EFFECT OF SUMMER AND WINTER ROTATIONS ON SELECTED SOIL PROPERTIES AND PRODUCTIVITY OF SUCCEEDING WINTER CHICKPEA (*CICER ARIETINUM* L.).

BY

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DECLARATION

I, the undersigned, Nnana Magdeline Kgobe, (student no: 18007405), hereby declare that this Dissertation for Master of Science (MSc.) in Agriculture (Plant Production) submitted to the Department of Plant Production, School of Agriculture, University of Venda has not been previously submitted by me or anybody for a degree at this or any other university. Also, this is my work in design and in execution, and related materials contained herein have been duly acknowledged.

18/08/2020

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As the supervisor/co-supervisor of the candidate, we agree to the submission of this dissertation.

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DEDICATION

I dedicate this Dissertation to my mother Mrs. Winnie Kgobe, for her love, support and encouragement. Thank you for always believing in me.

ABSTRACT

Chickpea (*Cicer arietinum* L.) is one of the minor pulse crops in South Africa, but there is hardly any commercial chickpea production in South Africa and the rest of Southern Africa despite its increasing domestic demand. The country meets its domestic demand through imports. Preliminary research has shown the potential of winter sowing of chickpea in rotation with summer crops in the dry environments of Limpopo Province, South Africa. This has provided an opportunity for development of summer and winter crop rotation in the semi-arid regions of the Limpopo province, South Africa. There is evidence that crop rotation positively affects physical, chemical and biological properties of the soil consequently increasing the yields in the long run. Therefore, this study assessed the residual effect of summer and winter crop rotations on selected soil chemical properties and soil biological health indicators, and productivity of the succeeding winter chickpea.

A field experiment was established during the summer of 2016/17 to determine the effects of summer and winter crop rotations on selected soil chemical properties, biological health indicators, and yield performance at the University of Venda, South Africa. The current study was based on two winter seasons i.e. 2017 and 2018 focusing on chickpea crop. Experimental materials consisted of summer crops [maize (*Zea mays*), bambara groundnut (*Vigna subterranea*), cowpea (*Vigna unguiculata*), mung bean (*Vigna radiata*)], fallow and winter crops [chickpea - mustard (*Brassica rapa*)] and combination treatments consisting of summer-winter crop rotations. The field experiments were laid out in a randomized complete block design (RCBD) with three replicates. Seeds were inoculated and sown manually at intra-row spacing of 10 cm and inter-row spacing of 30 cm. Single superphosphate (10.5% P) fertilizer was applied at planting at a recommended rate of 90 kg P ha^{-1}. Supplemental irrigation was applied whenever necessary. Plots were kept weed-free throughout the growing seasons.

Soil samples were collected at depths of 0–20, and 20–40 cm prior to planting (experiment I) and after harvesting (experiment II) in 2018. The following chemical properties were determined: soil reaction (pH), cation exchange capacity (CEC), exchangeable bases (M^{2+}, Ca^{2+}, Na^{+}, K^{+}), available P, and (NO_3^-) nitrate. Soil biological indicators that were analysed include soil active carbon (AC), organic carbon (OC), (NH_4^+) ammonium and potentially mineralizable nitrogen (PMN). Crop phenology (days to 50% emergence, flowering, and podding) and crop growth (plant height, canopy cover, number of primary and secondary branches) were determined at various crop growth stages. Grain yield and yield components (number of pods per plant, number of seeds per pod and 100 seed weight [100-SW]) were determined at maturity. The data (various agronomic and soil laboratory) obtained were subjected to analyses of variance (ANOVA) using the general linear model (GLM) of Genstat software version 18 to examine the effects of treatments on selected soil properties and crop productivity. Significant differences between treatment means were compared using the standard error of difference (SED) of the means at 5% level. Independent samples t-test was used to compare the differences between experiments and soil depths. Correlation analyses were conducted to assess the relationship between the various parameters measured.

Crop rotations did not affect soil pH, CEC, exchangeable cations, P, K and NO_3^- in both experiment I and II. However, relatively greater soil NO_3^- and P values were recorded in experiment II compared to experiment I. Similarly, crop rotations had no significant effect on soil AC, OC, NH_4^+ and PMN in both experiments. Soil organic carbon remained relatively constant across all the soil depths (0-20 cm and 20-40 cm) in experiment I, however, there was an increase in experiment II. There was a statistical difference between experiments on mean soil NH_4^+, greater mean soil NH_4^+ values were reported in experiment II in comparison to experiment I. There was no response of crop phenology and growth with respect to crop rotations in both growing seasons (2017 & 2018). However, the crop flowered earlier in 2018 compared to 2017, and the tallest plants were measured in 2017 compared to 2018 growing season. In contrast, 2018 growing season resulted in greater grain yield (1654 kg ha^{-1}) than the 2017 growing season (1319 kg ha^{-1}); for treatments there was no statistical difference found. A similar trend was found with number of pods per plant. There was no significant difference in 100 SW and number of seeds per pod. Based on the current results it can be concluded that crop rotations are generally less effective at improving soil properties and crop productivity in the short term. Many of the chemical and biological attributes of soil quality are stable and their manifestation is experimentally verifiable only over extended periods. Therefore, a study with a more prolonged period would provide useful insight, hence the importance of long-term studies.

Keywords: *Winter chickpea, summer-winter rotation, long-term, soil properties*

Table of contents

Contents **Page**

LIST OF ABBREVIATIONS

100 SW	100 Seed Weight
AC	Active carbon
AAS	Atomic Absorption Spectrometry
ANOVA	Analysis of variance
AMF	Arbuscular mycorrhizal fungi
BNF	Biological Nitrogen Fixation
CEC	Cation Exchange Capacity
DAE	Days after emergence
EC	Electrical Conductivity
FAO	Food and Agriculture Organization of the United Nations
GLM	General Linear Model
H_2O	Water
K	Potassium
KCl	Potassium chloride
N	Nitrogen
OC	Organic Carbon
P	Phosphorus
PGPR	Plant Growth Promoting Rhizobacteria
PMN	Potentially minerillizable nitrate
PAR	Photosynthetically Active Radiation
RCBD	Randomized Complete Block Design
SED	Standard Error of the Difference

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

1.1 Background information

Cropping system refers to the sequence and spatial arrangement of crops, or of crops and fallow in a particular land area, as well as their interaction with the environment, technology, and other farm enterprises over a fixed period (Rana and Rana, 2011). Cropping systems greatly influence the environment, and are important components of sustainable agriculture (Janušauskaitė and Velykis, 2010). The most commonly practiced cropping system in the semi-arid regions of Limpopo Province, South Africa, is summer cereal - winter fallow. However, this traditional cropping system is an unsustainable production system; particularly for nitrogen (N) availability. Therefore, there is a need to develop a sound summer-winter cropping system that effectively utilizes the winter fallow, and takes advantage of seasonal opportunities, while consequently sustaining soil productivity, and improving crop productivity of the succeeding summer crops. Preliminary research proposes winter sowing of chickpea in rotation with summer crops in the dry environment of Limpopo Province (Thangwana and Ogola, 2012). Therefore, the aim of the present research was to evaluate the possibility of growing winter chickpea succeeding traditional summer crops.

Maize mono-cropping is still the main practice in most of the summer rainfall areas of South Africa (Nel, 2005), and is generally prompted by economic and market-related considerations. However, there is evidence that monoculture of cereal crops results in soil degradation, increased weed populations, less efficient use of nutrients and low soil fertility leading to low crop productivity (Ramaru *et al.,* 2009). Soil infertility is one of the major constraints threatening sustainable crop production and could lead to food insecurity. Dependence on a small number of agricultural crops such as maize, is leading to reduction in agricultural biodiversity, soil infertility and land degradation. This degradation on soil biodiversity and fertility is one of the pressing concerns and a considerable threat to sustainability of agroecosystems (Ramaru *et al.,* 2009).

Winter fallow is used throughout the semi-arid regions of the Limpopo Province, South Africa. However, cropping systems that consistently employ fallow generally have negative impacts on soil fertility due to both decreased crop residue production and due to tillage used for weed control during the fallow period (Campbell *et al.,* 2000). Despite the negative effect of fallow on soil quality, vast farm-lands in the semi-arid regions of the Limpopo Province are still left fallow during the winter season. This decline in soil fertility and low crop productivity in the Province has led to renewed interest in crop rotation as a practice for economically sustainable grain production (Janušauskaitė and Velykis, 2010). The use of different crop rotation systems can improve soil fertility and crop nutrient absorption efficiency, thus increasing the production potential through nutrient cycling.

In an agricultural system, the harvested produce is the major avenue of nutrient removal. The sustainability of a cropping system is greatly dependent on optimizing the balance between nutrient inputs and outputs (Yadava and Garg, 2011). One way of achieving this balance is by ensuring that nutrients removed from the soil are returned to the system. These nutrients can be replenished by promoting such practices as legume-based crop rotation or applying organic and/or inorganic fertilizer (Yadava and Garg, 2011; Alam *et al.,* 2014). Better utilization of winter fallow by cultivating chickpea could improve soil fertility status, thereby contributing to the long-term sustainability of summer cropping.

