbon ranged from 667.30 to 1695 under irrigated plot and from 930.70 to 1926.50 under rainfed plot at Syferkuil. The range for irrigated plot at UNIVEN had a minimum and maximum values of 476.50 and 1896.80 while rainfed plot had a minimum of 169.70 and maximum of 1362.20 (Table 3.12).

Table 3.12: The effects of maize-legume and water regimes on active carbon (AC)

Treatments	AC (mg POXC/kg)					
	Syferkuil			UNIVEN		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	667.30^{a}	1926.50^{a}	1516.80^{A}	1359.20^{ab}	282.70^{b}	821.00^{A}
SC	1298.90^{a}	1680.90^{a}	1489.90^{A}	476.50^{ab}	454.50^{b}	465.50^{A}
SMB	900.60^{a}	1115.50^{a}	1008.10^{A}	557.70^{ab}	169.70^{b}	363.70^{A}
MC	1070.90^{a}	930.70^{a}	1000.80^{A}	906.17^{a}	823.80^{ab}	865.00^{A}
MMB	1695.00^{a}	1338.60^{a}	1516.80^{A}	1896.80^{a}	1362.20^{ab}	1629.50^{A}
Means	1126.60^{A}	1398.40^{A}		1039.30^{A}	618.60^{A}	
P (f-test)						
WR		0.38			0.21	
CS		0.88			0.11	
WR x CS		0.77			0.80	
CV (%)		91.30			98.95	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, MC-maize chickpea, and MMB-maize mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test. Response** (ns-not significant, ***-significant).

Potentially Mineralizable Nitrogen (PMN)

There was no significant effect ($p>0.05$) observed on soil potentially mineralizable nitrogen under the interaction of water regimes and cropping systems at both Syferkuil and UNIVEN. There was a highly significant effect ($p<0.01$) observed from Water regimes on potentially mineralizable nitrogen at Syferkuil while significant effect ($p<0.05$) was also observed at UNIVEN. Cropping systems at both locations did not show significant effect on soil potentially mineralizable nitrogen (Appendix 3.23 and 3.24). The range of PMN at Syferkuil had a minimum and maximum values of 0.05 and 0.07 respectively under irrigated plot while rainfed had 0.34 and 0.38 respectively. At UNIVEN, PMN ranged from 0.10 to 0.21 under irrigated plot whereas PMN under rainfed ranged from 0.20 to 0.47 (Table 3.13).

Table 3.13: The effects of maize-legume and water regimes on potentially mineralizable nitrogen (PMN)

Treatments	PMN (µg N/g)					
	Syferkuil			UNIVEN		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	0.05^{b}	0.38^{a}	0.21^{A}	0.10^{b}	0.20^{b}	0.15^{A}
SC	0.07^{b}	0.35^{a}	0.21^{A}	0.15^{b}	0.47^{a}	0.31^{A}
SMB	0.06^{b}	0.34^{a}	0.20^{A}	0.21^{b}	0.22^{b}	0.22^{A}
MC	0.06^{b}	0.37^{a}	0.22^{A}	0.20^{b}	0.25^{b}	0.23^{A}
MMB	0.06^{b}	0.35^{a}	0.20^{A}	0.18^{b}	0.21^{b}	0.20^{A}
Means	0.06^{B}	0.36^{A}		0.17^{A}	0.27^{A}	
P (f-test)						
WR		0.02			0.11	
CS		0.99			0.23	
WR x CS		0.99			0.18	
CV (%)		60.25			52.36	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, MC-maize chickpea, and MMB-maize mungbean. Column means followed by the same letter were not different ($p<0.05$)) according to Duncan Multiple Range Test. Response** (ns-not significant, ***-significant).

Root health rating

Root health rating scale (2-9) indicate the state of damage in roots by its environment, with lower value indicating lesser damage and higher indicating severe damage. Less affected plants have more roots (Figure 3.3B) than severely affected roots (Figure 3.3A).

Descriptive statistics for root health at Syferkuil: In irrigated plot; minimum value of root health rating among the treatments ranged from 2 to 6, with the lowest being SMB and MMB while the highest was MC. Maximum value had a range of 4 to 7 with the highest and lowest being SC and SMB respectively. Mean values ranged from 2.67 for SMB and 6 for MC. In rainfed plot, minimum and maximum values of root health both ranged from 2 to 6, mean values ranged from 3.33 to 6 (Table 3.14).

Descriptive statistics for root health at UNIVEN: In irrigated plot; minimum values for root health rating ranged from 2 to 4, Maximum values had a range of 4 to 7, Means varied from 2.67 to 5.33. The values of root health rating observed in rainfed treatments did not have a range, with all treatments rating 2 for minimum values. Maximum values ranged from 2 to 7, mean values varied from 2 to 5 (Table 3.14).

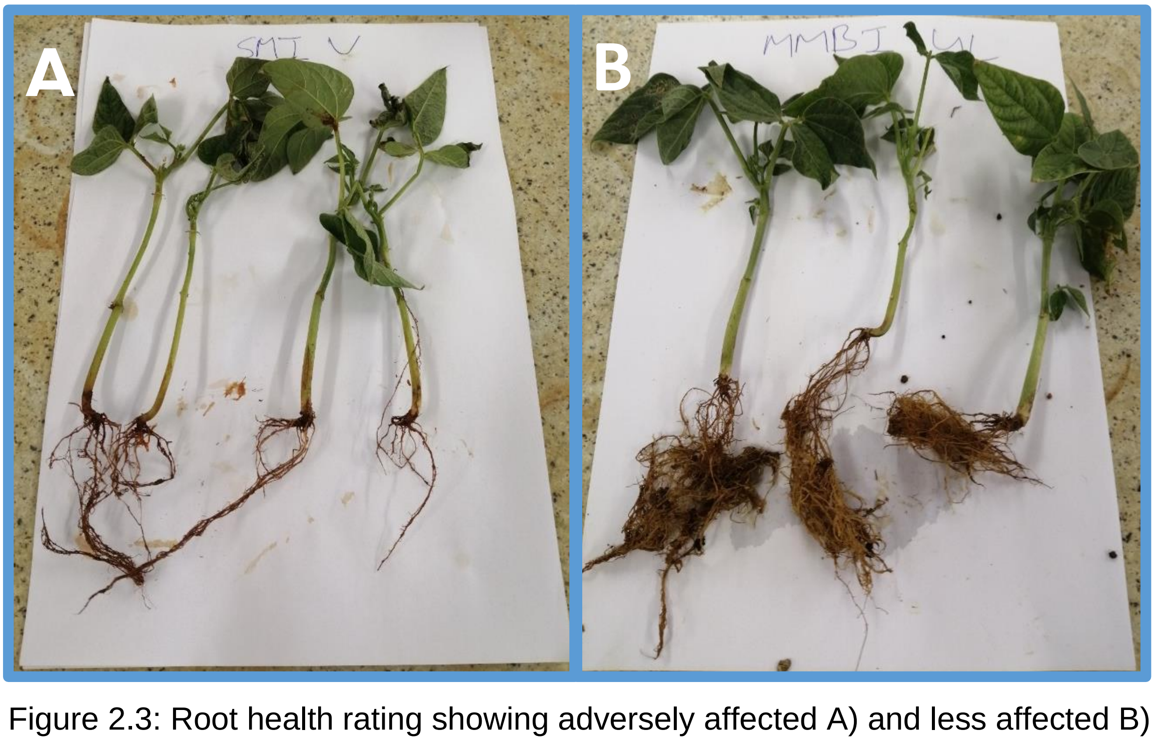

Figure 2.3: Root health rating showing adversely affected A) and less affected B)

Table 3.14: Descriptive statistics for root health rating of treatments at Syferkuil and UNIVEN

Descriptive Statistics	Syferkuil									
	Irrigated plot					Rainfed plot				
	SM	SC	SMB	MC	MMB	SM	SC	SMB	MC	MMB
Min	3,00	4,00	2,00	6,00	2,00	2,00	4,00	6,00	6,00	2,00
Max	6,00	7,00	4,00	6,00	6,00	2,00	4,00	6,00	6,00	4,00
	UNIVEN									
Min	4.00	2.00	4.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Max	4.00	4.00	6.00	7.00	4.00	6.00	4.00	7.00	6.00	2.00

Std.Dev = standard Deviation, Min= Minimum, Max = Maximum, SM= Sole Maize, SC= Sole Chickpea, SMB= Sole Mungbean, MC= Maize Chickpea, and MMB= Maize Mungbean.

3.4 Discussion

3.4.1 Effects of maize-legume intercropping systems on soil physical properties: Bulk density, aggregate stability

The results for soil bulk density (BD) observed in this study were not significant at both locations. However, irrigated SMB (7.54) and rainfed MMB (8.13) at Syferkuil had the greatest bulk density among treatments while irrigated (7.22) and rainfed (7.00) SC had the lowest BD. At UNIVEN, irrigated SMB (6.57) and rainfed SM (7.28) had higher BD while irrigated MMB (5.59) and rainfed MC (6.05). Xu *et al*. (2021) found BD significantly lowered with depth in the crop and grass intercropping than single cropping mode. Although BD was not measured with depth in this study, contrast was shown in this current study to Xu *et al*. (2021) study as BD was higher compared to its pre-soil at both locations. Soil bulk density may and may not improve soil cultivability, aeration, tightness, and reduce nutrients loss and in this study bulk density was not able to improve the above-mentioned indices. Kocira *et al*. (2020) stated that legumes can act as cover crops thereby reducing soil compaction and erosion, improving its structural and hydraulic properties.

In this study, soil aggregate stability as outlined in Table 3.4 showed no significance among the treatments and between the plots at Syferkuil while significance between the plots at UNIVEN was observed. Aggregate stability provides a better way to detect the effects of intercropping systems on soil aggregates (Cagna *et al*., 2019). Seidel *et al*. (2017) reported that aggregate stability and macro-porosity may be increased by intercropping systems, however, this did not concur with intercropping systems in this study at Syferkuil as there was no significant improvements observed. Furthermore, Cagna *et al*. (2019) found that soil aggregation was improved to a higher extent in a maize and *Urochloa ruziziensis* intercropping systems than maize-*Urochloa brizantha* and maize-*P. maximum* cv. However, significance was observed in UNIVEN by water regimes factor, and it can be inferred that this might be associated with maize-chickpea and maize-mungbean intercropping effects on increased aggregate stability. This agrees with the findings of Seidel *et al*. (2017) who found a positive correlation between maize-Jack bean intercropping systems with soil aggregate stability.

3.4.2 Effects of maize-legume intercropping systems soil chemical properties: pH, electrical conductivity, organic carbon, phosphorus, ammonium, and nitrate at Syferkuil and UNIVEN

The results of soil pH (H_2O) observed in the current study showed an increase in pH between rainfed and irrigated field in some of the treatments at both locations. It can be drawn from means outlined in Table 3.5 following pH range scale by Oliveira *et al*. (2016), that irrigated and rainfed plots at Syferkuil were both alkaline following a range of 8.50-9.00. On the other hand, the soil at UNIVEN was observed to be neutral following a range of 6.96-7.16. Calcium and magnesium are abundant at pH 7.8 or above, as in Syferkuil irrigated and rainfed plots (Neina, 2019). The most favourable pH for plants is in a range of 6-7 because most soil nutrients are readily available in this range (Neina, 2019). A pH of 6.6 to 7.3 range such in irrigated and rainfed plots at UNIVEN is suitable for microbial activities that contribute to primary nutrients phosphorus, nitrogen, potassium, and sulfur availability in soils. In this study, it was observed that soil pH (KCl and H_2O) of irrigated and rainfed chickpea intercrops at

Syferkuil and rainfed mungbean intercrop was greater compared to their sole crops. Soil pH in legumes showed a slight decrease and this aligns with Nwite *et al*. (2017) findings in that proton release from legume roots increases soil acidity. It was further explained by (Neina, 2019) that hydrogen ion is released from legume roots when absorbing cations. Another elucidation for lower pH could be consequences of nitrogen fixation resulting in acidification during legume growth (Uzoh *et al*., 2019). Contrastingly, Nwite *et al*. (2017) found that legume and cereal intercropping treatments had higher soil pH than mono-cropping treatments.

The observed soil EC in this study varied between the irrigated and rainfed plots at both locations. The lowest EC of 69.12-75.91 range was observed in rainfed and highest of 70.40-104.57 in irrigated plot at Syferkuil while the lowest of 47.34-50.18 under irrigated and highest of 44.86-61.43 under rainfed in UNIVEN. Soil EC was categorized as non-saline (< 200), moderately saline (200–1200), and extremely saline (> 1200) by Jimoh and Mahmud (2014). It can be drawn from this study that soils at both locations are less saline, but the observed variations could be the results of salts build-up added by borehole water used for irrigation. Generally, it was evident that irrigated plots had greater EC than rainfed ones and this agrees with Kgopa *et al*. (2018) who stated that soils irrigated with high EC water may results in salinity and high EC in the soil. Furthermore, Shahrivar *et al*. (2020), proved that EC rose in soil watered with recycled or rather treated wastewater in arid region following an increase of salts carried by the water.