Crop rotation is the practice of growing a series of different types of crops in the same area in sequenced seasons, while monoculture is producing or growing a single crop, plant, variety, or breed in a field or farming system at a time (Nel, 2005; Baldwin, 2006). Several beneficial aspects are associated with crop rotation in comparison with monoculture cropping. The positive effect of crop rotation on soil physical, chemical and biological properties and crop productivity are well documented (Moore *et al.,* 2000; Baldwin, 2006; Yusuf *et al.,* 2009; Alam *et al.,* 2014). Despite the well-known benefits of crop rotation, no study has considered the effect of summer-winter chickpea rotation in South Africa, which has proven to be beneficial elsewhere. Summer cereal - winter fallow cropping systems may offer greater scope to address food and nutrition insecurities by growing winter chickpea in rotation with summer crops.

Chickpea is a crop with good potential for South African small-holder farmers and commercial cereal farmers (Madzivhandila *et al.,* 2012). Chickpea can be cultivated in different cropping systems and rotated with other crops. It is a low-input crop and its production demands low external inputs compared to cereals (Sardar, 2011). A major rationale for including chickpea in the cropping systems of the semi-arid environments is its demonstrated potential to improve soil fertility through fixing atmospheric nitrogen, contributing to the sustainability of production and reducing the need for N fertilization (Namvar *et al.,* 2011). Currently, there is hardly any chickpea production in South Africa and the rest of Southern Africa despite the high and increasing domestic demand (Thangwana and Ogola, 2012; FAO, 2016). Therefore chickpea may have a role in the summer-winter cropping system as a replacement of winter fallow. The present study focussed on comprehensive rotation trials involving a range of traditional summer crops commonly grown in the semi-arid regions of the Limpopo Province in rotation with winter chickpea.

1.2 PROBLEM STATEMENT

Most farmlands in the north eastern region of South Africa are cultivated only in summer season and left fallow during the winter season. Moreover, planting only summer crops , and in particular maize as a monocrop, year after year in the same field could result in the build-up of disease causing pathogens, nematodes, insects and weeds that can lead to yield reductions and the need for increased inputs such as herbicides, insecticides and other agrochemicals, and ultimately decrease crop productivity. Legume species such as chickpea (*Cicer arietinum* L.) can be planted in the winter season following the summer crop when the land is often left fallow. Preliminary studies have shown a great potential of winter chickpea in the north eastern region of South Africa. However, there is no available information on the residual effect of summer crops on the succeeding winter chickpea productivity and soil properties.

1.3 JUSTIFICATION

Winter chickpea could effectively utilize the winter fallow, improve crop diversification, and give farmers a second crop, consequently increasing average annual yield and farmer income. The ability of chickpea to fix atmospheric nitrogen in a cropping system is a distinct benefit and has been attributed to nitrogen contribution to the succeeding summer crops. Therefore, including winter chickpea in the cropping system could improve soil fertility status and may reduce the need for nitrogen-rich inorganic fertilizers, thereby contributing to the long-term sustainability of summer cropping. Moreover, cultivation of chickpea in rotation with other crops has been recognized as one of the most cost-effective ways by which farmers can improve soil fertility and reduce the incidence of weeds, diseases and pests.

1.4 HYPOTHESES

- Summer crops would leave some residual effect on the soil and improve crop productivity of the succeeding winter chickpea.
- Summer-winter crop rotation would leave some residual effect on the soil and improve crop productivity of the succeeding winter chickpea.

1.5 OBJECTIVES

The main objectives of the study were to determine the residual effect of:

- Summer crops on succeeding winter chickpea productivity and selected soil properties
- Summer and winter rotation on succeeding winter chickpea productivity and selected soil properties

The specific objectives of the study were to assess the residual effect of summer and winter rotations on:

(i) Selected soil chemical and biological health indicators

(ii) Crop phenology, growth and yield of succeeding winter chickpea

2. CHAPTER 2: LITERATURE REVIEW

2.1. Chickpea origin and distribution

Chickpea (*Cicer arietinum* L.) is one of the most important grain legumes in the world, it is the second most important food legume after field peas (*Pisum sativum*), and constitutes 20% of the world's pulses production (FAO, 2016). It is believed to have originated from South-Eastern Turkey, based on the closely related annual species, *Cicer reticulatum Ladizinsky* and *C. echinospermum* (Ladizisky and Adler, 1975). The earliest remains of chickpea seeds date back to around 7000 BC in Syria and Turkey (van der Maesen, 1987). It was first domesticated in the Middle East, and later spread throughout the Mediterranean region, India and Ethiopia (Duke, 1981). Chickpea is the only cultivated species belonging to the *Cicer* genus (Aggarwal *et al*., 2013). The crop has many local names: hamaz (Arab `world), shimbra (Ethiopia), nohud or lablabi (Turkey), chana (India) and garbanzo (Latin America) (Muehlbauer and Tullu, 1997). The species is grown in over 50 countries throughout the tropical, subtropical and temperate regions in South, West and East Asia, Australia, East and North Africa, North and South America and Southern Europe (FAO, 2016). Chickpea is grown on about 13.2 million hectares of land across the world with an average productivity of 1053 kg ha^{-1}(FAO, 2016). Production of chickpea is expanding in areas where it has been recently introduced, e.g. in Australia, New Zealand, the United States and Canada (FAO, 2016).

In tropical Africa, it is mainly cultivated in East Africa (Sudan, Eritrea, Ethiopia, Kenya, and Tanzania) and in Malawi: where it is grown particularly in areas with a marked cool season (Rao *et al.,* 2011; FAO, 2016). In Kenya main production is in the eastern region in the drier areas of lower Machakos, Mwea, Karaba and Nakuru areas. Ethiopia is the leading chickpea producer in Africa (Rao *et al.,* 2011). Globally, chickpea production has increased over the past 30 years from 6.6 million metric tons to 12 million metric tons, with India being the largest producer, followed by Australia, Pakistan, Turkey, Burma, Iran, Ethiopia, Canada and the United States (FAO, 2016). There is hardly any chickpea production in South Africa (Thangwana and Ogola, 2012; FAO, 2016). The country meets its domestic demand through imports. It imported 2098 tonnes from India in the year 2016 (FAO, 2016). The imported chickpea grain is likely to be costly with a relatively lower nutritional value as is largely the case with most imported food products. A preliminary study has shown a greater chickpea potential in the winter season of the Limpopo province, South Africa (Thangwana and Ogola, 2012). Therefore, this study may encourage self-production of chickpea in South Africa which is likely to contribute towards the gross of the economy.

2.2 Crop description

Chickpea is an annual grain legume or pulse crop that can complete its life cycle in 90-180 days depending on the prevailing environmental conditions. Morphologically, the species comprises of primary, secondary and tertiary branches, resembling a small bush (Gaur *et al.,* 2010). Chickpea has an indeterminate growth habit in which vegetative growth continues even after the start of flowering. Five growth habits based on angles of branches from the vertical are classified: erect, semi-erect, semi-spreading, spreading and prostate (Gaur *et al.,* 2010). There are two types of chickpea; Kabuli and Desi. These types of chickpea are separated on the basis of the seed size, shape, colour and taste (Iqbal *et al.,* 2006). Kabuli has large rounded seeds with smooth white seed coat and grow relatively taller in areas of moderate rainfall. It produces white flowers and sometimes contains one seed per pod (Gaur *et al*., 2010). Desi has small seeds with an angular shape, dark thick seed coat, relatively short in height and is adapted to low rainfall areas. It produces purple or violet flowers and sometimes contains two seeds in one pod which are small and swollen (Iqbal *et al.,* 2006). Chickpea is a self-pollinated crop, with a tap root system and the lateral roots develop nodules with the symbiotic rhizobium bacteria, capable of fixing atmospheric nitrogen for plant use (Gaur *et al*., 2010). Leaves are compound, arranged in an alternate position and having a terminal unpaired leaflet with 11 to 13 leaflets (Iqbal *et al*., 2006).

Figure 1: Morphology of chickpea plant (Source: https://thumbs.dreamstime.com/t/ciclo-del-crecimiento-de-una-planta-garbanzo-aislada-en-un-fondo-blanco-121226396.) Accessed: 10 May 2018.

2.3 Crop Utilization

Chickpea serves as a multi-purpose crop, and it is widely grown for its nutritional potential (Kabbani, 2013), health benefits (Jukanti *et al.,* 2012) and medicinal purposes (Gaur *et al.,* 2010). It is an economical source of quality vegetable protein in human diet and animal nutrition (Kabbani, 2013). It is one of the most important cheap sources of protein food crops especially in developing countries. Consumption of chickpea has some physiological benefits that may reduce the risk of chronic diseases and optimize health. It offers numerous health benefits as it helps in stabilizing blood sugar levels, weight management, improving digestion and minimizing the risk of heart attack (Gaur *et al.,* 2010; Jukanti *et al.,* 2012).

The consumption pattern of chickpea goes with consumer preference; the seed can be consumed raw, roasted or they can be boiled (Rao *et al*., 2011). Dried chickpea seed is commonly used in making soup in India, while in the Middle East and elsewhere, it is more frequently cooked and blended with rice dishes (Jukanti *et al.,* 2012). Chickpea seeds are also added to many dishes to improve their taste, e.g. desserts, salads and soup. It offers a wide application of taste and aroma enhancing products such as sauces, dips, soups and spreads. The green immature seed is used as a snack or vegetable and the dry seed splits and flour are used in a variety of other preparations like stew, cake, samosa, doughnuts and buns (Rao *et al*., 2011). The fresh leaves of the crop are eaten as a vegetable or side dish with the staple food (Jukanti *et al.,* 2012), and are superior to spinach and cabbage in mineral content (Rao *et al*., 2011). In South Africa, the grain is used for human consumption, in the form of Indian dahl (a thick soup used like gravy). Also, the crop can be used in animal feeds (Sardar, 2011). The crop provides a source of energy and proteins to animals, and it has fewer digestive problems in non-ruminants (Bampidis and Christodoulou, 2011).

Chickpea has significant nutritional value; the seed is a good source of carbohydrates (59%), protein (29%), oil (5%), ash (4%), fibre (3%), minerals (calcium, phosphorus, iron) and vitamins (Iqbal *et al.,* 2006). It has all the essential amino acids except sulphur containing types which can be complemented by adding cereals to daily diet (Jukanti *et al.,* 2012). Although lipids are present in low amounts, chickpea is rich in nutritionally important unsaturated fatty acids such as linoleic and oleic acids. Chickpea is a good source of important vitamins such as riboflavin, niacin, thiamine, folate and the vitamin A precursor β-carotene (Jukanti *et al.,* 2012). There is a growing demand for chickpea due to its nutritional value. Therefore, chickpea can potentially be considered as a functional food and may thus be an important food and nutritional security crop for smallholder farmers in the semi-arid regions of Limpopo Province, South Africa.

Apart from its nutritional value, chickpea has the ability of fixing atmospheric nitrogen through symbiotic process and it has been estimated to fix 140 kg N per ha in a growing season (Beck, 1992; Gan *et al.,* 2010; SPG, 2016). Chickpea can be cultivated in different cropping systems and rotated with other crops (Namvar *et al.,* 2011). Obtaining N from legumes is potentially more sustainable than from mineral fertilization. Therefore, chickpea may be an important winter rotational crop for both small-holder and commercial cereal farmers in the semi-arid tropics of Limpopo Province, South Africa.

2.4 Crop rotation system and benefits

Crop rotation refers to the practice of growing a series of different types of crops in the same area in sequenced seasons (e.g. maize-cotton-chickpea or wheat-soybeans), while monoculture is producing or growing a single crop, plant, variety, or breed in a field or farming system at a time (Nel, 2005; Baldwin, 2006). Cropping systems such as crop rotation and monoculture affect soil properties and crop productivity. Crop rotation is the central system of all sustainable farming systems; it is both a system of production and a tool of management (Janušauskaitė and Velykis, 2010). Farmers in ancient times learned from experience that growing the same crop year after year on the same field (monoculture) resulted in low yields and environmental degradation. They shared a common understanding that they could increase crop productivity by cultivating a sequence of different crops over several seasons (Baldwin, 2006). In the past, the field was left fallow to replenish its nutrients, but crop rotation has helped to increase crop productivity by replacing fallow periods with growing different crops that replenish soil nutrients and also generate income (Baldwin, 2006).

Crop rotation was promoted in South Africa in the past; however, during the 1950's and 1960's when it appeared that chemical fertilizers and pesticides could be used as a substitute for crop rotation, monoculture became popular (Crookston *et al.,* 1991). Although these inputs resulted in high crop productivity, uncontrolled usage of them has also caused serious problems concerning human and environmental health such as contamination of the soil and groundwater (Caliskan *et al.,* 2013). Today, there is a growing concern about the environment and increasing demands for more sustainable agricultural production methods. Crop rotation is becoming a more valued cropping system due to changes in the understanding of the effect of cropping systems on the environment and desire for sustainability (Janušauskaitė and Velykis, 2010). Initially, crop rotation was practiced as a way to avoid depleting the soil of various nutrients and to manage pathogens and pests. Today, crop rotation is also an important component of soil health management in many agricultural production systems.

Crop rotations can be as simple as rotating between two crops and planting sequences in alternate years or they can be more complex and involve numerous crops over several years or even at the same time for improved soil health (Gugino *et al.,* 2009). Crop rotation includes both cyclical rotations, in which the same sequence of crops is repeated indefinitely on a field, and noncyclical rotations, in which the sequence of crops varies irregularly to meet the evolving business and management goals of the farmer. Cyclical rotation is the most common rotation practiced in South Africa. Crop rotation practiced in South Africa mainly involves summer soybean, cowpea and dry bean rotated with maize (Nel, 2005; Aziz *et al.,* 2011; Zuber *et al.,* 2015). The most common approach practiced is rotating crops of different families (e.g. traditional cereal-legume rotation), legume-based crop rotation is an effective and often profitable way of supplying N and improving soil properties. Non nitrogen rotation effects are attributed to increase in soil organic matter resulting in improved soil structure, fertility and the addition of growth promoting substances (Zuber *et al.,* 2015). Another approach is rotating heavy feeder crops with light feeders, as well as rotating shallow rooted crops like onions or carrots with deeper rooted crops like maize to recover nutrients that were not utilized by the shallow feeders (Baldwin, 2006). Rotating deep and shallow rooting plants assists in breaking up subsoil and reducing the effects of soil compaction.

Several beneficial aspects are associated with crop rotation in comparison with monoculture cropping. Crop rotation systems are effective in improving soil fertility in terms of its physical, chemical, and biological properties (Moore *et al*., 2000; Sharma and Bhushan, 2001; Crews, 2005; Alam *et al*., 2014), while promoting growth and yield of crops (Velykis and Satkus, 2005; Nel e*t al,* 2003; Nel and Loubser, 2004; Sanginga *et al*., 2002). Crop rotation can also act as an effective disease management tool, particularly if the pathogen has a narrow host range and overwinters in crop residue or soil (Baldwin, 2006). When a non-host is planted, the pathogen is unable to reproduce, inoculum in the soil or previous crop debris gradually dies and over time the inoculum levels are reduced. This will mitigate the build-up of pathogens and pests that often occur when one species is continuously cropped, leading to a reduction in the use of pesticides (Crews, 2005).

Crop rotation helps suppress weeds by including crops that out compete weeds for water, nutrients or sunlight (Baldwin, 2006). Over time, crop rotation can help increase soil organic matter; reduce soil erosion and run-off, resulting in improved soil structure and increased water infiltration (Moore *et al.,* 2000). A well-planned crop rotation system that includes a legume crop will not only contribute to replenishing soil nutrients but also reduce the demand for chemical fertilizers, substantially lowering related greenhouse gas emission (Muthoni and Kabira, 2010)

2.5 Beneficial effect of chickpea in crop rotation

Chickpea is a crop with good potential for South African small-holder farmers and commercial cereal farmers. It may be an important food security crop for smallholder resource poor farmers in the semi-arid tropics of South Africa (Madzivhandila *et al.,* 2012), and serve as an important winter rotational crop for commercial cereal farmers (Thangwana and Ogola, 2012). Also, the crop is drought and heat tolerant (Bekele *et al*., 2007; Thangwana and Ogola, 2012). The ability of chickpea to adapt to environmental stresses such as drought, high temperatures and poor soils provides an opportunity for commercial cereal farmers in semi-arid areas of the Limpopo Province and similar regions in South Africa to rotate winter chickpea with summer crops (Thangwana and Ogola, 2012). Chickpea derives most of its water requirements from residual stored soil moisture (Bekele *et al.,* 2007); therefore, smallholder farmers in the semi-arid areas of South Africa may grow chickpea at the end of the main rainy seasons using residual moisture.

Nitrogen is one of the most limiting nutrients for production in most agricultural systems. The principal benefit attributed to chickpea in crop rotations is their contribution of mineral N to the soil (Beck, 1992: Garg and Chandel 2011). Chickpea can form symbioses with beneficial microorganisms such as arbuscular mycorrhizal fungi (AMF), nitrogen-fixing bacteria such as *Mesorhizobium ciceri* and other plant-growth promoting rhizobacteria (PGPR) (Garg and Chandel 2011); it can fix up to 140 kg N ha^{-1} from symbiotic nitrogen fixation (Beck, 1992). The ability of chickpea to fix atmospheric N in the cropping system is a distinct benefit and has been attributed to nitrogen contribution to succeeding summer crops in the rotation (Namvar *et al.,* 2011). Legumes which can support biological nitrogen fixation (BNF), offer more environmentally sound and sustainable source of N to cropping systems (Bakšienė *et al*., 2009). When fertilizer-N is expensive or unavailable, crop production systems depend on the N fixed by legumes to maintain the N cycle. Legumes help keep usable nitrogen in the soil, to benefit the succeeding crop (Chemning'wa and Vessey, 2006). Therefore, including chickpea in a rotation may reduce the need for nitrogen-rich fertilizers, and help sustain usable nitrogen concentrations in soils for succeeding crops. The purpose of the present research is to evaluate the possibility of growing winter chickpea in agricultural systems that could be characterized by reductions in the use of fertilizer.