Organic carbon increased in the sole and intercropped legumes in the irrigated and rainfed plots at Syferkuil and UNIVEN as outlined in Table 3.9, but it was greater in sole legumes at both locations. OC was greatest in SMB (1.58) irrigated and SC (2.34) rainfed plots while SM (0.75 and 0.95) was the lowest in both cases at Syferkuil. OC was greatest in irrigated (6.49) and rainfed (6.65) SC plots while SM (1.56 and 1.78) was the lowest in both cases at UNIVEN outlined in Table 3.7. Implication drawn from Table 3.7 is that soil at UNIVEN was generally greater in organic carbon than the one at Syferkuil. In terms of sole maize crops, there was no significant increase in organic carbon compared to intercrops at both locations. These observations are in line with Cong *et al*. (2015) demonstrations, that intercrops sequester more soil carbon over time owing to increased root litter input thereby enhancing rhizosphere productivity. In addition, plant species variety was found to increase soil carbon (C) and nitrogen (N) storage in an 11-year grassland biodiversity and a 7-year intercropping experiments (Dyer *et al*., 2012). According to a recent 2-year study by (Dyer *et al*., 2012), soil organic C concentration in the top 20 cm of intercrops was 4% +/- 1% higher than in single crops, showing a difference in C sequestration rate between intercrop and sole crop systems.

Phosphorus content observed in this study varied between Syferkuil and UNIVEN plots outlined in Table 3.8. P was greatest in rainfed (2.64) and irrigated (2.89) SMB plots while SM (2.18) and MC (2.10) were respectively the lowest at Syferkuil. P was greatest in irrigated (7.52) and rainfed (8.40) SMB plots while SM (2.24 and 2.76) was the lowest in both cases at UNIVEN. On average, intercrops exhibit higher P uptake in aboveground biomass than single crops (Tang *et al*., 2021). The results of soil P observed in this study showed an increase among the legume and intercrops between irrigated and rainfed plots at Syferkuil and UNIVEN. The above observation was similarly found by Tang *et al*. (2021) who reported that P levels and uptake were significantly enhanced significantly enhanced, with an average land equivalent ratio (LER_P) for P uptake, of 1.24. Furthermore, Uzoh *et al*. (2019) reported that the availability of P was increased by rotations compared to sole maize in legume-maize rotations.

In the current study, soil ammonium observed at Syferkuil was greatest in irrigated SM (12.19) and rainfed SC (9.05) while SMB (4.13 and 2.52) was the lowest. At UNIVEN, ammonium was greatest in SMB under both irrigated (13.09) and rainfed (13.68) plots while it was the lowest in SM (3.50 and 2.53) for both cases. Xu *et al*. (2021), reported that intercropping had little effect on ammonium accumulation and this case was observed also observed at Syferkuil and robustly at UNIVEN. Legumes are promising intercrops that could transfer the fixed N to maize and improve N absorption (Dolijanović *et al*., 2013). Zhang *et al*. (2015) observed significant accumulation of high total N content and system capacity improvement in maize intercropped with soybean than pure stand. Nwite *et al*. (2017) reported that soil N was substantially enhanced by intercropping activities of soybean and maize, groundnut and maize, and bambaranut and maize. Slight increase of ammonium in legume (sole and intercrop) crops suggests that N improvement was evident at both locations, especially at

UNIVEN. The above is in line with Mobasser *et al*. (2014) findings in that accumulation of 80-350kg/ha N in leguminous crops such as groundnut, cowpea, and soybean improved soil N compounds acquisition and fertility. In exception to the current study, Nwite *et al*. (2017) reported that soil total N (TN) did not change between intercropping and monocropping except for maize/faba bean intercropping.

This study showed differences in amount of soil nitrate among the irrigated and rainfed treatments, despite insignificant and significant effects observed at Syferkuil and UNIVEN respectively. There was no increase in NO_3 between Irrigated treatments while a slight increase was observed in rainfed with MC (0.10) being the lowest and SC the greatest (0.50) as outlined in Table 3.12. The amount of NO_3 at UNIVEN had significant increase, with SMB being the highest in irrigated (1.37) and rainfed (1.42) plots while SM was the lowest (0.34 and 0.33) (Table 3.12). These differences observed could be associated with NO_3 being mobile under unfavourable soil conditions that prohibit its accumulation. The results by Manevski *et al*. (2014) indicated no effect on soil nitrate concentration by maize-red clover intercropping, whereas nitrate buildup was decreased in the 0-200 cm soil layer by maize-sweet clover and maize-pea intercropping systems. Furthermore, reduction of NO_3 to NH_4 could have been the case at both locations as NO_3 was less and NH_4 was greatly increased. This could have attributed to spatial effect of environmental factors and nitrate reducing microbes as it was reported by Giles *et al*. (2012), that control factors of nitrate reduction mechanisms includes moisture content, nitrogen, organic carbon, pH, and community structure of nitrate reducing microbes.

3.4.3 Effects of maize-legume intercropping systems on soil biological parameters: Organic matter, soil active carbon, potentially mineralizable nitrogen, and root health rating

The soil organic matter (SOM) observed in this study was significantly greater in sole legumes crops followed by intercrops at Syferkuil and UNIVEN, with latter location being greater than former. As outlined in Table 3.13, SOM was greater in irrigated (4.37) and rainfed (5.98) SMB and the lowest in SM (1.60 and 2.56) at Syferkuil. Like SOM at Syferkuil, SMB showed greater SOM in irrigated (9.43) and rainfed (9.71) plots while the lowest (3.89 and 3.25) was observed in SM at UNIVEN as outlined in Table

3.13. SOM was generally greater under the intercrops compared to the monocrops and this observation was supported by Wang *et al*. (2014) who discovered that soil organic matter (OM) did not differ significantly from monocropping in general, despite rising in maize/chickpea and maize/turnip intercropping systems. Intercropping with legumes has been shown to improve soil organic matter content by sequestering atmospheric carbon (Dolijanovi *et al*., 2013). Furthermore, organic matter has been found to improve soil structural stability and resilience to rainfall effect (Baveye *et al*., 2020). Sileshi *et al*. (2012) stated that including legumes into maize cropping systems, significant amounts of organic matter were added to the soil, further mitigating land degradation.

There was no significant increase or decrease on SAC by treatments at both locations in this current study. SAC was generally higher in rainfed than irrigated at Syferkuil while the contrast was observed at UNIVEN. However, SAC among the treatments at Syferkuil was greater in irrigated MMB (1695.00) and rainfed SM (1926.50) while at UNIVEN it was greater in irrigated (1896.80) and rainfed (1362.20) in MMB. As outlined in Table 3.14, irrigated SM (667.30) and rainfed MC (930.70) showed lower SAC at Syferkuil and irrigated SC (476.50) and rainfed SMB (169.70) at UNIVEN. These variations at both locations indicates sensitivity of SAC to soil management and serves as proxies for soil organic carbon (SOC) (Mashapa *et al*., 2020). An increase of labile soil carbon (SAC) was reported by Mashapa *et al*. (2020) under no till (NT) system of vetch-sweet sorghum intercropping system compared to conventional tillage (CT). Results of SAC in this study were not significant and concur with the findings of Zhao *et al*. (2016) who did not find a significant effect on soil organic carbon under NT and CT.

In the study, significant variation on potentially mineralizable nitrogen (PMN) was observed between irrigated and rainfed plots at Syferkuil and UNIVEN. SM at Syferkuil had higher (0.38) and lower (0.05) PMN under rainfed and irrigated plots respectively while irrigated SC was highest (0.07) and rainfed SMB (0.34) the lowest. Irrigated (0.21) and rainfed (0.47) SMB had greater PMN while SM had the lowest (0.10 and 0.20) as shown by Table 3.15. It can be drawn from this study that PMN was improved by maize-chickpea and maize-mungbean intercropping systems and seemingly with the presence of soil moisture for a conducive environment. However, rainfed also provided a conducive environment as PMN was not severely affected. Odhiambo *et al*. (2015) demonstrated significantly greater PMN in maize-bean intercropping during short rainy season compared to long rainy season and fallow period, implying increased nitrogen and carbon mineralization due to warmer temperatures and frequent tillage.

The observations of root health rating in this study among the treatments at both locations showed some contrasting figures between irrigated and rainfed plots as outlined in Table 3.16. At Syferkuil, irrigated SMB (2.67), rainfed SM (3.33) and MMB (3.33) had the lowest values which represents better health or very less pathogens induced while irrigated MC, rainfed SMB and MC had greater value of 6 which represents moderate root damage by pathogens. Irrigated SC (2.67) and rainfed MMB (2) at UNIVEN had the lowest values while irrigated SMB (5.33) and rainfed SMB (5) had the highest values. All treatments at UNIVEN were below moderate damage. Kumar *et al*. (2021), reported that root development and nutrient improvement may be positively boosted by companion crops in the intercropping, which is in contrast with the observed effects particularly under rainfed plots where water could have hindered root development compared to irrigated plot.

3.5 Conclusion

In this objective, sole crops of maize and legumes were used and compared to the performance of maize-legume intercropping on important soil health variables. Compared to sole crops, it was found in this study that mineral elements such as phosphorus, organic matter and carbon, ammonium, and nitrate had improved. Furthermore, the concentration of these elements was increased as compared to their concentration prior planting at two locations. Therefore, there was a positive response from selected soil health variables in terms of soil fertility improvement signs under maize-chickpea and maize-mungbean intercropping systems in both rainfed and irrigated water regimes.

CHAPTER 4

EFFECTS OF RAINFED AND IRRIGATED MAIZE-LEGUME INTERCROPPING SYSTEMS ON PLANT GROWTH AND YIELD PARAMETERS

4.1 Introduction

Past agricultural intensification has substantially increased crop yields but future improvements in productivity necessary to support a growing population must come at a reduced environmental cost (Ghosh and Devi, 2019). Plants, especially agricultural crops have immediate response to abiotic factors such as soil in their microenvironment (Bukovsky-Reyesa *et al*., 2019). Shifting to more biologically based or minimal input cropping systems holds potential for maintaining or increasing yields while lowering environmental costs and boosting resilience to harsh disturbances (El-Ramady *et al*., 2015). Active and beneficial bacteria that drives soil health are highly associated with crop yield, and fruit quality thereby improving plant health and soil fertility (Leskovar *et al*., 2016). The supply of healthy soil related nutrients such as nitrogen and other important nutrients has major impact on leaf growth because it improves plant leaf area, which impacts photosynthesis (Knight *et al*., 2013). Nitrogen content of crops is closely linked with chlorophyll content and latter is approximately proportional to leaf nitrogen content, too (Evans, 1983). Therefore, this chapter explores the effects of soil health variables on crop growth and yield parameters in rainfed and irrigated maize-legume intercropping systems at Syferkuil and UNIVEN regions.

4.2 Materials and methods

4.2.1 Study site description and research design

This chapter's materials and methods were a continuation of that in Chapter 3. Therefore, study site description and research design is the same as in chapter 3. However the number of treatments in this chapter is 7 because intercropped plants are assessed individually in terms of data collection.

4.2.2 Cultural practices

The plot (22.4 m x 16 m) which had been fallowed for at least three years was identified and divided into equal sub-plots (length = 2.4 m and breadth = 2.4 m) prior to establishment of experiment at both experimental farms. The plot was prepared for desirable seedbed using mechanized tillage. During planting, the length and width of the plots and subplots were demarcated using measuring tape, strings and T-markers. The seeds of sole maize, chickpea, and mungbean were planted at depths of 5 cm. Maize was planted at an inter-row spacing of 60 cm and intra-row spacing of 30 cm while both legumes had inter-row spacing and intra-row spacing of 30 cm and 20 cm respectively. In intercropped subplots, maize spacing were used as reference and legumes were planted in between. In the light of two water regimes, irrigated trial was irrigated two days a week for 2 hours while the rainfed trial was left to depend on rain. However, rainfed trial was given a round of irrigation at its vegetative stage because it was certainly struggling due to prolonged rainless days (Chapter 3).

4.2.3 Data collection

The data (plant height, chlorophyll, and plant vigour) was collected at two growth stages at both Syferkuil and Thohoyandou regions: Vegetative, and flowering.

Growth parameters

Plant height (cm) was collected in each subplot from three randomly selected plants using a meter stick. Chlorophyll (CCI) was collected in each subplot from three randomly selected crops using a handheld chlorophyll meter. Plant vigour or greenness was collected in each subplot from three randomly selected plants using a handheld Normalized Difference Vegetation Index (NDVI) Green-Seeker ™ (Figure 4.1). Measurements were taken from 28 days after emergence at a 2-week time interval.

Figure 4.1: Collection of growth parameters in the field, A) Plant vigour, B) Chlorophyll content

<u>Yield parameters</u>

Biomass

The biomass for both maize and legume crops was collected by harvesting their stalks where the wet weight was recorded and oven dried weight after drying for at least 48 hours at 60 °C and expressed per unit area (g/m^2). Grain yield was not determined because the cobs and pods were damaged by monkeys which were very difficult to control.

4.2.4 Data analysis

Data were summarized using descriptive statistics and subjected to split plot analysis of variance (ANOVA) through GenStat software. Mean separation for significant plant growth and yield parameters was determined at probability level of 5% confidence interval using Duncan Multiple Range Test.

4.3 Results

4.3.1 Interactive effects of irrigation and maize-legume intercropping systems on plant growth parameters during different stages of growth at Syferkuil and UNIVEN.

Plant height

There was a high significant effect ($p<0.01$) observed on plant height at Syferkuil during vegetative stage while no significant effect ($p>0.05$) was observed during flowering stage under the interaction of water regimes and maize-legume intercropping systems. Cropping systems showed significant effect on plant height during vegetative (Appendix 4.1) and flowering (Appendix 4.2) stages while water regimes showed no significant effect. Plant height under irrigated plot at Syferkuil during vegetative stage ranged from 12.51 to 89.83 where both SC and SMB were greater than their intercrops and contrary to the rainfed plot with a range of 14.08 to 66.53 where SC and SMB were lesser than their intercrops. SM (89.83) under irrigated plot had greater height than intercrops whereas intercrops were higher under rainfed (Table 4.1). The range of plant height at Syferkuil during flowering stage for irrigated plot was 23.67 to 141.89 with SC being greater than its intercrop and contrary for SMB whereas the range under rainfed was 20.39 to 122.45 with SC being lesser than its intercrop and SMB being greater than its intercrop. Both irrigated (143.11) and rainfed (130.22) 5M intercrops had greater heights than SM and 4M intercrops (Table 4.1).

There was no significant effect ($p>0.05$) observed on plant height at UNIVEN during both vegetative and flowering stages. Cropping systems showed significant effect on plant height during vegetative (Appendix 4.3) and flowering (Appendix 4.4) stages while water regimes showed no significant effect. Plant height during vegetative stage ranged from 15.61 to 95.06 under irrigated plot where SC was lesser than intercrop and SMB greater than intercrop. Rainfed plot had a range of 9.80 to 100.61 where SC was lesser than intercrop and SMB greater than its intercrop. Irrigated (110.39) and rainfed (125.93) 4M intercrop had greater height compared to SM and 5M intercrops (Table 4.2). Plant height during flowering stage ranged from 14.56 to 130.91 under irrigated plot with SC being lesser than its intercrop except for SMB. In rainfed plot, plant height ranged from 12.56 to 152.11 where SC was also lesser than its intercrop while SMB was greater than its intercrop. Height of irrigated (184.44) and rainfed (185.89) 4M was the highest among all maize crops (Table 4.2).

Table 4.1: Interactive effects of water regimes and intercropping systems on plant height at Syferkuil.

Treatments	Plant height (cm)					
	Vegetative			Flowering		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	89.83[a]	66.53[b]	78.18[A]	141.89[a]	122.45[a]	132.17[A]
SC	35.84[c]	33.49[c]	34.67[B]	39.78[b]	36.45[b]	38.11[BC]
SMB	15.15[de]	14.38[de]	14.77[C]	23.67[b]	21.33[b]	22.50[C]
4M	77.38[ab]	73.81[ab]	75.60[A]	127.33[a]	116.89[a]	122.11[A]
4C	30.82[cd]	34.30[c]	32.56[B]	37.33[b]	41.78[d]	39.56[B]
5M	89.03[a]	68.26[b]	78.65[A]	143.11[a]	130.22[a]	136.67[A]
5MB	12.51[e]	14.08[de]	13.30[C]	26.22[b]	20.39[b]	23.30[BC]
Means	50.08[A]	43.55[A]		77.05[A]	69.93[A]	
P (f-test)						
WR		0.08			0.14	
CS		0			0	
WR x CS		0			0.39	
CV (%)		11.96			12.43	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, 4M-intercropped maize, 4C-intercropped chickpea, 5M-intercropped maize, 5MB-intercropped mungbean. Column means followed by the same letter were not different ($p<0.05$)) according to Duncan Multiple Range Test.

Table 4.2: Interactive effects of water regimes and intercropping systems on plant height at UNIVEN.

Treatments	Plant height (cm)					
	Vegetative			Flowering		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	95.06^{b}	100.61^{ab}	97.83^{B}	130.91^{a}	152.11^{a}	141.51^{B}
SC	15.61^{de}	9.80^{e}	12.71^{E}	14.56^{b}	12.56^{b}	13.56^{D}
SMB	59.06^{c}	59.44^{c}	59.25^{C}	55.16^{b}	48.21^{b}	51.68^{C}
4M	110.39^{ab}	125.93^{a}	118.16^{A}	184.44^{a}	185.89^{a}	185.17^{A}
4C	22.28^{de}	27.94^{de}	25.11^{DE}	27.21^{b}	25.78^{b}	26.49^{CD}
5M	90.50^{b}	110.83^{ab}	100.67^{AB}	150.82^{a}	164.56^{a}	157.69^{AB}
5MB	31.33^{cde}	41.11^{cd}	36.22^{D}	31.04^{b}	35.56^{b}	33.30^{CD}
Means	60.60^{A}	67.95^{A}		84.88^{A}	89.24^{A}	
P (f-test)						
WR		0.19			0.27	
CS		0			0	
WR x CS		0.32			0.88	
CV (%)		15.17			22.55	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, 4M-intercropped maize, 4C-intercropped chickpea, 5M-intercropped maize, 5MB-intercropped mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test.

<u>Chlorophyll content</u>

There was no significant effect (p>0.05) observed under the interaction of water regimes and maize-legume intercropping systems on chlorophyll content at Syferkuil during both vegetative (Appendix 4.5) and flowering (Appendix 4.6) stages. Water regimes did not show significant effect on chlorophyll content during both stages while significant effect (p<0.01) was observed from cropping systems during vegetative stage only. Irrigated plot during vegetative stage had a range of 3.23 to 20.58 in chlorophyll content where SC had lesser chlorophyll than its intercrop and SMB had greater chlorophyll than its intercrop. Under rainfed plot, chlorophyll content ranged from 3.63 to 28.13 where SC and SMB were both lesser than their intercrops. SM intercrops under both irrigated and rainfed plots had greater chlorophyll content than sole crops (Table 4.3). The range of chlorophyll content at Syferkuil was 2.79 to 25.15

where SC and SMB were both lesser than their intercrops under irrigated plot. The range of chlorophyll content during flowering stage under rainfed plot was from 6.47 to 51.82 where SC and SMB were both lesser than their intercrops. Intercrop of 5M (33.33) under irrigation had higher chlorophyll content and rainfed SM (23.30) was also greatest among maize crops (Table 4.3).

At UNIVEN, the interaction of water regimes and cropping systems showed significant effect ($p<0.01$) only during flowering stage while significant effect was also observed during vegetative and flowering stages from cropping systems. Water regimes at both stages did not show significant effect (Appendix 4.7 and 4.8). Chlorophyll content at UNIVEN for irrigated plot ranged from 1.87 to 34.42 where SC was lesser than its intercrop and SMB greater than its intercrop. Under rainfed plot, chlorophyll content ranged from 2.24 to 36.66 where SC like irrigated was lesser than intercrop while SMB was greater than intercrop. In terms of maize crop, 4M intercrop had higher chlorophyll in irrigated plot whereas 5M intercrop was higher under rainfed (Table 4.4). During flowering stage, chlorophyll content ranged from 1.13 to 52.82 under irrigated plot where SC was lesser than its intercrop and contrary for mungbean where intercrop was greater than sole crop. In rainfed plot, chlorophyll content ranged from 1.32 to 28.09 where SC and SMB were both lesser than their intercrops. Both irrigated (17.18) and rainfed (24.06) 4M intercrops had higher chlorophyll content amongst other maize crops (Table 4.4)

Table 4.3: Interactive effects of water regimes and intercropping systems on chlorophyll content at Syferkuil.

Treatments	Chlorophyll (SPAD)					
	Vegetative			Flowering		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	20.30[abc]	28.13[a]	24.22[A]	25.15[a]	23.30[a]	24.23[A]
SC	3.23[d]	3.63[d]	3.43[B]	2.79[a]	6.47[a]	4.63[A]
SMB	20.58[ab]	18.61[abc]	19.59[A]	13.10[a]	15.70[a]	14.40[A]
4M	19.09[abc]	21.97[ab]	20.53[A]	18.83[a]	22.79[a]	20.81[A]
4C	5.65[d]	7.69[bcd]	6.67[B]	5.53[a]	8.40[a]	6.97[A]
5M	26.06[a]	28.22[a]	27.14[A]	33.33[a]	19.61[a]	26.47[A]
5MB	19.98[abc]	19.18[abc]	19.57[A]	14.22[a]	51.82[a]	33.02[A]
Means	16.41[A]	18.20[A]		16.14[A]	21.15[A]	
P (f-test)						
WR		0.36			0.66	
CS		0			0.15	
WR x CS		0.69			0.46	
CV (%)		28.10			104.	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, 4M-intercropped maize, 4C-intercropped chickpea, 5M-intercropped maize, 5MB-intercropped mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test.

Table 4.4: Interactive effects of water regimes and intercropping systems on chlorophyll content at UNIVEN

Treatments	Chlorophyll (SPAD)					
	Vegetative			Flowering		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	11.80^{def}	16.78^{cdef}	14.29^{CD}	14.84^{bcd}	13.10^{bcd}	13.97^{C}
SC	1.87^{f}	2.24^{f}	2.05^{E}	1.13^{d}	1.32^{d}	1.23^{D}
SMB	34.42^{ab}	36.66^{a}	35.54^{A}	52.82^{a}	26.46^{bc}	39.64^{A}
4M	17.58^{bcdef}	18.53^{bcdef}	18.06^{BC}	17.18^{bcd}	24.06^{bc}	20.62^{BC}
4C	6.44^{ef}	5.25^{ef}	5.85^{DE}	1.31^{d}	1.35^{d}	1.33^{D}
5M	17.10^{cdef}	23.88^{abcd}	20.49^{BC}	11.00^{cd}	17.30^{bcd}	14.15^{C}
5MB	21.03^{abcde}	30.58^{abc}	25.80^{AB}	29.49^{b}	28.09^{bc}	28.79^{B}
Means	15.75^{A}	19.13^{A}		18.25^{A}	15.96^{A}	
P (f-test)						
WR		0.05			0.33	
CS		0			0	
WR x CS		0.68			0	
CV (%)		33.37			33.62	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, 4M-intercropped maize, 4C-intercropped chickpea, 5M-intercropped maize, 5MB-intercropped mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test.

Plant vigour

There was no significant effect ($p>0.05$) observed on plant vigor under the interaction of water regimes and maize-legume intercropping systems at Syferkuil during both vegetative and flowering stages. Significant effect ($p<0.01$) was observed from cropping systems while water regimes did not show significant effect during both stages (Appendix 4.9 and 4.10). Plant vigor during vegetative stage at Syferkuil ranged from 0.19 to 0.74 under irrigated plot where SC was greater than its intercrop and SMB lesser than its intercrop. In rainfed plot, plant vigor ranged from 0.23 to 0.66 where SC and SMB were both lesser than their intercrops. SM (0.74) sole crop had greater plant vigour than both intercrops under irrigated plot whereas 4M intercrop was greatest under rainfed plot (Table 4.5). During flowering stage, plant vigor for irrigated plot ranged from 0.33 to 0.73 where SC was greater than its intercrop except for SMB where intercrop was highest. Plant vigor ranged from 0.29 to 0.69 under rainfed where SC was greater than its intercrop and SMB lesser than its intercrop. Plant vigour was greater in irrigated (0.77) and rainfed (0.70) 4M intercrop than other maize crops (Table 4.5).

At UNIVEN, the interaction of water regimes and cropping systems showed significant effect on plant vigour during vegetative only. Significant effect was observed from cropping systems during both vegetative and flowering stages while water regimes showed significant effect ($p<0.05$) during flowering stage only (Appendix 4.11 and 4.12). Plant vigor for irrigated plot ranged from 0.22 to 0.75 where SC was lesser than its intercrop while SMB was greater than its intercrop. Plant vigor for rainfed plot during vegetative stage ranged from 0.20 to 0.61 where SC had lesser plant vigor than its intercrop while SMB had greater plant vigor than intercrop. Both irrigated (0.74) and rainfed (0.75) 4M intercrop had highest plant vigour than SM and 5M intercrops (Table 4.6). Plant vigor at UNIVEN during flowering stage for irrigated plot ranged from 0.37 to 0.61 where SC and SMB were both lesser than their intercrops. Under rainfed plot, plant vigor ranged from 0.29 to 0.69 where SC was greater than its intercrop and SMB lesser than its intercrop. Under irrigated plot, 5M (0.65) intercrop had higher vigour whereas SM (0.55) was high under rainfed amongst other maize crops (Table 4.6).

Table 4.5: Interactive effects of water regimes and intercropping systems on plant vigour at Syferkuil

Treatments	Plant vigour					
	Vegetative			Flowering		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	0.74^{a}	0.66^{a}	0.70^{A}	0.73^{ab}	0.69^{abc}	0.71^{A}
SC	0.47^{b}	0.39^{bc}	0.43^{B}	0.60^{bcd}	0.56^{cd}	0.58^{B}
SMB	0.19^{d}	0.23^{d}	0.20^{C}	0.33^{f}	0.29^{f}	0.31^{C}
4M	0.73^{a}	0.72^{a}	0.73^{A}	0.77^{a}	0.70^{abc}	0.74^{A}
4C	0.44^{b}	0.46^{c}	0.45^{B}	0.52^{de}	0.52^{d}	0.52^{B}
5M	0.66^{a}	0.66^{a}	0.70^{A}	0.76^{ab}	0.69^{abc}	0.72^{A}
5MB	0.24^{d}	0.29^{cd}	0.27^{C}	0.36^{ef}	0.33^{f}	0.35^{C}
Means	0.51^{A}	0.49^{A}		0.58^{A}	0.54^{A}	
P (f-test)						
WR		0.22			0.21	
CS		0			0	
WR x CS		0.06			0.87	
CV (%)		9.8			8.99	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, 4M-intercropped maize, 4C-intercropped chickpea, 5M-intercropped maize, 5MB-intercropped mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test.