The challenge of soil infertility remains a constraint for agricultural production globally (Pikul *et al*., 2005). Cultivation of chickpea in rotation with other food crops has been recognized as one of the most cost-effective ways of maintaining soil fertility and reducing the incidence of weeds, diseases and pests (Namvar *et al.,* 2011). A study elsewhere reported that the inclusion of chickpea in a cereal based rotation increased soil organic matter and benefited the other crops in the rotation. The inclusion of chickpea in a rotation with cereal crops may help restore soil organic matter levels. Furthermore, chickpea has a tap root system which is usually deep and strong. It has been reported that including deep-rooted cover crops in rotations helps to extract phosphorous and potassium from deep within the soil profile to the soil surface where plant roots have better access to them (Muthoni and Kabira, 2010). The crop will also retrieve available nutrients in the soil following summer crops and prevent nutrients leaching and soil erosion.

Increasing dependence on a small number of agricultural crops, such as maize, is leading to reductions in agricultural biodiversity and land degradation. Land degradation is a challenge to sustainable agriculture. To effectively reverse soil degradation, improve crop diversification and achieve greater sustainability of land use, replacing winter fallow with chickpea is advocated. Diversification is a generally accepted measure against production risk. Crop rotation as a unit of diversification can reduce risk even further (Nel and Loubser, 2004). This provides important economic advantages to smallholder resource-poor farmers.

Chickpea provides a unique opportunity of enhancing legume production in South Africa as it does not compete for area with other major legumes. Traditional crops such as maize, groundnut, cowpea, soybean and common bean are wet season (summer season) crops, whereas chickpea is a dry-season (post-rainy season) legume (Rao *et al.,* 2012). There is not much choice of legumes for growing on the residual moisture in the post-rainy season; the conditions and season in which chickpea is grown. Preliminary studies show great yield potential of chickpea in the north eastern part of South Africa.

Though the beneficial effect of chickpea has been recognized, the mechanism by which chickpea benefits from summer crops remains unclear. However, studies elsewhere reported that optimum yield potential and success in chickpea production is obtained by practicing crop rotation (McKay *et al*., 2002). Chickpea is susceptible to some pathogens such as Ascochyta blight (*Ascochyta rabiei*). Recently, in a study to assess the agronomic performance of 66 elite chickpea lines from the International Crop Research Institute for Semi-Arid Tropics, Mzinti, South Africa, Mathews *et al.* (2016) reported the first root rot incidence on chickpea in South Africa. It is encouraged that rotation will narrow the chances of the crop infection. The use of non-host crops such as maize, for one or two years between chickpea crops can significantly reduce the level of root rot infection rate.

2.6 Effect of crop rotation on soil properties

Soil properties are important for supporting plant growth, microbial communities, and chemical decomposition. Positive effects of crop rotation on soil physical, chemical and biological properties are well documented (Moore *et al.,* 2000; Nel *et al.,* 2003; Pikul *et al.,* 2005; Crews, 2005; Janušauskaitė and Velykis, 2010; Alam *et al.,* 2014; Balota *et al.,* 2014; Zuber *et al.,* 2015). Although the effect of crop rotation is well documented, summer-winter crop rotation is not commonly practiced in South Africa.

2.6.1 Effect of crop rotation on soil chemical properties

Nutrient deficiencies, especially of the major nutrients (nitrogen and phosphorus) are among the major constraints to crop production globally (Shah *et al.,* 2003; Pikul *et al*., 2005). This constraint can lead to chronic food insecurity and rural poverty in Africa. Chemical fertilizers can be used to address the soil nutrient deficiencies; however, most of the resource-poor farmers in the semi-arid regions cannot access chemical fertilizers because of their high cost. Legume based crop rotation could be beneficial mostly in the semi-arid regions where soil infertility is one of the major constraints in crop production (Nel, 2005; Bakšienė *et al*., 2009). Including legumes such as chickpea which are capable of biological nitrogen fixation in a rotation offers a more environmentally sound and sustainable source of N to cropping systems (Bakšienė *et al*., 2009; Garg and Chandel, 2011; Namvar *et al.,* 2011). Therefore, incorporation of N- fixing legume in a crop rotation could be beneficial mostly in the semi-arid regions where soil N is one of the constraints in crop production.

Crop rotation is known to beneficially influence many soil chemical properties including pH, supply and transformation of N, availability of P, K, Ca and Mg (Moore *et al*., 2000; Alvey *et al*., 2001; Yusuf *et al*., 2009; Aschia *et al*., 2017). For example, in a study to compare the effect of six 2-year rotations involving two genotypes each of cowpea and soybean, a natural bush fallow and maize on soil microbial and chemical properties and yield of subsequent maize. Yusuf *et al*. (2009) reported slightly higher soil pH in soybean-maize rotation compared to fallow-maize and mono cropped maize. Similarly, in a controlled study to examine the effect of cereal-legume crop rotation on soil chemical and biological activities in West African soils, higher soil pH was observed with cereal-legume rotation compared to continuous maize (Alvey *et al*., 2001). The increase in soil pH was attributed to plant residues accumulation in the top layer of the soil which has buffering effect. In contrast, Hulugalle and Weaver (2005) reported a decrease in soil pH as a result of organic acid production and microbial respiration during the decomposition of crop residues.

Recently, Aschia *et al*. (2017) also reported a significant increase in N in Faba beans (*Vicia faba*) rotation systems compared to rotation without Faba bean. In a meta-analysis of 122 studies to examine crop rotation effects on total soil C and N concentrations, and the faster cycling microbial biomass C and N pools that play key roles in soil nutrient cycling and physical processes, McDaniel *et al.* (2013) reported that adding legumes in rotation increases soil N by 5.3 % compared to monoculture. Soil N content under crop rotation is increased in two major ways: N input from legume crops rotation and reduced leaching N. Leaching of NO_3^- under crop rotation is reported to be considerably lower than under continuous cropping or fallow. Contribution of N from legume based rotations is well documented (Alvey *et al.,* 2001; Yusuf *et al*., 2009; McDaniel *et al.*, 2013; Aschia *et al*., 2017).

Crop rotation generally results in increased organic matter content compared to continuous cropping or fallow. An increase in soil organic matter is primarily due to increase in plant residues and the amount of biomass production (McDaniel *et al.*, 2013). Soil organic matter help in the sequestering of soil organic carbon. Soil organic carbon is the primary source of plant nutrients which plays a critical role in nutrient cycling. Proper crop rotation can result in an increase in soil organic matter (Liu *et al.,* 2006). McDaniel *et al.* (2013) also reported that adding legumes in rotation increases soil carbon by 3.6% compared to monoculture. Meanwhile, with an increase in organic matter returns and organic carbon, microbial activity can be stimulated thereby enhancing the decomposition process and release of P, K, Ca, Mg and various micronutrients (Yusuf *et al*., 2009; McDaniel *et al.*, 2013; Aschia *et al*., 2017).

The inclusion of leguminous crops such as chickpea in a rotation system with other food crops may be one of the most cost-effective ways by which farmers can maintain soil fertility, compared to fallow and monoculture (Aschia *et al.,* 2017). Continuous cultivation of cereal cropping leads to lowering of the nutritional status of soil (Alam *et al.*, 2014). Monoculture promotes high levels of nutrient extraction from soils without natural replenishment, leading to low soil fertility among small-holder farmers. However, significant areas of the semi-arid regions of South Africa still practice maize mono-cropping and winter fallow. Research is needed to understand the effect of incorporating winter chickpea production in the winter fallow-summer cropping system on soil fertility.

2.6.2 Effect of crop rotation on soil biological health indicators

Crop rotation generally supports soil biological activities compared to monoculture and/ or fallow. Soil microbiological properties play important roles in returning nutrients (nutrients cycling) to their mineral forms, which plants can take up again (Balota *et al.,* 2014; Venter *et al.,* 2016). A number of studies show that crop rotation significantly increases the soil microbial activity and diversity in comparison with continuous systems. For example, Venter *et al.* (2016) conducted meta-analysis of 20 studies to determine whether decreased above ground crop diversity affects below ground microbial biodiversity by comparing monocultures and crop rotations. They observed that soils under crop rotations produced higher average microbial richness (+15.1%) and diversity scores (+3.4%) than soils under monoculture. Additionally, Venter *et al.* (2016) examined the relationship between crop diversity, soil microbial diversity and agroecosystem from a long-term (19 years) experimental trial initiated in 1996 at Langgewons in Western Cape, South Africa. They reported a positive relationship between crop diversity and microbial activities. Plant diversity by rotating crops will likely increase soil microbial biomass, alters microbial functions, and enhances soil ecosystem services (Venter *et al*., 2016).

Including a legume crop in a cropping system could help increase soil microbial diversity. This has been shown by Bierderbeck *et al.* (2005) where a 6-years study was conducted to compare the influence of crop rotation (four legume-wheat, fallow–wheat) and a continuous wheat system, on soil microbial communities, microbial biomass (MB) and activities. They reported an increase in the number of bacteria (by 385%), filamentous fungi (by 210%), MB-C (by 170%), MB-N (by 191%), cumulative C mineralization (by 205%), dehydrogenase (by 202%), phosphatase (by 171%), and for arylsulfatase activity (by 287%) with 4 wheat-legume rotation compared to fallow–wheat and a continuous wheat system.