Table 4.6: Interactive effects of water regimes and intercropping systems on plant vigour at UNIVEN

Treatments	Plant vigour					
	Vegetative			Flowering		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	0.68^{a}	0.61^{ab}	0.64^{AB}	0.61^{ab}	0.55^{abc}	0.58^{A}
SC	0.22^{c}	0.20^{c}	0.21^{D}	0.37^{ef}	0.29^{f}	0.33^{D}
SMB	0.75^{a}	0.61^{ab}	0.68^{AB}	0.39^{def}	0.41^{cdef}	0.40^{CD}
4M	0.74^{a}	0.75^{a}	0.75^{A}	0.57^{abc}	0.54^{abcd}	0.55^{AB}
4C	0.41^{e}	0.37^{bc}	0.39^{C}	0.44^{cdef}	0.42^{cdef}	0.43^{CD}
5M	0.59^{ab}	0.69^{a}	0.64^{AB}	0.65^{a}	0.52^{abcde}	0.58^{A}
5MB	0.70^{a}	0.44^{bc}	0.59^{B}	0.49^{bcde}	0.45^{cde}	0.47^{BC}
Means	0.58^{A}	0.52^{A}		0.50^{A}	0.45^{B}	
P (f-test)						
WR		0.17			0.02	
CS		0			0	
WR x CS		0.02			0.36	
CV (%)		14.52			11.43	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, 4M-intercropped maize, 4C-intercropped chickpea, 5M-intercropped maize, 5MB-intercropped mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test.

Leaf area index

There was significant effect ($p<0.05$) observed under the interaction of water regimes and maize-legume intercropping systems on leaf area index (LAI) at Syferkuil during vegetative stage while significant effect ($p<0.01$) was observed during flowering stage. Significant effect was observed from cropping systems while water regimes showed no significant effect during both stages (Appendix 4.13 and 4.14). LAI during vegetative stage ranged from 0.04 to 1.33 under irrigated plot where SC and SMB were both lesser than their intercrops. LAI under rainfed plot ranged from 0.09 to 1.50 where SC and SMB were also lesser than their intercrops. LAI in terms of irrigated maize was greatest in 5M intercrop whereas SM and 4M intercrop did not vary (Table 4.7). During flowering stage, LAI for sole crops under irrigated plots ranged from 0.09 to 1.86 where both SC and SMB were lesser than their intercrops while similar trend was observed in rainfed plot at a range of 0.14 to 1.79. The LAI of irrigated 5M and 4M intercrops (0.10) was the same and higher than sole maize crop whereas SM (0.13) was higher under rainfed (Table 4.7).

At UNIVEN, the interaction of water regimes and intercropping systems did not show significant effect ($p>0.05$) on leaf area index during both vegetative and flowering stages. Significant effect ($p<0.01$) was observed from cropping systems during vegetative and flowering stages while water regimes did not show significant effect (Appendix 4.15 and 4.16). LAI under irrigated plot at UNIVEN during vegetative stage ranged from 0.07 to 1.72 where SC and SMB had lesser LAI than their intercrops. Like irrigated plot, SC and SMB had lesser LAI than their intercrops at a range of 0.11 to 1.95. LAI was the same between irrigated SM and intercrops whereas SM was greater in rainfed (Table 4.8). During flowering stage, LAI ranged from 0.13 to 2.50 under irrigated plot where both SC and SMB were lesser than their intercrops. Like irrigated plot, SC and SMB were lesser than their intercrops under rainfed plot at a range of 0.20 to 2.75. SM for both irrigated (0.13) and rainfed (0.20) plots were greater than intercrops (Table 4.8).

Table 4.7: Interactive effects of water regimes and intercropping systems on leaf area index at Syferkuil

Treatments	Leaf Area Index (m^2)					
	Vegetative			Flowering		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	0.04^{f}	0.09^{ef}	0.07^{C}	0.09^{e}	0.14^{de}	0.11^{D}
SC	0.37^{d}	0.76^{c}	0.56^{B}	0.93^{c}	1.67^{a}	1.30^{B}
SMB	0.31^{de}	0.53^{cd}	0.42^{B}	0.68^{cd}	1.04^{bc}	0.86^{C}
4M	0.05^{f}	0.09^{ef}	0.07^{C}	0.10^{e}	0.13^{de}	0.12^{D}
4C	1.33^{ab}	1.50^{a}	1.42^{A}	1.86^{a}	1.79^{a}	1.83^{A}
5M	0.06^{f}	0.08^{ef}	0.18^{C}	0.10^{e}	0.13^{de}	0.25^{D}
5MB	1.17^{b}	1.29^{ab}	1.23^{A}	1.63^{a}	1.57^{ab}	1.60^{AB}
Means	0.48^{A}	0.65^{A}		0.81^{A}	0.92^{A}	
P (f-test)						
WR		0.07			0.41	
CS		0			0	
WR x CS		0.14			0	
CV (%)		19.84			21.78	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, 4M-intercropped maize, 4C-intercropped chickpea, 5M-intercropped maize, 5MB-intercropped mungbean. Column means followed by the same letter were not different ($p<0.05$)) according to Duncan Multiple Range Test.

Table 4.8: Interactive effects of water regimes and intercropping systems on leaf area index at UNIVEN

Treatments	Leaf Area Index (m^2)					
	Vegetative			Flowering		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	0.07^{f}	0.11^{f}	0.09^{D}	0.13^{f}	0.20^{f}	0.17^{E}
SC	0.69^{e}	0.96^{de}	0.83^{C}	1.03^{e}	1.49^{de}	1.26^{D}
SMB	1.23^{cd}	1.28^{bcd}	1.26^{B}	1.91^{bcd}	1.78^{cd}	1.85^{C}
4M	0.07^{f}	0.09^{f}	0.08^{D}	0.11^{f}	0.14^{f}	0.13^{E}
4C	1.59^{abc}	1.63^{abc}	1.61^{A}	2.26^{abc}	2.14^{abcd}	2.20^{B}
5M	0.07^{f}	0.09^{f}	0.08^{D}	0.11^{f}	0.15^{f}	0.13^{E}
5MB	1.72^{ab}	1.95^{a}	1.83^{A}	2.50^{ab}	2.75^{a}	2.63^{A}
Means	0.78^{A}	0.87^{A}		1.15^{A}	1.24^{A}	
P (f-test)						
WR		0.25			0.41	
CS		0			0	
WR x CS		0.52			0.11	
CV (%)		17.27			15.32	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, 4M-intercropped maize, 4C-intercropped chickpea, 5M-intercropped maize, 5MB-intercropped mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test.

4.3.2 Interactive effects of irrigation and maize-legume intercropping systems on biomass yield at Syferkuil and UNIVEN.

Biomass yield: There was no significant effect (p>0.05) observed on biomass yield under the interaction of water regimes and maize-legume intercropping systems at Syferkuil and UNIVEN locations. Significant effect (p<0.01) was observed from cropping systems in both locations while water regimes did not show significant effect on biomass yield at both locations. Cropping systems at both locations showed a highly significant effect (p<0.01) on biomass yield (Appendix 4.17 and 4.18). The biomass yield between legume plants at Syferkuil ranged from 16.56 to 60 and 19.67 to 40.41 under irrigated and rainfed plot respectively. The range of biomass yield between maize crops was 127.17 to 164.83 under irrigated and 112.73 to 185.05 under rainfed plots. SC and SMB had greater biomass than their intercrops under both irrigated and rainfed plots whereas irrigated 4M and rainfed 5M intercrops showed greater yield than other maize treatments (Table 4.9). At UNIVEN, biomass yield under irrigated plot ranged from 17.44 to 42.32 between irrigated legumes and 20.27 to 26.41 for rainfed legumes. The yield range between maize plants was 65.53 to 85.05 under irrigated plot and 83.55 to 99.40 under rainfed plot. SC and SMB under irrigation and rainfed had higher biomass than their intercrops whereas irrigated SM and rainfed 5M intercrop had greater yield amongst maize crops (Table 4.9).

Table 4.9: Interactive effects of irrigation and maize-legume intercropping systems on biomass and grain yield at Syferkuil and UNIVEN.

Treatments	Biomass yield (g/m^2)					
	Syferkuil			UNIVEN		
	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
SM	127.17^{bc}	124.33^{bc}	125.75^{A}	85.05^{ab}	83.55^{ab}	84.30^{A}
SC	60.76^{d}	40.41^{d}	50.63^{B}	32.45^{d}	25.20^{d}	19.22^{B}
SMB	29.67^{d}	21.92^{d}	25.80^{B}	42.32^{cd}	26.41^{d}	34.37^{B}
4M	164.83^{ab}	112.73^{c}	138.78^{A}	65.53^{bc}	86.11^{ab}	75.82^{A}
4C	26.04^{d}	28.36^{d}	27.20^{B}	17.44^{d}	20.27^{d}	18.86^{B}
5M	138.77^{abc}	185.09^{a}	25.80^{B}	81.55^{ab}	99.40^{a}	90.48^{A}
5MB	16.56^{d}	19.67^{d}	18.11^{B}	21.20^{d}	21.36^{d}	21.28^{B}
Means	80.54^{A}	76.09^{A}		49.36^{A}	51.76^{A}	
P (f-test)						
WR		0.70			0.42	
CS		0			0	
WR x CS		0.25			0.81	
CV (%)		38.65			48.60	

WR- Water regimes, CS- Cropping systems, CV- coefficient of variation, SM-sole maize, SC-sole chickpea, SMB-sole mungbean, 4M-intercropped maize, 4C-intercropped chickpea, 5M-intercropped maize, 5MB-intercropped mungbean. Column means followed by the same letter were not different (p<0.05)) according to Duncan Multiple Range Test.

4.4 Discussion

4.4.1 Interactive effects of water regimes and maize-legume intercropping systems on growth parameters (height, chlorophyll, vigour, and LAI) and biomass yield.

Plant height, chlorophyll, vigour, and LAI at three growing stages (*vegetative, flowering, and maturity*)

The results of plant height at three growing stages showed a highly significant effect by maize-legume intercropping systems during all stages of growth at both locations. However, variation was observed among intercrops and sole crops in terms of height between irrigated and rainfed plots at both locations. Amongst the legumes, highest values of plant height were recorded in sole chickpea at Syferkuil and mungbean at UNIVEN. Irrigated SC (35.84) and SMB (15.15) during vegetative stage at Syferkuil had greater height than their intercrops while only SMB (14.38) was greater than its intercrop in rainfed plot. At UNIVEN, SC (9.80) had lesser height while SMB (59.44) had greater height than their intercrops under irrigated plot. Similar trend was observed under rainfed plot where SC was less and SMB greater than their intercrops. During flowering stage at Syferkuil, irrigated SC was greater than intercrop while SMB sole crop was lesser than its intercrop while contrary was observed under rainfed. At UNIVEN, irrigated SC intercrop had greater height and SMB intercrop was less than their sole crop while contrary was observed under rainfed plot. During maturity stage, irrigated SC and SMB intercrops had greater height than their sole crops while *former* treatments had less height than sole crops at Syferkuil. For both irrigated and rainfed plots at UNIVEN, SC intercrop had higher plant height while SMB intercrop had lesser plant height than their sole crops (Table 4.7).

The increase of legume plant height at both locations might be linked to better use of sunlight, soil nutrients, space and these results are in close conformity with the findings of Ginwal *et al*. (2019), who reported higher cowpea height. In the current study, plant height of pure stand crops was higher than their intercrops. This does not agree with the results of Mas-uda *et al*. (2016), results which showed greater production of plant height under groundnut-intercropped than sole groundnut. Furthermore, Fan *et al*. (2018), previously showed that shadow impacts on legume crops enhance their height.

The general trend of chlorophyll content observed decreased with growing stages at Syferkuil, while this was not the case at UNIVEN. At Syferkuil, rainfed SC and SMB were greater than their sole crops throughout all growing stages as well irrigated plot except for vegetative stage where intercrop was greater than SC and lesser than SMB sole crops. At UNIVEN, chlorophyll content of SC intercrop was greater than sole crop while SMB was greater under both irrigated and rainfed plots during vegetative stage. Both rainfed SC (1.35) and SMB (28.09) intercrops were greater than their sole crop during flowering while SC intercrop was the only treatment greater than its sole crop under irrigated at UNIVEN.

The chlorophyll content at Syferkuil decreased with growing stages for SC and this agrees with the findings of Pandey *et al*. (2020), who reported increasing SPAD values of chlorophyll in maize and soybean leaves 20 days after sowing with highest being recorded at 60 days where SPAD values decreased afterwards. Furthermore, SPAD values were shown to increase with fertility level as recommended dose of fertilizer (125%) significantly increased chlorophyll content (Pandey *et al*., 2020). Concurrently, Kubota *et al*. (2015), found maize leaves SPAD values enhanced by intercropping with leguminous crops. Nitrogen is an essential component of chlorophyll synthesis; the nitrogen status of a crop may be determined using chlorophyll concentration. Sole chickpea at Syferkuil and mungbean at UNIVEN exhibited higher chlorophyll content in their leaves at vegetative stage and started decreasing at flowering, this can also be supported by Pandey *et al*. (2020), where sole soybean showed greater chlorophyll content during observational stages which may have correlated with the soil nitrogen content.

The observed results of plant vigour amongst the treatments varied significantly during growing stages at both locations. The sole crop of SC (0.47) had greater vigour than its intercrop and *vice versa* for SMB (0.19) while rainfed sole crops of both treatments were lesser than their intercrops at Syferkuil during vegetative stage. Plant vigour during flowering stage was greater for irrigated and rainfed sole crops than intercrops in SC while SMB intercrops had greater vigour than sole crops. Both irrigated and rainfed sole crop legumes had greater vigour than their intercrops during flowering stage. At UNIVEN, irrigated (0.41) and rainfed (0.37) SC intercrop had higher vigour than sole crops while contrary was observed between SMB intercrop and sole crop during vegetative stage. SC and SMB intercrops under both irrigated and rainfed had greater vigour than sole crops during flowering.

According to Zhalnina *et al*. (2018), vigour indicates plant fitness, and it can be improved by critical interactions between plant roots and rhizosphere microbiome, hence expressing the impact of climatic conditions and soil fertility. The increase of plant vigour with growing stages in this study shows that both locations were suitable environments for maize-chickpea and -mungbean intercropping systems though mungbean came better off chickpea at UNIVEN while contrary was observed at Syferkuil. In a study by Leskovar *et al*. (2016), it was found that greenness index rose from week 1-4 in overall leaves based on the temporal dynamics.

Leaf area index (LAI) observed in this study varied significantly among the treatments at both locations. During vegetative and flowering stages at both locations under irrigated and rainfed plots, SC and SMB intercrops had higher LAI compared to their respective sole crops. In this study, leaf area index of chickpea- and mungbean-maize were greatly increased in the intercrops compared to pure stands. Yang *et al*. (2018), also found great increment in the leaf area index of pea-maize intercropping in 2011 and 2012 years, compared to weighted average of sole maize and sole pea. Furthermore, the maize/soybean canopy exhibited a greater LAI (3.2) than the maize mono-canopy (1.7), which is a positive indicator for evaporation reduction (Kubota *et al*., 2015).

Singh *et al*. (2019), reported greater number of leaves under intercropping which influences better crop canopy and better utilization of solar energy. Allah *et al*. (2014) also reported greater number of leaves per plant in intercropped maize than sole crop. The above-mentioned findings agree with the results of the current study as greater leaf index was found under the intercropped plots than the sole crops. Meena *et al*. (2017), discovered that intercropping maize and beans resulted in a denser canopy growth and greater LAI values, resulting in decreased soil surface evaporation.

Biomass yield

In this study, biomass yield observed varied among the treatments and between both locations. Biomass yield was greater at Syferkuil than UNIVEN and at both locations in sole crops than intercrops among the treatments except mungbean. At Syferkuil, irrigated SC (60) and SMB (40) sole crops had greater biomass compared to their intercrops, 26.04 and 28.36 g/m^2 respectively and the same trend was observed under rainfed plot at Syferkuil. At UNIVEN, irrigated (42.32) and rainfed (26.41) SMB had greater biomass among other legumes in their sole crops and intercrops (Table 4.9). Schmidt *et al*. (2016), found a strong positive correlation between clay, organic matter, and microbial biomass nitrogen soil health indicators and lettuce dry biomass.

Higher fodder or biomass yield of cereals and legumes under intercropping may be associated with greater plant height, number of leaves and length, and stem girth (Pandey *et al*., 2020). However, this was not the case with biomass results observed in this current study as sole legume crops (chickpea and mungbean) had greater biomass yield than their intercrops. Contrary to the findings of current study, Salama and Abdel-Moneim (2021), found a significantly higher total dry matter yield under maize-guar followed by maize-cowpea intercropping treatment. However, several researchers (He *et al*., 2013; Liu *et al*., 2017; and Mas-uda *et al*., 2016), have shown that when maize is intercropped rather than grown alone, dry matter output rises.

4.5 Conclusion

Mungbean crops performed better at UNIVEN whereas chickpea performed better at Syferkuil between the two legumes as monocrops and intercrops. In terms of height, chlorophyll content, plant vigour, and leaf area index; intercrops including maize crops were greater compared to their sole crops. Intercrops of maize at both locations showed greater biomass than sole crops whereas greater biomass in legumes was found among sole crops. Irrigated plot generally performed better than rainfed plot as was observed in varying growth parameters between the plots.

CHAPTER 5

SUMMARY OF FINDINGS, SIGNIFICANCE OF FINDINGS, RECOMMENDATIONS AND CONCLUSIONS

5.1 Summary of findings

The study focused on interactive effects that maize-legume intercropping systems and water regimes have on soil health variables in two ecological regions, Syferkuil and UNIVEN. The effects of maize-chickpea and maize-mungbean under irrigation and rainfed were investigated in order to prove whether they aid in improving soil health variables. Furthermore, the interactive effects of maize-legume intercropping systems and water regimes on plant growth parameters. Soil health results revealed that some parameters such as bulk density and aggregate stability were not significantly affected by the maize-legume intercropping systems while OC, P, and NH_4 were significantly higher in the intercropped plots and pure stand of legumes at both locations than in maize pure stand. However, it was also observed from this study that chickpea performance was better at Syferkuil whereas mungbean was better at UNIVEN. Hence, this could have been brought by variation in soil physicochemical properties coupled with climatic variations between the two agro-ecological regions.

The amounts of some soil chemical properties increased due to performance of intercropping, NH_4 increment could be due to biological nitrogen fixation by legumes as no synthetic or other nitrogenous fertilizers were added. Although there had been increase of other chemical properties in plots incorporated with legumes and slight decrease in maize pure stands, significant effects in terms of maize-legume intercropping systems and water regimes on some health variables such as OM was observed. There had been a variation in SAC among treatments at Syferkuil, however no significant effect was observed whereas it was observed at UNIVEN. It was also observed from this study, that UNIVEN was better in terms of improving some soil health variables compared to Syferkuil although both locations showed some strong positives. Greater amount of EC observed at Syferkuil was due to salts in borehole water used for irrigation although significance was observed between treatments. Significance was also observed in plant growth parameters such as height, vigour, and leaf area index which had increased throughout the two growing stages. Though significance was observed in chlorophyll content, chlorophyll had decreased during flowering stage. Both soil health variables and plant growth parameters were significantly improved by intercropping.

5.2 Significance of findings

The study showed the importance of investigating and understanding interspecific interactions of maize-legume intercropping systems and water regimes on soil health variables. Chickpea in pure stand and intercrop contributed to greater improvement of soil health variables at Syferkuil while mungbean did at UNIVEN. This also shows the complimentary effects between maize and legume in supporting each other for better resource utilization. The study proved the ability and power of legumes to elevate some soil properties and this is a positive approach to safely improve soil fertility and productivity on sustainable basis.

The study also proved that monocropping, as it was seen in sole maize slightly reduced some of the nutrient elements such as P, OC, and NH4 at both locations. So inclusion of legumes was the best strategy to conserve and improve some the nutrients listed above. The study further revealed in objective 1 that irrigation with borehole water at Syferkuil led to increase in soil pH and EC. However, the study was able to show the benefits of intercropping system especially with the newly introduced and less explored legumes in South Africa, especially in Limpopo. Therefore, it is important to understand and investigate the responses of soil health variable under intercropping of such newly introduced legume crops.

5.3 Conclusions

In conclusion, intercropping has been proved to have beneficial effects not only on the soil health variables but also plant growth parameters as it was observed with plant, chlorophyll content, plant vigor, and leaf area index. Intercropping approach has been reported to efficiently influence sustainable agriculture by reserving some soil mineral nutrients. The findings of this study showed that intercropping may have beneficial effects on soil health variables as well as adverse effects on plant growth parameters and biomass yield.

5.4 Recommendations

Farmers in South Africa may adopt and readopt the approach of intercropping as it is of low-cost technology and a better strategy towards sustainable crop production. South African soils have problems of low fertility status and as it proved in several studies across the world that the use inorganic fertilizers is not sustainable and has a long term detrimental effects in causing toxicities in soil agro-ecosystems. Hence, the inclusion of legumes in intercropping has shown to be a sustainable and reliable approach to sustainable means of crop production.

REFERENCES

Aasha, M., Baraka, A.H., Eltayeb, R.M., Nahid, A.A. and Khalil, A. (2017). Effects of Intercropping Pearl Millet with Some Legumes on *Striga Hermonthica* Emergence. *SSRG International Journal of Agriculture and Environmental Science*. 4: 64–72.

Acosta-Martínez, V. and Cotton, J. (2017). Lasting effects of soil health improvements with management changes in cotton-based cropping systems in a sandy soil. *Biology and Fertility of Soils*. 53: 533–546.

Ananthi, T., Amanullah, M.M., Rahman, A. and Al-Tawaha, M.S. (2017). A Review on Maize-Legume Intercropping for Enhancing the Productivity and Soil Fertility for Sustainable Agriculture in India. *Advances in Environmental Biology*. 11: 49–63.

Aslam, M.F., Ellis, P.R., Berry, S.E., Latunde-Dada, G.O. and Sharp, P.A. (2018). Enhancing mineral bioavailability from cereals: Current strategies and future perspectives. *Nutrition Bulletin*. 43: 184–188.

Astiko, W., Ernawati, N.M.L. and Silawibawa, I.P. (2021). The effect of row proportion of maize and soybean intercropping on growth and yield of component crops in sandy soil North Lombok, Indonesia. *Earth and Environmental Science*. 637: 1–5.

Backer, R., Rokem, J.S., Ilangumaran, G., Lamont, J., Praslickova, D., Ricci, E., Subramanian, S. and Smith, D.L. (2018). Plant Growth-Promoting Rhizobacteria: Context, Mechanisms of Action, and Roadmap to Commercialization of Biostimulants for Sustainable Agriculture. *Frontiers in Plant Science*. 9: 1–10.

Bakari, R., Mungai, N., Thuita, M. and Masso, C. (2020). Impact of soil acidity and liming on soybean (*Glycine max*) nodulation and nitrogen fixation in Kenyan soils. *Acta Agriculturae Scandinavica, Section B — Soil and Plant Science*. 70: 667–678.

Baveye, P.C., Schnee, L.S., Boivin, P., Laba, M. and Radulovich, R. (2020). Soil Organic Matter Research and Climate Change: Merely Re-storing Carbon versus Restoring Soil Functions. *Frontiers in Environmental Science*. 8:579904. doi: 10.3389/fenvs.2020.579904

Beukes, C.W., Venter, S.N., Law, I.J., Phalane, F.L. and Steenkamp, E.T. (2013). South African Papilionoid Legumes Are Nodulated by Diverse *Burkholderia* with Unique Nodulation and Nitrogen-Fixation Loci. *PLoS ONE* 8(7): e68406. https://doi.org/10.1371/journal.pone.0068406

Bukovsky-Reyesa, S., Marney E.I. and Blesha, J. (2019). Effects of intercropping and soil properties on root functional traits of cover crops. *Agriculture, Ecosystems and Environment*. 285: 1–10.

Bybee-Finley, K.A. and Ryan, M.R. (2018). Advancing intercropping research and practices in industrialized agricultural landscapes. *Agriculture*. 8, 80.

Chen, P., Du, Q., Liu, X., Zhou, L., Hussain, S. and Lei, L. (2017). Effects of reduced nitrogen inputs on crop yield and nitrogen use efficiency in a long-term maize-soybean relay strip intercropping system. *PLoS ONE* 12(9): e0184503. https://doi.org/10.1371/journal.pone.0184503

Cong, W., Hoffland, E., Li, L., Six, J., Sun, J.H., Bao, X.G., Zhang, F.S. and Van der Werf, W. (2015). Intercropping enhances soil carbon and nitrogen. *Global Change Biology*. 21: 1715–1726.

DAFF. (2012). Planting chickpeas. Department of Agriculture, Fisheries and Forestry August 2012, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/chickpeas/planting.

Dai, J., Qiu, W., Wang, N., Wang, T., Nakanishi, H. and Zuo, Y. (2019). From Leguminosae/Gramineae Intercropping Systems to See Benefits of Intercropping on Iron Nutrition. *Frontier Plant Sciences*. 10:605. doi: 10.3389/fpls.2019.00605.

Dhakal, Y., Meena, R.S. and Kumar, S. (2016). Effect of INM on nodulation, yield, quality and available nutrient status in soil after harvest of green gram. *Legume Research*. 39: 590–594.

Dhakal, Y., Meena, R.S., De, N., Verma, S.K. and Singh, A. (2015). Growth, yield and nutrient content of mungbean (Vigna radiata L.) in response to INM in eastern Uttar Pradesh, India. *Bangladesh Journal of Botany*. 44: 479–482.

Dolijanović, Ž., Oljača, S., Kovačević, D., Simić, M., Momirović, N. and Jovanović, Ž. (2013). Dependence of the productivity of maize and soybean intercropping systems on hybrid type and plant arrangement pattern. *Genetika*. 45: 135–144.

Duchene, O., Vian, J.F. and Celette, F. (2017). Intercropping with legume for agroecological cropping systems: complementarity and facilitation processes and the importance of soil microorganisms. A review. *Agriculture, Ecosystems and Environment*. 240: 148–161.

Dwivedi, A., Dev, I., Kumar, V., Yadav, R.S., Yadav, M. Gupta, D., Singh, A and Tomar, S.S. (2015). Potential Role of Maize-Legume Intercropping Systems to Improve Soil Fertility Status under Smallholder Farming Systems for Sustainable Agriculture in India. *International Journal of Life Sciences Biotechnology and Pharma Research*. 4: 1–3.

Fan, Y., Chen, J., Cheng, Y., Raza, M.A., Wu, X., Wang, Z., Yong, T., Liu, W., Liu, J., Du, J., Shu, K., Yang, W. and Yang, F. (2018) Effect of shading and light recovery on the growth, leaf structure, and photosynthetic performance of soybean in a maize-soybean relay-strip intercropping system. *PLoS ONE*. 13(5): e0198159. https://doi.org/10.1371/journal.pone.0198159.

FAO. (2012). FAOSTAT, Food Supply. Cited October 10, 2013. http://faostat.fao.org/site/345/default.aspx.

Fischer, K., Van den Berg, J. and Mutengwa, C. (2015). Is Bt maize effective in improving South African smallholder agriculture? *South African Journal of Science*. 111(1/2), Art. #a0092, 2 pages. http://dx.doi.org/10.17159/sajs.2015/a009.

Gao, X., Wu, M., Xu, R., Wang, X. and Pan, R. (2014). Root Interactions in a Maize/Soybean Intercropping System Control Soybean Soil-Borne Disease, Red Crown Rot. *PLoS ONE* 9(5): e95031. doi:10.1371/journal.pone.0095031.