In another long-term experiment (23 years), evaluating the benefits of winter cover crops and reduced tillage on soil microbial quality indicators, winter crops increased soil microbial quality parameters compared to fallow (Balota *et al.,* 2014). Similarly, in a study to estimate the middle-term effects of introducing faba bean in crop rotation on the structure and function of soil microbial communities, Aschia *et al.* (2017) observed that including faba bean in a rotation presented a greater rate of complex carbon sources utilization by soil bacterial communities than control rotation. It has been posited that above ground biodiversity drives below ground biodiversity (Balota *et al.,* 2014; Giguno *et al.,* 2009). Therefore, proper crop rotation will generally increase species diversity, and soil microbial diversity, as different chemical composition of organic residues will result in microbial diversity and improve nutrients availability.

2.6.3 Effect of crop rotation on soil physical properties

Soil physical properties influence the chemical and biological properties for crop productivity and growth (Sharma and Bhushan, 2001). Crop rotation has positive effects on soil physical properties such as soil aggregate stability, bulk density, soil structure, and hence is an important sustainable agricultural practice (Alam *et al.,* 2014; Balota *et al.,* 2014; Zuber *et al.,* 2015; Crews, 2005). These positive effects are attributed to the high amount of crop residue added to the soil during crop rotation (Zuber *et al.,* 2015). Good aggregate soils are able to maintain a balance of air and water and consequently promote nutrient cycling and root development, while resisting erosion. Aziz *et al.* (2011) evaluated the impact of continuous maize, maize-soybean and maize–soybean-wheat-cowpea crop rotation on soil quality. They reported that soil aggregate stability and particulate organic matter were significantly higher under maize-soybean–wheat rotation than continuous maize and maize-soybean rotation (Aziz *et al.,* 2011). Earlier, Velykis and Satkus (2005) observed low bulk density in a rotation with high proportions of winter crops compared to the rotation with spring crops only. In rotation with 100%, 75% and 50% winter crops, the bulk density was lower by 5.8%, 4.5% and 4.5% respectively, compared to the rotation with spring crops only (Velykis and Satkus, 2005).

Recently, Zuber *et al.* (2015) reported positive effect of crop rotation on water aggregate stability, being greatest for 3 years maize-soybean rotation than in 2 years maize-soybean and sequence of continuous maize. Balota *et al*. (2014) reported a positive crop rotation effect on soil physical properties compared to fallow, fallow exposes the soil to raindrop impact which results to damage soil physical properties. Currently, the major constraints for agricultural production are declining soil quality and increasing environmental degradation (Baldwin, 2006). Therefore, summer-winter crop rotation could be the best alternative cropping system to maintain soil physical properties in the semi-arid regions of Limpopo Province, South Africa where land is normally left fallow.

2.7 Effect of crop rotation on crop productivity

Crop rotation has been recognized to have positive influence on crop productivity. Numerous studies show that a 10% or greater yield advantage is seen when maize is rotated with another crop compared to monoculture (Nel *et al.,* 2003; Caliskan *et al.,* 2013). The yield increase associated with crop rotations has been attributed to ecosystem services such as soil fertility, water-use efficiency, maintenance of soil chemical and biological factors such as higher levels of mineral nitrogen structure, and disruption of pest cycles (Smith *et al*., 2008).

Yusuf *et al*. (2009) compared the effect of six 2-year rotations involving two genotypes each of cowpea and soybean, a natural bush fallow and maize on soil microbial and chemical properties and yield of subsequent maize. An increase in grain yield of subsequent maize was reported compared to that of maize succeeding fallow and mono cropped maize (Yusuf *et al*., 2009). Earlier, in a study to quantify the nitrogen contribution by soybeans to a succeeding crop of maize grown in rotation with soybean for two consecutive years, using two methods of introducing 15 N into soil and three maize cultivars used as reference plants, Sanginga *et al.* (2002) reported higher kernel yield in maize following soybean, which was attributed to the availability of extra N through biological nitrogen fixation (BNF).

Similarly, Nel and Loubser (2004) compared net yield of maize and wheat in monoculture with rotations involving fallow, dry bean, soybean and sunflower crops in Bethlehem, South Africa. An increase in net return was reported with maize rotated with soybean (by 27%) compared to monocropped maize (Nel and Loubser, 2004). In another study conducted to compare the impact of rice-maize-mungbean rotation with continuous rice cultivation. Alam *et al.* (2014) obtained highest crop yield with rice-maize-mungbean rotation (6.33 tons ha^{-1}) compared to continuous rice cultivation (4.33 tons ha^{-1}). Also, Singh *et al.* (2001) observed a 65% yield increase in maize following soybean compared to maize after maize even without the application of N fertilizer. Clearly, crop rotation improves crop productivity, and may thus be an alternative strategy to maintain soil nutrients and crop productivity compared to monoculture. However, significant areas of the semi-arid regions of Limpopo province in South Africa still practice mono-cropped maize succeeding winter fallow. Therefore, summer – winter chickpea rotation may thus be an important cropping system to improve crop productivity while conserving resources.

2.8 Summer cereal - winter chickpea cropping system

Maize (*Zea mays L*) is a major cereal crop grown in diverse agro-ecological zones and farming systems, and is consumed by people with varying food preferences and socio-economic backgrounds in South Africa (Macauley, 2015). It is one of the cereal crops grown under monoculture, intercropping system or rotated with a wide range of summer crops. Currently, there is a dramatic decline in maize yield under continuous cultivation in South Africa. Maize yield decreased from 42 466 kg ha^{-1} in 2013 to 39 556 kg ha^{-1} in 2016 (FAO, 2016). The yield loss has been attributed to low soil fertility, variety of insect pests, diseases and weeds, loss of organic matter and soil compaction, which subsequently leads to poor soil moisture relations and low soil nitrogen content (Papastylianou, 2004; Caliskan *et al.,* 2013).

Field and greenhouse studies have shown that cereal–legume cropping system increased yields of many crops such as maize, sorghum, millet, cotton, sunflower and rice (Singh *et al.*, 2001; Sanginga *et al.*, 2002; Nel and Loubser, 2004; Alam *et al.,* 2014). Yusuf *et al.* (2009) reported an increase in grain yield of maize succeeding legume compared to that of maize planted in previous fallow (fallow-maize) and maize (maize-maize) plots. The available evidence shows positive effect of cereal–legume crop rotation. However, the effects may not be immediate but observable in subsequent years. Although the effect of crop rotation is well documented, summer cereal – winter chickpea is not commonly practiced in South Africa.

CHAPTER 3: MATERIALS AND METHODS

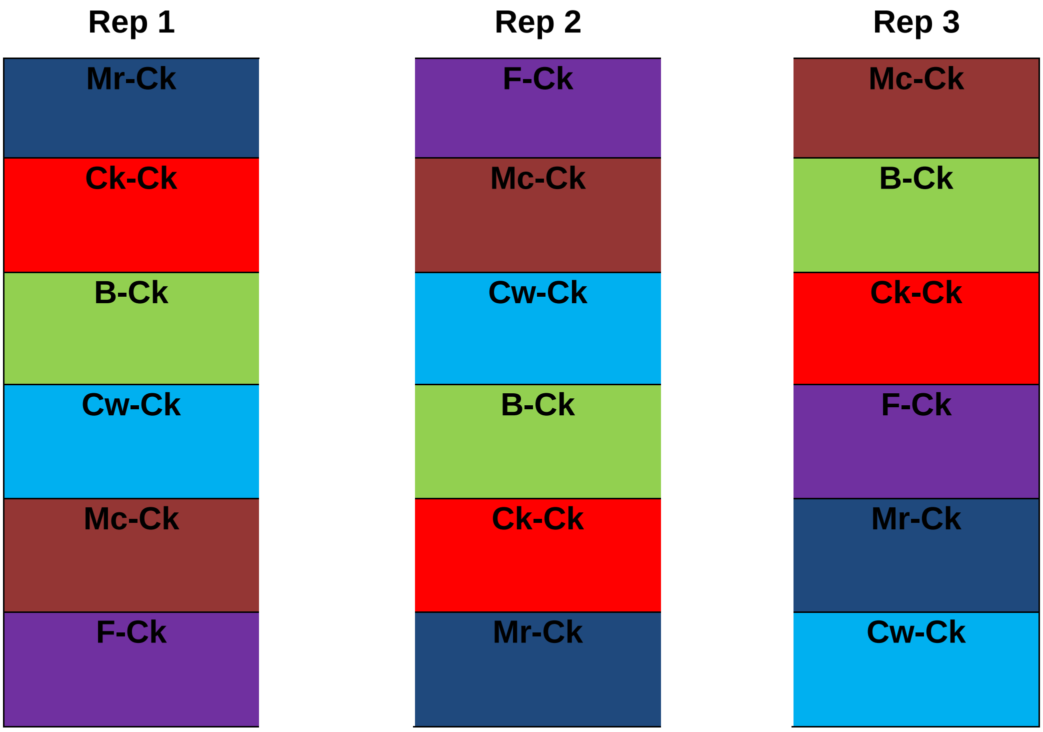
3.1 Experimental site

The field experiments were conducted at the University of Venda’s experimental Farm, Thohoyandou (22° 58' 08" S and 26.4° 4' E, 595m above sea level), Limpopo Province, South Africa. The experimental site is characterized by red, deep (>150 cm), well-drained clay soil with an apedal structure and pH of around 5.0 (Soil Classification Working Group, 1991). Daily temperatures vary from about 22 - 26ºC in winter and 25 - 40º C in summer (Tadross *et al.,* 2006). The site receives an annual rainfall of ± 500 mm that falls predominantly in summer, with 95% occurring between October and March, often with mid-season dry spell during critical growth periods (FAO 2009).