Ghosh, M. and Devi, A. (2019). Assessment of crop growth, soil properties and crop yield in an upland acidic soil with inorganic fertilizer blended with organic amendments in summer rice cropping season. *International Journal of Recycling of Organic Waste in Agriculture*. 8: 1–9.

Hauggaard-Nielsen, H. and Jensen, E. (2001). Evaluating pea and barley cultivars for complementarity in intercropping at different levels of soil N availability. *Field Crops Research*, 72: 185e196.

He, Y., Ding, N., Shi, J., Wu, M., Liao, H. and Xu, J. (2013). Profiling of microbial PLFAs: Implications for interspecific interactions due to intercropping which increase phosphorus uptake in phosphorus limited acidic soils. *Soil Biology and Biochemistry*. 57: 625–634.

Huang, X.F., Chaparro, J.M., Reardon, K.F., Zhang, R.F., Shen, Q.R. and Vivanco, J.M. (2014). Rhizosphere interactions: root exudates, microbes, and microbial communities. *Botany*. 92: 267–275.

Jani, A.H.A., Hossain, M.A. and Karim, M.M. (2015). Performance of maize-lentil/chickpea intercropping as influenced by row arrangement. *International Journal of Sustainable Crop Production*. 10: 1–7.

Jensen, E.S., Carlsson, G. and Hauggaard-Nielsen, H. (2020). Intercropping of grain legumes and cereals improves the use of soil N resources and reduces the requirement for synthetic fertilizer N: A global-scale analysis. *Agronomy for Sustainable Development*. 40: 2–8.

Kgopa, P.M., Mashela, P.W. and A. Manyevere. (2017). Treated wastewater quality with respect to heavy metal concentrations in wastewater and borehole water used for irrigation in a semi-arid area, Limpopo Province, South Africa. *Transylvanian Review*. 25: 12–14.

Kim, J., Song, Y., Kim, D.W., Fiaz, M. and Chan Ho Kwon, H.O. (2018). Evaluating different inter-row distance between corn and soybean for optimum growth, production and nutritive value of intercropped forages. *Journal of Animal Science and Technology*. 60: 1–5.

Kocira, A., Staniak, M., Tomaszewska, M., Kornas, R., Cymerman, J., Panasiewicz, K. and Lipi´nska, H. (2020). Legume Cover Crops as One of the Elements of Strategic Weed Management and Soil Quality Improvement. A Review. *Agriculture,* 10: 394.

Kumar, A., Rosinger, C., Chen, H., Protic, S., Bonkowski, M. and Temperton, V.M. (2021). Gone and forgotten: facilitative effects of intercropping combinations did not carry over to affect barley performance in a follow-up crop rotation. *Plant and Soil*. 467:405–419.

Kumar, S., Sheoran, S., Kumar, S.K., Kumar, P. and Meena, R.S. (2016). Drought: a challenge for Indian farmers in context to climate change and variability. *Progressive Research-An International Journal*. 11: 6243–6246.

Layek, J., Anup, D., Ramkrushna, G.I., Venkatesh, A., Verma, B.C., Roy, A., Panwar, A.S. and Ngachan, S.V. (2014). Improving productivity of jhum rice through agronomic management practices. In: Book of abstracts. National seminar on shifting cultivation (jhum) in 21st century: fitness and improvement, p 65.

Layek, J., Das, A., Mitran, T. and Nath, C. (2018). Cereal+Legume Intercropping: An Option for Improving Productivity and Sustaining Soil Health. Legumes for Soil Health and Sustainable Management. Pp.347–386.

Layek, J., Shivakumar, B.G., Rana, D.S., Munda, S. and Lakshman, K. (2012). Growth pattern, physiological indices and productivity of different soybean (Glycine max) based intercrops as influenced by nitrogen nutrition. *Indian Journal of Agronomy*. 57: 349–356.

Leskovar, D., Othman, Y. and Dong, X. (2016). Strip tillage improves soil biological activity, fruit yield and sugar content of triploid watermelon. *Soil and Tillage Research*. 163: 266–273.

Li, C., He, X., Zhu, S., Zhou, H. and Wang, Y. (2009). Crop diversity for yield increase. *PLoS ONE* 4, e8049.

Li, L., Tilman, D., Lambers, H. and Zhang, F.S. (2014). Plant diversity and overyielding: insights from belowground facilitation of intercropping in agriculture. *New Phytologist*. 203: 63–69.

Li, X., Mu, Y., Cheng, Y., Liu, X. and Nian, H. (2013). Effects of intercropping sugarcane and soybean on growth, rhizosphere soil microbes, nitrogen and phosphorus availability. *Acta Physiologiae Plantarum*. 35: 1113–1119.

Liu, M., Han, G. and Zhang, Q. (2019). Effects of Soil Aggregate Stability on Soil Organic Carbon and Nitrogen under Land Use Change in an Erodible Region in Southwest China. *International Journal of Environmental Research and Public Health.* 16: 1–14.

Liu, X., Rahman, T., Song, C. and Yang, F. (2018). Relationships among light distribution, radiation use efficiency and land equivalent ratio in maize-soybean strip intercropping. *Field Crops Research*. 224: 91–101.

Liu, Y.C., Qin, X.M., Xiao, J.X., Li, T., Wei, C.Z., Wei, J.J. and Zheng, Y. (2017). Intercropping influences component and content change of flavonoids in root exudates and nodulation of faba bean. *Journal of Plant Interactions*. 12: 187–192.

Lopes, T., Hatt, S., Xu, Q., Chen, J., Liu, Y. and Francis, F. (2016). Wheat (Triticum aestivum L.)-based intercropping systems for biological pest control. *Pest Management Science*. 72: 2193–2202.

Manasa, P., Maitra, S. and Reddy, M.D. (2018). Effect of summer maize-legume intercropping system on growth, productivity, and competitive ability of crops. *International Journal of Management Technology and Engineering*. 8: 2871–2875.

Manevski, K., Børgesen, C.D., Andersen, M.N. and Kristensen, I.S. (2014). Reduced nitrogen leaching by intercropping maize with red fescue on sandy soils in North Europe: a combined field and modeling study. *Plant and Soil*. DOI:10.1007/s11104-014-2311-6

Mao, L., Zhang, L. and Li, W. (2012). Yield advantage and water saving in maize/pea intercrop. *Field Crops Research*. 138: 11–20.

Mas-uda, M., Kabab, J.S., Oforic, K. and Salifud, G. (2016). Relative Planting Dates Effect on the Agronomic Performance of Maize (*Zea Mays* L.) and Groundnut (*Arachis Hypogea* L) in an Intercrop System. *American Scientific Research Journal for Engineering, Technology, and Sciences*. 16: 262–276.

Masvaya, E.N., Nyamangara, J., Descheemaeker, K. and Giller, K. (2017). Is maize-cowpea intercropping a viable option for smallholder farms in the risky environments of semi-arid southern Africa? *Field Crops Research*. 209: 73–87.

Matusso, J.M.M., Mugwe, J.N. and Mucheru-Muna, M. (2014). Potential role of cereal-legume intercropping systems in integrated soil fertility management in smallholder farming systems of Sub-Saharan Africa. *Research Journal of Agriculture and Environmental Management*. 3: 162–174.

Meena, R.S., Kumar, V., Yadav, G.S. and Mitran, T. (2017). Response and interaction of *Bradyrhizobium japonicum* and Arbuscular mycorrhizal fungi in the soybean rhizosphere: a review. Plant Growth Regulators. Accepted in press.

Meena, R.S., Yadav, R.S., Meena, H., Kumar, S., Meena, Y.K. and Singh, A. (2015). Towards the current need to enhance legume productivity and soil sustainability worldwide: a book review. *Journal of Cleaner Production*. 104: 513–515.

Mimmo, T., Del Buono, D., Terzano, R., Tomasi, N., Vigani, G. and Crecchio, C. (2014). Rhizospheric organic compounds in the soil-microorganism-plant system: their role in iron availability. *European Journal of Soil Science*. 65: 629–642.

Muhammad, Z., Muhammad, N., Thu Huong, P., Waqar, A., Waqas, A., Syed, M.G.S., Sathya, E., Kavanagh, V., Cheema, M., Galagedara, L. and Thomas, R. (2019). The potential of corn-soybean intercropping to improve the soil health status and biomass production in cool climate boreal ecosystems. *Scientific report*. 9: 31–48.

Neina, D. (2019). The Role of Soil pH in Plant Nutrition and Soil Remediation. *Applied and Environmental Soil Science*. https://doi.org/10.1155/2019/5794869.

Nwite, J.N., Njoku, C. and Alu, M.O. (2017). Effects of intercropped legumes with maize (*Zea mays* L.) on chemical properties of soil and grain yield of maize in Abakaliki, Nigeria. *The Nigerian Agricultural Journal*. 48: 1–8.

Nyawade, S.O., Gachene, C.K.K., Karanja, N.N., Gitari, H.I., Schulte-Geldermann, E. and Parker, M.L. (2019). Controlling soil erosion in smallholder potato farming systems using legume intercrops. *Geoderma Regional*. 17: 1–10.

Odhiambo, A.J, Norton, U., C. Omondi, E.O., Ashilenje, D. and Norton, J.B. (2015). Soil Carbon and Nitrogen Mineralization and Crop Parameters in Typical Maize-Bean Intercropping in Western Kenya. *International Journal of Plant and Soil Science*. 5: 127–142.

Odhiambo, A.J., Norton, U., Omondi, C.E., Ashilenje, D. and Norton, J.B. (2015). Soil Carbon and Nitrogen Mineralization and Crop Parameters in Typical Maize-Bean Intercropping in Western Kenya. *International Journal of Plant and Soil Science*. 5: 127–142.

Ogola, J.B.O. (2015). Growth and yield response of chickpea to rhizobium inoculation: productivity in relation to interception of radiation. *Legume Research*. 38: 837–843.

Ogola, J.B.O., Macil, P.J. and Odhiambo, A.J. (2021). Biochar Application and Rhizobium Inoculation Increased Intercepted Radiation and Yield of Chickpea in Contrasting Soil Types. *International Journal of Plant Production*. 15: 1–11.

Ojiem, J., Franke, A., Vanlauwe, B., de Ridder, N. and Giller, K.E. (2014). Benefits of legume–maize rotations: Assessing the impact of diversity on the productivity of smallholders in Western Kenya. *Field Crops Research*. 168: 75–85.

Ozturkmen, A.R., Ramazanoglu, E., Almaca, A. and Çakmakli, M. (2020). Effect of intercropping on soil physical and chemical properties in an olive orchard. *Applied Ecology and Environmental Research*. 18: 7783–7793.

Punyalue, A., Jamjod, S. and Rerkasem, B. (2018). Intercropping Maize with legumes for Sustainable Highland Maize Production. *Mountain Research and Development*. 38: 35–44.

Queensland Department of Primary Industries and Fisheries. (2006). Mungbean varieties and planting. http://www.mungbean.org.au/aboutAMA.htm

Rodriguez, C., Carlsson, G., Englund, J., Flöhr, A., Pelzer, E., Jeuffroy, M., Makowski, D. and Jensen, E.S. (2020). Grain legume-cereal intercropping enhances the use of soil-derived and biologically fixed nitrogen in temperate agroecosystems. A meta-analysis. *European Journal of Agronomy*. 118: 1–9.

Rosenblueth, M., Ormeño-Orrillo, E., López-López, A., Rogel, M.A., Reyes-Hernández, B.J., Martínez-Romero, J.C., Reddy, P.M. and Martínez-Romero, E. (2018). Nitrogen Fixation in Cereals. *Frontiers in Microbiology*. 9:1794.doi: 10.3389/fmicb.2018.01794

Salahin, N., Alam, K., Anwarul, M. and Taher, A. (2017). Effect of Tillage and Residue Retention on Soil Properties and Crop Yields in Wheat-Mungbean-Rice Crop Rotation under Subtropical Humid Climate. *Open Journal of Soil Science*. 7: 1–17.

Salama, H.S.A. and Abdel-Moneim, M.H. (2021). Maximizing Land Use Efficiency and Productivity of Soybean and Fodder Maize Intercrops through Manipulating Sowing Schedule and Maize Harvest Regime. *Agronomy*. 11, 863. https://doi.org/10.3390/agronomy11050863

Savci, S. (2012). An agricultural pollutant: chemical fertilizer. *International Journal Environmental Science and Development*. 3: 73–80.

Schipanski, M.E., Barbercheck, M., Douglas, M.R., Finney, D.M., Haider, K., Kaye, J.P., Kemanian, A.R., Mortensen, D.A., Ryan, M.R. and Tooker, J. (2014). A framework for evaluating ecosystem services provided by cover crops in agro-ecosystems. *Agricultural Systems*. 125: 12–22.

Schmidt, J.E., Bowles, T.M. and Gaudin, A.C.M. (2016). Using Ancient Traits to Convert Soil Health into Crop Yield: Impact of Selection on Maize Root and Rhizosphere Function. *Frontiers of Plant Science*. 7:373. doi: 10.3389/fpls.2016.00373

Seidel, E.P., dos Reis, W., Mottin, M.C., Fey, E. Schneider, A.P.R. and Sustakowski, M.C. (2017). Evaluation of aggregate distribution and selected soil physical properties under maize–jack bean intercropping and gypsum rates. *African Journal of Agricultural Research*, 1–8.

.

Shahrivar, A.A., Hagare, D., Maheshwari, B. and Rahman, M.M. (2020). The effect of irrigation using recycled waters obtained from MBR and IDAL wastewater treatment systems on soil pH and EC under kikuyu grass (Pennisetum clandestinum) production. *Water Science and Technology Water Supply*. 20: 1–8.

Simunji, S., Munyinda, K.L., Lungu, O.I., Mweetwa, A.M. and Phiri, E. (2019). Evaluation of Cowpea (*Vigna unguiculata* L. Walp) Genotypes for Biological Nitrogen Fixation in Maize-cowpea Crop Rotation. *Sustainable Agriculture Research*. 8: 1–10.

Singh, D.G., Kumar, R., Ram, H., Dutta, S., Arjun, M. and Hindoriya, P.S. (2019). Fodder productivity and profitability of different maize and legume intercropping systems. *Indian Journal of Agricultural Sciences*. 89: 1451–1455.

Su, B.Y., Song, Y.X., Song, C. and Cui, L. (2014). Growth and photosynthetic responses of soybean seedlings to maize shading in relay intercropping system in Southwest China. *Photosynthetica*. 52: 1–3.

Subhadip, P., Neha, C., Bohra, J.S., Singh, S.P., Dutta, D., Singh, R.K. and Rakshit, A. (2019). Soil Health in Cropping Systems: An Overview. *Agronomic Crops*. https://doi.org/10.1007/978-981-32-9151-5_4.

Tandzi, L.N. and Mutengwa, C.S. (2020). Estimation of Maize (*Zea mays* L.) Yield Per Harvest Area: Appropriate Methods. *Agronomy*, 10, 29; doi:10.3390/ agronomy10010029.

Tang, X., Zhang, C., Yang, Y., Shen, J., Van der Werf, W. and Zhang, F. (2021). Intercropping legumes and cereals increases phosphorus use efficiency; a meta-analysis. *Plant and Soil*. 460: 89–104.

Tang, X., Zhang, C., Yu, Y., Shen., Wopke, J., Van der Werf, W. and Zhang, F. (2021). Intercropping legumes and cereals increase phosphorus use efficiency; a meta-analysis. *Plant Soil Journals*. 460: 89–104.

Uzoh, I.M., Igwe, C.A., Okebalama, C.B. and Babalola, O.O. (2019). Legume-maize rotation effect on maize productivity and soil fertility parameters under selected agronomic practices in a sandy loam soil. *Scientific Reports* | 9:8539 | https://doi.org/10.1038/s41598-019-43679-5.

Vanlauwe, B., Hungria, M., Kanampiu, F. and Giller, K.E. (2019). The role of legumes in the sustainable intensification of African smallholder agriculture: Lessons learnt and challenges for the future. *Agriculture, Ecosystems and Environment*. 284: 1–4.

Von Cossel, M., Wagner, M., Lask, J., Magenau, E., Bauerle, A., Von Cossel, V., Warrach-Sagi, K. and Winkler, B. (2019). Prospects of Bioenergy Cropping Systems for A More Social-Ecologically Sound Bioeconomy. *Agronomy*. 9, 605.

Wang, Y., Qin, Y., Chai, Q., Feng, F., Zhao, C. and Yu, A. (2018). Interspecies Interactions in Relation to Root Distribution across the Rooting Profile in Wheat-Maize Intercropping Under Different Plant Densities. *Frontier Plant Sciences*. 9:483. doi: 10.3389/fpls.2018.00483

Wang, Z.G., Jin, X., Bao, X.G., Li, X.F. and Zhao, J.H. (2014) Intercropping Enhances Productivity and Maintains the Most Soil Fertility Properties Relative to Sole Cropping. *PLoS ONE.* 9(12): e113984. doi:10.1371/journal.pone. 0113984.

Weerarathne, L.V.Y., Marambe, B. and Chauhan, B.S. (2017). Does intercropping play a role in alleviating weeds in cassava as a non-chemical tool of weed management? – A review. *Crop Protection*. 95: 81–88.

Woliy, K., Degefu, T. and Frostegård, Å. (2019). Host Range and Symbiotic Effectiveness of N2O Reducing Bradyrhizobium Strains. *Frontiers in Microbiology*. 10:2746. doi: 10.3389/fmicb.2019.0274

Xu, Q., Xiong, K., Chi, Y. and Song, S. (2021). Effects of Crop and Grass Intercropping on the Soil Environment in the Karst Area. *Sustainability*. 13, 5484. https://doi.org/10.3390/su13105484.

Yadav, G.S., Lal, R., Meena, R.S., Babu, S., Das, A., Bhomik, S.N., Datta, M., Layak, J. and Saha, P. (2017). Conservation tillage and nutrient management effects on productivity and soil carbon sequestration under double cropping of rice in North Eastern Region of India. *Ecological Indicators*. 105: 303–315.

Yang, C., Fan, Z. and Chai, Q. (2018). Agronomic and Economic Benefits of Pea/Maize Intercropping Systems in Relation to N Fertilizer and Maize Density. *Agronomy*. 8, 52; doi: 10.3390/agronomy8040052.

Yang, C., Fan, Z., and Chai, Q. (2018). Agronomic and Economic Benefits of Pea/Maize Intercropping Systems in Relation to N Fertilizer and Maize Density. *Agronomy* 2018, 8, 52; doi: 10.3390/agronomy8040052.

Yang, T., Siddique, K.H.M. and Liu, K. (2020). Cropping systems in agriculture and their impact on soil health-A review. *Global Ecology and Conservation*. 23: 1–10.

Zhalnina, K., Louie, K.B., Hao, Z., Mansoori, N., da Rocha, U.N. and Shi, S. (2018). Dynamic root exudate chemistry and microbial substrate preferences drive patterns in rhizosphere microbial community assembly. *Nature Microbiology*. 3: 470–480.

Zhang, G., Yang, Z. and Dong, S. (2012). Interspecific competitiveness affects the total biomass yield in an alfalfa and corn intercropping system. *Field Crop Resources* 124: 66–73.

Zhao, S., Li, K., Zhou, W., Qiu, S., Huang, S. and He, P. (2016). Changes in soil microbial community, enzyme activities and organic matter fractions under long-term straw return in north-central China. *Agriculture, Ecosystems and Environment*. 216: 82–88.

APPENDICES

Appendices of soil health variables of maize-legume intercropping systems at Mankweng and Thohoyandou.

Appendix 3.1: ANOVA for Bulk density of maize-legume intercropping in Syferkuil

Source	DF	SS	MS	F	P
Rep	2	4,523	2,26152		
Factor	1	0,0137	0,01365	0,06	0,8266
Error Rep*Factor	2	0,4402	0,22012		
Treatment	4	2,4343	0,60857	1,29	0,3154
Factor*Treatment	4	1,9911	0,49778	1,06	0,4103
Error Rep*Factor*Treatment	16	7,5485	0,47178		
Total	29	16,9509			

Appendix 3.2: ANOVA for Bulk density of maize-legume intercropping in UNIVEN

Source	DF	SS	MS	F	P
Rep	2	1,6422	0,82111		
Factor	1	1,3782	1,37816	64,81	0,0151
Error Rep*Factor	2	0,0425	0,02126		
Treatment	4	1,6394	0,40985	1,13	0,3755
Factor*Treatment	4	2,4738	0,61846	1,71	0,1965
Error Rep*Factor*Treatment	16	5,7801	0,36126		
Total	29	12,9562			

Appendix 3.3: ANOVA for Aggregate stability of maize-legume intercropping in Syferkuil

Source	DF	SS	MS	F	P
Rep	2	0,00141	7,03E-04		
Factor	1	0,0012	1,20E-03	1,15	0,3952
Error Rep*Factor	2	0,00209	1,04E-03		
Treatment	4	0,00289	7,22E-04	1,66	0,2092
Factor*Treatment	4	0,00158	3,95E-04	0,91	0,4836
Error Rep*Factor*Treatment	16	0,00697	4,36E-04		
Total	29	0,01614			

Appendix 3.4: ANOVA for Aggregate stability of maize-legume intercropping in UNIVEN

Source	DF	SS	MS	F	P
Rep	2	0,00321	1,60E-03		
Factor	1	0,00261	2,61E-03	21,19	0,0441
Error Rep*Factor	2	0,00025	1,23E-04		
Treatment	4	0,00382	9,55E-04	1,82	0,1751
Factor*Treatment	4	0,00389	9,72E-04	1,85	0,1691
Error Rep*Factor*Treatment	16	0,00841	5,26E-04		
Total	29	0,02219			

Appendix 3.5: ANOVA for soil pH (KCl) of maize-legume intercropping in Syferkuil

Source	DF	SS	MS	F	P
Rep	2	0,08834	0,04417		
Factor	1	0,42721	0,42721	51,83	0,0188
Error Rep*Factor	2	0,01649	0,00824		
Treatment	4	0,22105	0,05526	3,19	0,0417
Factor*Treatment	4	0,48329	0,12082	6,98	0,0019
Error Rep*Factor*Treatment	16	0,27711	0,01732		
Total	29	1,51348			

Appendix 3.6: ANOVA for pH (KCl) of maize-legume intercropping in UNIVEN

Source	DF	SS	MS	F	P
Rep	2	0,05853	0,02926		
Factor	1	0,15987	0,15987	8,17	0,1037
Error Rep*Factor	2	0,03914	0,01957		
Treatment	4	0,10575	0,02644	1,04	0,4177
Factor*Treatment	4	0,20411	0,05103	2,01	0,1422
Error Rep*Factor*Treatment	16	0,40713	0,02545		
Total	29	0,97454			

Appendix 3.7: ANOVA for pH (H_2O) of maize-legume intercropping in Syferkuil

Source	DF	SS	MS	F	P
Rep	2	0,02493	0,01246		
Factor	1	0,003	0,003	0,13	0,7552
Error Rep*Factor	2	0,04706	0,02353		
Treatment	4	0,02469	0,00617	0,35	0,843
Factor*Treatment	4	0,06223	0,01556	0,87	0,5021
Error Rep*Factor*Treatment	16	0,28548	0,01784		
Total	29	0,44739			

Appendix 3.8: ANOVA for pH (H_2O) of maize-legume intercropping in UNIVEN

Source	DF	SS	MS	F	P
Rep	2	0,02261	0,0113		
Factor	1	0,11532	0,11532	50,36	0,0193
Error Rep*Factor	2	0,00458	0,00229		
Treatment	4	0,09715	0,02429	5,48	0,0057
Factor*Treatment	4	0,13038	0,03259	7,35	0,0015
Error Rep*Factor*Treatment	16	0,07095	0,00443		
Total	29	0,44099			

Appendix 3.9: ANOVA for Electrical conductivity of maize-legume intercropping in Syferkuil

Source	DF	SS	MS	F	P
Rep	2	445,71	222,85		
Factor	1	1242,41	1242,41	12,8	0,07
Error Rep*Factor	2	194,17	97,09		
Treatment	4	1153,75	288,44	1,64	0,2141
Factor*Treatment	4	936,75	234,19	1,33	0,3023
Error Rep*Factor*Treatment	16	2822,36	176,4		
Total	29	6795,15			

Appendix 3.10: ANOVA for Electrical conductivity of maize-legume intercropping in UNIVEN

Source	DF	SS	MS	F	P
Rep	2	519,29	259,645		
Factor	1	34,93	34,927	0,41	0,5859
Error Rep*Factor	2	168,71	84,356		
Treatment	4	276,71	69,177	0,64	0,6384
Factor*Treatment	4	294,47	73,617	0,69	0,6118
Error Rep*Factor*Treatment	16	1716,27	107,267		
Total	29	3010,38			

Appendix 3.11: ANOVA for organic carbon of maize-legume intercropping in Syferkuil

Source	DF	SS	MS	F	P
Rep	2	0,32701	0,1635		
Factor	1	1,31043	1,31043	1,92	0,3006
Error Rep*Factor	2	1,36838	0,68419		
Treatment	4	3,34655	0,83664	8,37	0,0008
Factor*Treatment	4	0,95209	0,23802	2,38	0,0951
Error Rep*Factor*Treatment	16	1,59988	0,09999		
Total	29	8,90434			

Appendix 3.12: ANOVA for organic carbon of maize-legume intercropping in UNIVEN

Source	DF	SS	MS	F	P
Rep	2	2,941	1,4705		
Factor	1	0,7776	0,7776	0,63	0,5106
Error Rep*Factor	2	2,4687	1,2343		
Treatment	4	89,035	22,2587	100,77	0
Factor*Treatment	4	0,9972	0,2493	1,13	0,378
Error Rep*Factor*Treatment	16	3,5342	0,2209		
Total	29	99,7536			

Appendix 3.13: ANOVA for organic matter of maize-legume intercropping in Syferkuil

Source	DF	SS	MS	F	P
Rep	2	2,0167	1,0084		
Factor	1	16,875	16,875	45,23	0,0214
Error Rep*Factor	2	0,7462	0,3731		
Treatment	4	34,1452	8,5363	71,73	0
Factor*Treatment	4	0,6364	0,1591	1,34	0,2992
Error Rep*Factor*Treatment	16	1,9041	0,119		
Total	29	56,3236			

Appendix 3.14: ANOVA for organic matter of maize-legume intercropping in UNIVEN

Source	DF	SS	MS	F	P
Rep	2	3,275	1,6375		
Factor	1	0,187	0,1872	0,25	0,6664
Error Rep*Factor	2	1,495	0,7474		
Treatment	4	121,198	30,2996	16,81	0
Factor*Treatment	4	9,131	2,2828	1,27	0,3239
Error Rep*Factor*Treatment	16	28,845	1,8028		
Total	29	164,132			

Appendix 3.15: ANOVA for Phosphorus of maize-legume intercropping in Syferkuil

Source	DF	SS	MS	F	P
Rep	2	0,17318	0,08659		
Factor	1	0,08856	0,08856	0,34	0,6179
Error Rep*Factor	2	0,51793	0,25896		
Treatment	4	1,32229	0,33057	1,27	0,3217
Factor*Treatment	4	0,29255	0,07314	0,28	0,8857
Error Rep*Factor*Treatments	16	4,15776	0,25986		
Total	29	6,55227			