3.2 Experimental design

The study is a component of long-term summer and winter crop rotations; the field experiment was established in the summer of 2016/17 at the University of Venda, South Africa. However, the current study is based on two winter seasons i.e. 2017 and 2018 focusing on chickpea crop (*Cicer arietinum L*). First season experiment (experimental I) was conducted between 5th May 2017 and 23rd September 2017, and the second experiment was conducted between 6th May 2018 and 28th September 2018. Experimental materials consisted of summer crops [maize (*Zea mays*), bambara groundnut (*Vigna subterranea*), cowpea (*Vigna unguiculata*), mung bean (*Vigna radiata*)], fallow, winter crops [chickpea (*Cicer arietinum*) - mustard (*Brassica rapa*)] and summer-winter crop rotation. This study is based on the winter chickpea crop, laid out in a randomized complete block design (RCBD) with three replicates. The field layout was divided into six rotation plots per block, giving a total of 18 plots in 3 blocks. The sizes of individual plots were 2m x 4m with 6 rows. In the first experiment (2017) winter chickpea was succeeding first summer (2016/17) planting. In the second experiment (2018) chickpea succeeded 2 combination treatments consisting of (S1) first summer planting (2016/17) – (W1) first winter planting (2017/18) – (S2) second summer planting (2018/19). The treatment combinations are given in Figure 2a and 2b.

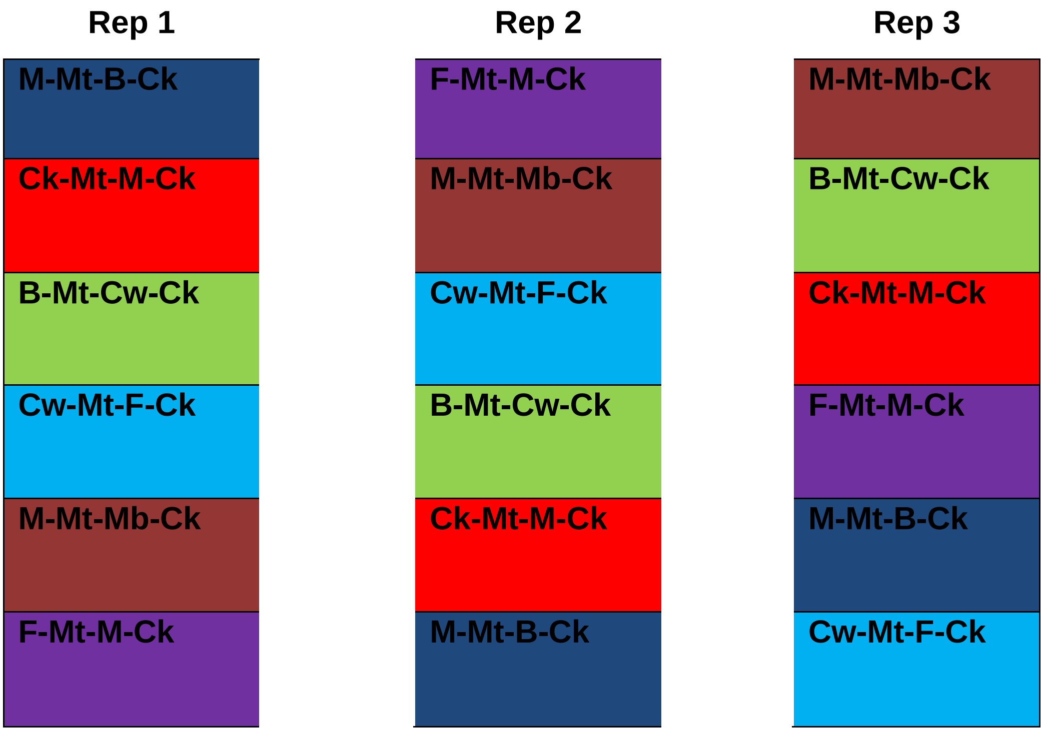
Treatments details	
Mr-Ck	Chickpea succeeding rotational Maize (*Zea mays*)
Ck-Ck	Chickpea succeeding summer chickpea (*Cicer arietinum*)
B-Ck	Chickpea succeeding Bambara (*Vigna subterranea*)
Cw-Ck	Chickpea succeeding Cowpea (*Vigna unguiculata*)
Mc-Ck	Chickpea succeeding continuous Maize(*Zea mays*)
F-Ck	Chickpea succeeding Fallow



Rep 1	Rep 2	Rep 3
Mr-Ck	F-Ck	Mc-Ck
Ck-Ck	Mc-Ck	B-Ck
B-Ck	Cw-Ck	Ck-Ck
Cw-Ck	B-Ck	F-Ck
Mc-Ck	Ck-Ck	Mr-Ck
F-Ck	Mr-Ck	Cw-Ck

Figure 2a. Field layout- Experiment 1

Treatments details	
M-Mt-B-Ck	Maize(S1) - Mustard(W1) – Bambara (S2) – Chickpea
Ck-Mt-M-Ck	Chickpea (S1) – Mustard(W1) – Maize (S2) – Chickpea
B-Mt-Cw-Ck	Bambara (S1) – Mustard(W1) – Cowpea (S2) – Chickpea
Cw-Mt-F-Ck	Cowpea(S1) – Mustard(W1) – Fallow(S2) – Chickpea
M-Mt-Mb-Ck	Maize(S1) – Mustard(W1) – Mung bean (S2) – Chickpea
F-Mt-M-Ck	Fallow(S1) – Mustard(W1) – Maize(S2) – Chickpea



Rep 1	**Rep 2**	**Rep 3**
M-Mt-B-Ck	**F-Mt-M-Ck**	**M-Mt-Mb-Ck**
Ck-Mt-M-Ck	**M-Mt-Mb-Ck**	**B-Mt-Cw-Ck**
B-Mt-Cw-Ck	**Cw-Mt-F-Ck**	**Ck-Mt-M-Ck**
Cw-Mt-F-Ck	**B-Mt-Cw-Ck**	**F-Mt-M-Ck**
M-Mt-Mb-Ck	**Ck-Mt-M-Ck**	**M-Mt-B-Ck**
F-Mt-M-Ck	**M-Mt-B-Ck**	**Cw-Mt-F-Ck**

Figure 2b. Field layout- Experiment 2

3.3 Soil sample collection

Although the experiment was established in 2016, data on soil characteristics prior to the initiation of the experiment is not available, soil sampling and analysis started only in the winter of 2018 immediately prior to planting, and after harvesting. Soil samples were collected from two depths (0-20 and 20-40 cm) using a hole-auger at three random points per plot (3 sub samples) in each plot. A composite sample was obtained by mixing all the three sub samples thoroughly and unwanted materials present were removed. The collected soil samples were then air-dried at room temperature for 48hours and ground to pass through 2mm sieve in preparation for the analysis of selected soil chemical properties. Fresh soil samples taken for the determination of selected soil biological health determination were placed in a cooler box filled with ice and kept at 0°C in a freezer until analysis.

3.4 Soil analysis

Soil samples were subjected to chemical and biological analyses.

The following chemical properties were determined: soil reaction (pH), Cation Exchange Capacity (CEC), exchangeable bases (M^{2+}, Ca^{2+}, Na^{+}), K^{+}, available P, and Nitrate (NO_3^{-}).

3.4.1 Soil Reaction (pH)

The soil pH was determined using 1:2:5 extracts using a glass electrode pH meter (Figure 3.2). Ten grams of air-dried soil was weighed into 50 ml beakers to which 1N KCl was added and equilibrated for 30 minutes using a mechanical shaker (Figure 3.1). The pH meter was standardized using buffer solutions of pH 4.0 and 7.0 prior to taking the readings. The soil pH was then determined after an hour of equilibrating (Rhoades, 1982).

Figure 3.1: Preparing soil for pH determination

Figure 3.2: Determining soil pH using pH meter.

3.4.2 Exchangeable bases ($Ca^{2+,}$ Mg^{2+}, K^+ and Na^+)

The exchangeable bases were determined following the manual of Okalebo, Gathua and Woomer (2005). Five grams of air-dried soil sample in replicates of four was weighed into 100 ml beaker and 50 ml of ammonium acetate (NH_4Oac) buffered at pH 7.0 was added to each beaker then equilibrated for 30 minutes. The mixture was filtered and the filtrate was then used to determine the amount of K^+ and Na^+ ions in the soil. For the determination of Ca^{2+} and Mg^{2+} ions, 20 cm^3 of 5000 mg/cm^3 strontium chloride solution was added to the 100 cm^3 volumetric flask containing 10 cm^3 of the filtrate and made up to the volume with NH_4Oac extracting solution. Calcium and magnesium ions were then determined using the Atomic Absorption Spectrometry (AAS). Prior to reading the soil samples, the atomic absorption spectrometry machine was calibrated using the blank (distilled water).