Appendix 3.16: ANOVA for Phosphorus of maize-legume intercropping in UNIVEN

Source	DF	SS	MS	F	P
Rep	2	0,0918	0,0459		
Factor	1	0,1456	0,1456	5,1	0,1526
Error Rep*Factor	2	0,0571	0,0286		
Treatment	4	96,1207	24,0302	357,32	0
Factor*Treatment	4	1,8542	0,4635	6,89	0,002
Error Rep*Factor*Treatment	16	1,076	0,0673		
Total	29	99,3454			

Appendix 3.17: ANOVA for Ammonium of maize-legume intercropping in Syferkuil

Source	DF	SS	MS	F	P
Rep	2	75,767	37,8833		
V001	1	1,82	1,8204	0,34	0,6207
Error Rep*Factors	2	10,835	5,4174		
Treatment	4	114,02	28,5049	4,83	0,0096
Factor*Treatment	4	94,204	23,551	3,99	0,0197
Error Rep*Factor*Treatment	16	94,471	5,9045		
Total	29	391,117			

Appendix 3.18: ANOVA for Ammonium of maize-legume intercropping in UNIVEN

Source	DF	SS	MS	F	P
Rep	2	1,318	0,6588		
Factor	1	5,267	5,2668	13,31	0,0676
Error Rep*Factor	2	0,791	0,3956		
Treatment	4	351,74	87,9349	69,44	0
Factor*Treatment	4	7,245	1,8112	1,43	0,2693
Error Rep*Factor*Treatment	16	20,26	1,2663		
Total	29	386,62			

Appendix 3.19: ANOVA for Nitrate of maize-legume intercropping in Syferkuil

Source	DF	SS	MS	F	P
Rep	2	0,23329	0,11664		
Factor	1	0,192	0,192	1,22	0,3842
Error Rep*Factor	2	0,31434	0,15717		
Treatment	4	0,29479	0,0737	0,66	0,6283
Factor*Treatment	4	0,90467	0,22617	2,03	0,1389
Error Rep*Factor*Treatment	16	1,78531	0,11158		
Total	29	3,72439			

Appendix 3.20: ANOVA for Nitrate of maize-legume intercropping in UNIVEN

Source	DF	SS	MS	F	P
Rep	2	0,00434	0,00217		
Factor	1	0,034	0,034	1,67	0,3249
Error Rep*Factor	2	0,04061	0,0203		
Treatment	4	3,59409	0,89852	77,55	0
Factor*Treatment	4	0,04985	0,01246	1,08	0,4011
Error Rep*Factor*Treatment	16	0,18539	0,01159		
Total	29	3,90827			

Appendix 3.21: ANOVA for active carbon of maize-legume intercropping in Syferkuil

Source	DF	SS	MS	F	P
Rep	2	329564	164782		
Factor	1	554374	554374	1,22	0,385
Error Rep*Factor	2	911241	455621		
Treatments	4	1504753	376188	0,28	0,8846
Factor*Treatment	4	2332241	583060	0,44	0,7787
Error Rep*Factor*Treatment	16	2,13E+07	1328552		
Total	29	2,69E+07			

Appendix 3.22: ANOVA for Active carbon of maize-legume intercropping in UNIVEN

Source	DF	SS	MS	F	P
Rep	2	524240	262120		
Factor	1	1327485	1327485	3,26	0,2128
Error Rep*Factor	2	814771	407386		
Treatment	4	5944725	1486181	2,21	0,1141
Factor*Treatment	4	1076329	269082	0,4	0,8058
Error Rep*Factor*Treatment	16	1,08E+07	672790		
Total	29	2,05E+07			

Appendix 3.23: ANOVA for potentially mineralizable nitrogen (PMN) of maize-legume intercropping in Syferkuil

Source	DF	SS	MS	F	P
Rep	2	0,00773	0,00386		
Factor	1	0,66901	0,66901	53,08	0,0183
Error Rep*Factor	2	0,02521	0,0126		
Treatments	4	0,00113	0,00028	0,02	0,9993
Factor*Treatment	4	0,00332	0,00083	0,05	0,9941
Error Rep*Factor*Treatment	16	0,24807	0,0155		
Total	29	0,95447			

Appendix 3.24: ANOVA for Potentially mineralizable nitrogen of maize-legume intercropping in UNIVEN

Source	DF	SS	MS	F	P
Rep	2	0,02017	0,01008		
Factor	1	0,07301	0,07301	7,43	0,1123
Error Rep*Factor	2	0,01965	0,00982		
Treatment	4	0,08195	0,02049	1,55	0,2346
Factor*Treatment	4	0,09215	0,02304	1,75	0,1891
Error Rep*Factor*Treatment	16	0,21105	0,01319		
Total	29	0,49799			

Appendices of plant growth parameters of maize-legume intercropping systems in Mankweng and Thohoyandou.

Appendix 4.1: ANOVA for plant height during vegetative stage in maize-legume intercropping systems in Syferkuil

Source	DF	SS	MS	F	P
REP	2	180,1	90,03		
FCT	1	447,8	447,79	9,76	0,089
Error REP*FCT	2	91,8	45,89		
TRT	6	31962,3	5327,05	169,97	0
FCT*TRT	6	1063,7	177,28	5,66	0,0009
Error REP*FCT*TRT	24	752,2	31,34		
Total	41	34497,8			

Appendix 4.2: ANOVA for plant height during flowering stage in maize-legume intercropping systems in Syferkuil

Source	DF	SS	MS	F	P
REP	2	289	144,3		
FCT	1	532	532,1	5,54	0,1429
Error REP*FCT	2	192	96,1		
TRT	6	103919	17319,9	207,69	0
FCT*TRT	6	553	92,2	1,11	0,3879
Error REP*FCT*TRT	24	2001	83,4		
Total	41	107487			

Appendix 4.3: ANOVA for plant height during vegetative stage in maize-legume intercropping systems in UNIVEN

Source	DF	SS	MS	F	P
REP	2	46,4	23,2		
FCT	1	567,5	567,5	3,81	0,1903
Error REP*FCT	2	298,1	149,1		
TRT	6	62157,8	10359,6	109	0
FCT*TRT	6	704	117,3	1,23	0,3239
Error REP*FCT*TRT	24	2281,1	95		
Total	41	66054,8			

Appendix 4.4: ANOVA for plant height during flowering stage in maize-legume intercropping systems in UNIVEN

Source	DF	SS	MS	F	P
REP	2	90	45,1		
FCT	1	200	199,5	2,33	0,2668
Error REP*FCT	2	172	85,8		
TRT	6	184746	30791	79,86	0
FCT*TRT	6	873	145,4	0,38	0,8862
Error REP*FCT*TRT	24	9253	385,6		
Total	41	195333			

Appendix 4.5: ANOVA for chlorophyll content during vegetative stage in maize-legume intercropping systems in Syferkuil

Source	DF	SS	MS	F	P
REP	2	116,25	58,125		
FCT	1	33,71	33,715	1,33	0,3682
Error REP*FCT	2	50,74	25,372		
TRT	6	2824,93	470,822	19,91	0
FCT*TRT	6	91	15,167	0,64	0,6963
Error REP*FCT*TRT	24	567,63	23,651		
Total	41	3684,27			

Appendix 4.6: ANOVA for chlorophyll content during flowering stage in maize-legume intercropping systems in Syferkuil

Source	DF	SS	MS	F	P
REP	2	1419,5	709,77		
FCT	1	264,3	264,25	0,25	0,6693
Error REP*FCT	2	2152,5	1076,24		
TRT	6	3927,7	654,62	1,74	0,1549
FCT*TRT	6	2209,8	368,31	0,98	0,4609
Error REP*FCT*TRT	24	9030	376,25		
Total	41	19003,8			

Appendix 4.7: ANOVA for chlorophyll content during vegetative stage in maize-legume intercropping systems in UNIVEN

Source	DF	SS	MS	F	P
REP	2	78,45	39,227		
FCT	1	120,06	120,058	16,77	0,0548
Error REP*FCT	2	14,32	7,16		
TRT	6	4729,91	788,318	23,28	0
FCT*TRT	6	133,91	22,318	0,66	0,683
Error REP*FCT*TRT	24	812,87	33,87		
Total	41	5889,52			

Appendix 4.8: ANOVA for chlorophyll content during flowering stage in maize-legume intercropping systems in UNIVEN

Source	DF	SS	MS	F	P
REP	2	21,29	10,64		
FCT	1	55,45	55,45	1,64	0,3293
Error REP*FCT	2	67,81	33,9		
TRT	6	7057,74	1176,29	35,57	0
FCT*TRT	6	1124,83	187,47	5,67	0,0009
Error REP*FCT*TRT	24	793,62	33,07		
Total	41	9120,74			

Appendix 4.9: ANOVA for plant vigour during vegetative stage in maize-legume intercropping systems in Syferkuil

Source	DF	SS	MS	F	P
REP	2	0,01495	0,00747		
FCT	1	0,00549	0,00549	2,97	0,2272
Error REP*FCT	2	0,0037	0,00185		
TRT	6	1,68696	0,28116	118,34	0
FCT*TRT	6	0,03345	0,00557	2,35	0,0633
Error REP*FCT*TRT	24	0,05702	0,00238		
Total	41	1,80156			

Appendix 4.10: ANOVA for plant vigour during flowering stage in maize-legume intercropping systems in Syferkuil

Source	DF	SS	MS	F	P
REP	2	0,00943	0,00472		
FCT	1	0,01761	0,01761	3,39	0,2068
Error REP*FCT	2	0,01038	0,00519		
TRT	6	1,15099	0,19183	75,49	0
FCT*TRT	6	0,00599	0,001	0,39	0,8763
Error REP*FCT*TRT	24	0,06099	0,00254		
Total	41	1,25539			

Appendix 4.11: ANOVA for plant vigour during vegetative stage in maize-legume intercropping systems in UNIVEN

Source	DF	SS	MS	F	P
REP	2	0,002	0,001		
FCT	1	0,0378	0,0378	4,31	0,1734
Error REP*FCT	2	0,01753	0,00876		
TRT	6	1,27325	0,21221	32,69	0
FCT*TRT	6	0,12107	0,02018	3,11	0,0213
Error REP*FCT*TRT	24	0,1558	0,00649		
Total	41	1,60745			

Appendix 4.12: ANOVA for plant vigour during flowering stage in maize-legume intercropping systems in UNIVEN

Source	DF	SS	MS	F	P
REP	2	0,00063	0,00032		
FCT	1	0,02194	0,02194	38,89	0,0248
Error REP*FCT	2	0,00113	0,00056		
TRT	6	0,34343	0,05724	19,1	0
FCT*TRT	6	0,02072	0,00345	1,15	0,3634
Error REP*FCT*TRT	24	0,0719	0,003		
Total	41	0,45976			

Appendix 4.13: ANOVA for leaf area index during vegetative stage in maize-legume intercropping systems in Syferkuil

Source	DF	SS	MS	F	P
REP	2	0,1206	0,06029		
FCT	1	0,3242	0,32419	12,88	0,0696
Error REP*FCT	2	0,0503	0,02516		
TRT	6	11,0004	1,83341	146,85	0
FCT*TRT	6	0,1347	0,02245	1,8	0,142
Error REP*FCT*TRT	24	0,2996	0,01248		
Total	41	11,9299			

Appendix 4.14: ANOVA for leaf area index during flowering stage in maize-legume intercropping systems in Syferkuil

Source	DF	SS	MS	F	P
REP	2	0,2704	0,1352		
FCT	1	0,1418	0,14175	1,09	0,4058
Error REP*FCT	2	0,2597	0,12984		
TRT	6	18,9201	3,15335	88,7	0
FCT*TRT	6	0,9886	0,16477	4,63	0,0029
Error REP*FCT*TRT	24	0,8533	0,03555		
Total	41	21,4338			

Appendix 4.15: ANOVA for leaf area index during vegetative stage in maize-legume intercropping systems in UNIVEN

Source	DF	SS	MS	F	P
REP	2	0,1157	0,05784		
FCT	1	0,101	0,10104	2,53	0,253
Error REP*FCT	2	0,08	0,04001		
TRT	6	20,8206	3,47011	171,12	0
FCT*TRT	6	0,108	0,01799	0,89	0,5194
Error REP*FCT*TRT	24	0,4867	0,02028		
Total	41	21,712			

Appendix 4.16: ANOVA for leaf area index during flowering stage in maize-legume intercropping systems in UNIVEN

Source	DF	SS	MS	F	P
REP	2	0,0689	0,03447		
FCT	1	0,0797	0,07974	1,09	0,4068
Error REP*FCT	2	0,1468	0,07342		
TRT	6	40,8811	6,81352	203,5	0
FCT*TRT	6	0,3968	0,06614	1,98	0,1092
Error REP*FCT*TRT	24	0,8035	0,03348		
Total	41	42,377			

Appendix 4.17: ANOVA for biomass yield in maize-legume intercropping systems in Syferkuil

Source	DF	SS	MS	F	P
REP	2	12814	6407		
FCT	1	4466	4466	0,98	0,336
TRT	4	1086578	271645	59,44	0
FCT*TRT	4	12590	3148	0,69	0,6091
Error	18	82262	4570		
Total	29	1198710			

Appendix 4.18: ANOVA for biomass yield in maize-legume intercropping systems at Thohoyandou

Source	DF	SS	MS	F	P
REP	2	2449	1224,5		
FCT	1	3250	3250,2	0,68	0,4221
TRT	4	398916	99729	20,71	0
FCT*TRT	4	7663	1915,8	0,4	0,8075
Error	18	86669	4815		
Total	29	498948			