3.4.3 Cation Exchange Capacity

The cation exchange capacity is the amount of exchangeable cations per unit weight of soil, and was determined using the procedure of Schollenberger and Simon (1945). The sum of the exchangeable bases (K^+, Na^+, $Ca^{2+,}$ $Mg^{2+,}$ H^+, and Al^{3+}) is the effective CEC of the soil. It is measured in milli-equivalents of cations per 100 g of soil. In the new SI units, this quantity is expressed in milli-mole percent.

3.4.4 Available phosphorus (P)

The available phosphorus was determined following the procedure of Bray and Kurtz (1945). Three grams of air-dried soil was weighed into 15 ml beakers to which 21 ml of extracting solution was added and allowed to equilibrate on a mechanical shaker for 1 minute. Five milliliters of the supernatant were pipetted into 25 ml volumetric flasks and 10 ml of distilled water was added followed by 4 ml of reagent B (1.056 g Ascorbic acid dissolved in 200 cm^3 of a mixture of 12 g Ammonium Molybdate in 250 cm^3 distilled water, 0.2908 g potassium Antimony Tartrate in 100 cm^3 distilled water and 2.5 M sulphuric acid). The solution was allowed to develop colour for 15 minutes and P content in the samples was read on the Spectrophotometer at 882 nm.

3.4.5 NO_3^- and NH_4^+

The NO_3^- was determined using the colorimetric method according to Okalebo, Gathua and Woomer (2005). Ten grams of air-dried soil samples were weighed into a shaker to which 100 ml of 2 M KCl extracting solution was added and allowed to equilibrate on a mechanical shaker for 1 hour. The mixture was filtered through No. 5 Whatman filter paper. Five ml of the boric acid indicator solution was added to a 50 ml conical flask having a calibration of 30 ml. Ten millilitres of soil extract was pipetted into distillation flask to which 0.2 g (scoop) of ignited (and cool) MgO was directly added to the bulb of the distillation flask. Distillation continued until when the distillate reaches the 30 ml mark on the receiver conical flask.

The following biological indicators were determined: soil organic carbon, active carbon, potentially mineralizable nitrogen.

3.4.6 Soil organic carbon

The Walkley and Black (1934) procedure was used to determine soil organic carbon. One gram of air-dried soil was weighed into 250 ml conical flask and 10 ml of 1N potassium dichromate ($K_2Cr_2O_7$) was added followed by 20 ml of concentrated sulphuric acid. The solution was swirled and allowed to stand for 30 minutes in the fume hood after which 150 ml of distilled water was added followed by 10 ml of phosphoric acid (H_3PO_4). Then 1 ml of diphenylamine indicator was added and the solution titrated with 20 iron II sulphate (FeSO4). A blank titration was carried out to standardize the dichromate solution. Percentage organic carbon was calculated using equation 3.1:

$\% \ C = (a - b) \times 0.4$

Where a = FeSO4 added to the blank

b = FeSO4 added to the sample.

3.4.7 Soil active carbon

Active carbon was quantified using the simplified Bliar *et al.* (1995) method. Briefly, a 2.5 g air-dried soil sample was mixed with 20 ml 0.02 M potassium permanganate ($KMnO_4$) to oxidise the active carbon and then centrifuged for 5 minutes prior to the absorbance measurement on the spectrophotometer.

3.4.8 Potentially mineralizable nitrogen and NH_4^+

Potentially mineralizable nitrogen (PMN) was measured from two 8 g soil samples which were placed in 50 ml centrifuge tubes. The first tube was mixed with 40 ml 2.0 M potassium chloride (KCl) and shaken for one hour, centrifuged and analysed for NH_4^+ concentration. In the second tube, 10 ml distilled water was added, hand-shaken and incubated for 7 days at 30°C. After 7 days, 2.67 M KCl was added to the mixture, mechanically shaken for 1 hour, then centrifuged and analysed for NH_4^+(Gugino *et al.,* 2009).

3.5 Cultural Practices

The land was prepared manually using a hand hoe to bring the soil to fine tilth. Single superphosphate (10.5% P) fertilizer was applied at planting at the recommended rate of 90 kg P ha^{-1}. Seeds were inoculated according to the manufacturer's recommendation, to ensure effective nodulation (Figure 3.3). The seeds were sown manually at an intra-row spacing of 10 cm and inter-row spacing of 30 cm to give a plant population density of 33 plants per m^2 (Thangwana and Ogola, 2012). The first experiment was planted on the 5th May 2017 and the second experiment was planted on the 6th May 2018. The plots were watered uniformly immediately after sowing to promote uniform germination, emergence and crop establishment. Supplemental irrigation was applied whenever necessary. Plots were kept weed-free throughout the growing seasons. Crop residues were incorporated in the soil after harvesting.

Figure 3.3: Inoculated chickpea seeds

3.6 Measurements

Data was collected at different growth stages throughout the growing season to assess crop growth and yield. The following parameters were determined: crop phenology, crop growth, grain yield and yield components.

3.6.1 Crop phenology

Crop phenology was assessed by determining the number of days to 50% crop emergence, number of days to 50% flowering, and the number of days to 50% podding. Days to crop emergence was determined by counting the number of days from the day of sowing up to the day when 50% crop emergence was reached in each plot. The number of days to 50%

flowering was determined from the day after 50% crop emergence up to the day in which 50% of the plants in a plot had reach flowering. The number of days to 50% podding was determined from the day after 50% crop emergence up to a day where 50% of the plants per plot were podding.

3.6.2 Crop growth

Five plants from each plot were randomly selected and tagged, and observations on plant height, number of primary branches, and secondary branches were recorded weekly to assess the crop growth. Plant height was measured from the base of the plant to the apical bud of the plant, using a measuring tape, expressed in centimeters. The number of branches was determined by counting both primary and secondary plant branches. Canopy cover was determined by measuring the proportion of intercepted radiation using the AccuPAR, model LP-80 ceptometer (Decagon Devices Ltd., Pullman, USA). The measurements were taken at different plant growth stages during the growing season between 10h00 and 12h00, every 7 days. The ceptometer was used to measure photosynthetically active radiation (PAR) above (Pa) and below (Pb) the canopy (Figure 3.4). Measurements below and above the crop canopy were taken by placing the ceptometer perpendicular to the rows. The proportion of intercepted radiation was calculated using equation1:

$$\alpha = 1 - (P_b / P_a) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

P_a is the photosynthetically active radiation (PAR) above the canopy

P_b is the photosynthetically active radiation (PAR) below the canopy

α is the proportion of the intercepted radiation

Figure 3.4: Measuring intercepted radiation using ceptometer

3.6.3 Yield and yield components

At harvest maturity, grain yield and yield components were determined using all plants from four inner rows, in a sample area of 4m^2, all plants were cut at ground level. The pods were manually removed from all the harvested plants and counted to determine number of pods per plant (Figure 3.5.). The number of seeds per pod was determined by shelling the pods and counting the number of seeds found in each pod. All the seeds were air-dried and weighed to determine the grain yield (kg ha^{-1}). The sub-samples of the seeds were used to determine 100 seed weight (100-SW), by calculating the average of the 100 seed samples that were measured.

Figure 3.5: Separating pods from the plant

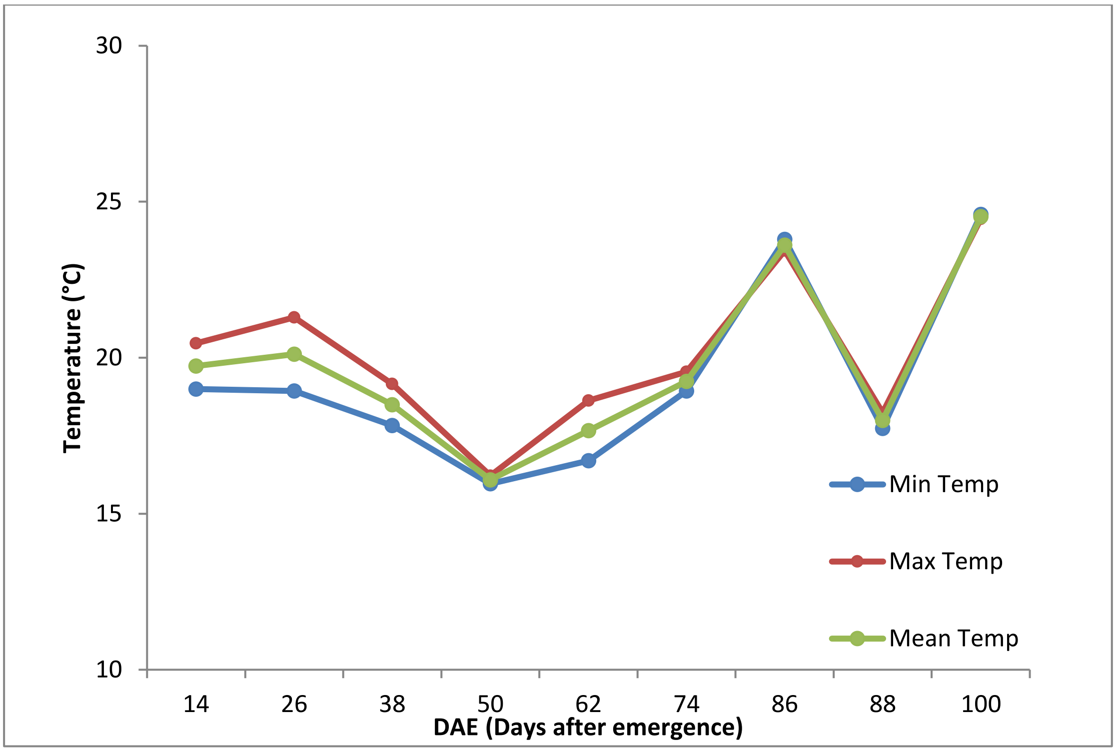
3.7 Weather data during winter 2017 and 2018 growing season

Daily weather data for winter 2017 and 2018 experiments in Thohoyandou was obtained from an automatic weather station located approximately 100 m from the experimental site. Due to periodic malfunctioning of the station rainfall data was incomplete. Average daily temperatures (°C), solar radiation (MJ m^{-2} d^{-1}), and relative humidity (%), were recorded each day during the experiments (Table 3.1). Summary of temperature (maximum, minimum and average) during 2017 (Figure 3.6a) and 2016 (Figure 3.6b) growing season relative to the crop growth stages was also recorded.

Table 3.1. Temperature, relative humidity and mean solar radiation in Thohoyandou during winter 2017 and 2018.

Month/ Season	Temperature (°C)	Relative humidity (%)	Solar radiation (MJ m^{-2} d^{-1})
Winter 2017			
May	18.39	70.90	13.22
June	16.83	68.02	11.46
July	17.29	64.32	11.59
August	18.15	59.39	13.47
September	20.77	52.69	16.88
Mean/Total	**18.29**	**63.06**	**13.32**
Winter 2018			
May	18.80	72.79	11.81
June	16.85	64.95	11.48
July	15.61	69.73	9.68
August	18.98	62.58	11.70
September	23.09	49.97	17.34
Mean/Total	**18.67**	**64.00**	**12.40**

(a)



(b)

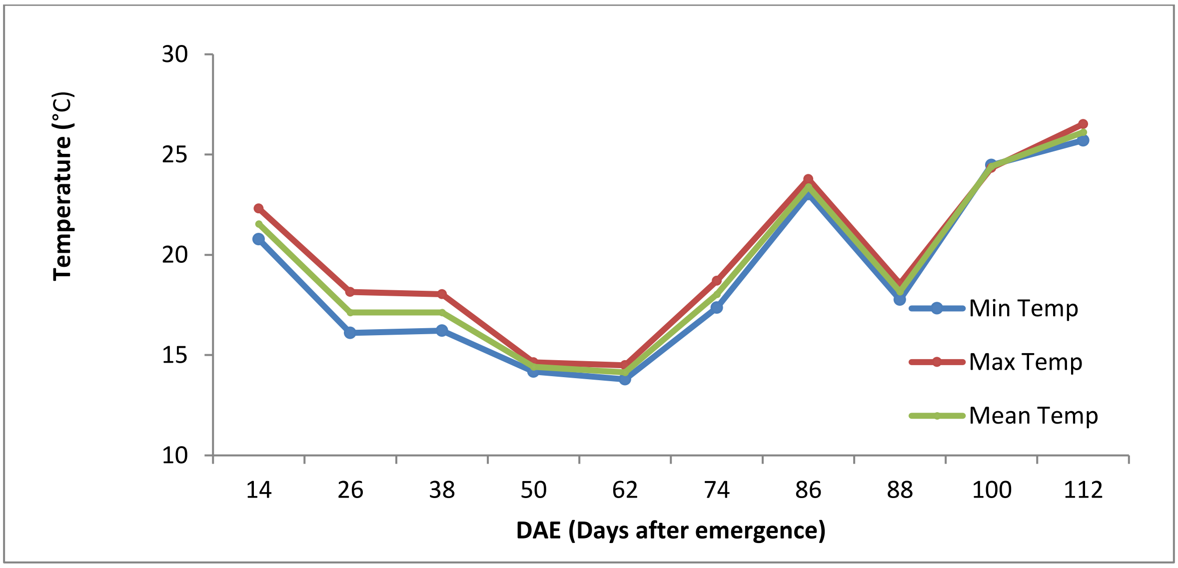


Figure 3.6: Minimum, mean and average temperature during winter 2017 (a) and 2018 (b)

3.8 Data analysis

The various agronomic data and laboratory data obtained from soil samples were subjected to analysis of variance using the general linear model (GLM) of Genstat software version 18 to examine the effects of treatments on crop productivity and selected soil properties. Significant difference between treatment means was compared using the standard error of difference (SED) of the means at the 5% level of significance. Independent samples t-test was used to compare the differences between experiments and soil depths. Correlation analyses were conducted to assess the relationship between the various parameters measured.

CHAPTER 4: RESIDUAL EFFECT OF SUMMER AND WINTER CROP ROTATIONS ON SELECTED SOIL CHEMICAL PROPERTIES

4.1 INTRODUCTION

Nutrient deficiencies, especially of the major nutrients (nitrogen and phosphorus) are among the major constraints to crop production globally (Pikul *et al*., 2005; Shah *et al.,* 2003). This constraint can lead to chronic food insecurity and rural poverty. Most of the small holder farms in Limpopo province, South Africa are located in soil of inherently low fertility however; the most commonly practised cropping system includes an intensive cereal cropping combined with shorter or no fallow periods and lack of inputs. This has caused significant loss of organic matter and depletion of nutrient reserves in soil overtime (Ramaru *et al.,* 2009). These declining soil qualities pose a significant threat to soil fertility, crop productivity and economic returns in arid and semi-arid agro ecosystems. The soil degradation trends can be reversed by use and adoption of management practices such as crop rotations (Lal, 2015).

Crop rotation is a systematic or recurrent sequence of crops grown over a number of cropping seasons and is known to positively influence many soil chemical properties including soil pH, supply and transformation of nitrogen, availability of phosphorous, potassium, calcium and magnesium (Moore *et al*., 2000; Yusuf *et al.,* 2009; McDaniel *et al.,* 2013; Aschia *et al.,* 2017). Although, monoculture, which is growing the same crop in the same field year after year, is the alternative to crop rotations. Monoculture is the most commonly used production system in cereal production however, it is associated with a number of problems. For example, soil degradation in arable lands of South Africa is largely attributed to monoculture (Ramaru *et al.,* 2009). Therefore, it is crucial to develop cropping systems which promote soil health and minimize soil degradation in the semi-arid regions of the Limpopo province, South Africa.

The current emphasis on low chemical inputs, regenerative and sustainable agricultural systems has led to renewed interest in adopting old practices such as legume- based crop rotations, manure additions and other practices that improve chemical and biological properties of the soil. These practices are important not only in maintaining the soil properties but also in enhancing crop yields at reduced external inputs. Chickpea (*Cicer arietinum* L) is a promising winter season crop to succeed traditional summer crops cultivated in the semi-arid regions of the Limpopo province, South Africa. It is a soil-enriching crop and can be grown before or after cereals. When included in crop rotations, they improve soil fertility and may also help to exploit soil more efficiently. The aim of this chapter was to investigate the dynamics and changes of selected soil chemical properties under summer and winter crop rotations. It was hypothesized that summer and winter crop rotations will affect selected soil chemical properties.

4.2 Materials and methods

Full experimental details are given in chapter 3, but a brief summary is described in this section. The study is a component of a long-term summer and winter crop rotations; the field experiment was established in summer 2016/17 at the University of Venda, South Africa but the current study is based on two winter seasons i.e. 2017 and 2018. Experimental materials consisted of summer crops [maize (*Zea mays*), bambara (*Vigna subterranea*), cowpea (*Vigna unguiculata*), mung bean (*Vigna radiata*)], fallow, and winter crops [chickpea (*Cicer arietinum*) - mustard (*Brassica rapa*)] and summer-winter crop rotation. The experiments were laid out in a randomized complete block design (RCBD) with three replicates. Although the experiment was established in 2016, soil sampling and analysis started only in 2018, therefore the represented soil data is for 2018. The current chapter is based on the residual effect of combination treatments consisting of summer and winter crop rotations on selected soil chemical properties (see Figure 2a and 2b). Soil samples were collected prior to planting (experiment I) and after harvest (experiment II) at a depth of 0-20 cm and 20-40 cm in each plot during winter 2018. The collected soil samples were air-dried at room temperature for 48 hours and were subjected to chemical analysis after sieving through a 2mm sieve. Soil chemical properties that were analysed includes soil pH, CEC, exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+), available phosphorus (P), and NO_3^-. Soil pH was determined using 1:2:5 extracts using a benchtop pH meter (Rhoades, 1982). The cation exchange capacity was determined using the procedure of Schollenberger and Simon (1945). The available phosphorus was determined following the procedure of Bray and Kurtz (1945). The NO_3^- was determined using the colorimetric method according to the laboratory method of soil and plant manual of Okalebo *et al*. (2005). The soil data obtained were subjected to analysis of variance using the general linear model of Genstat 18th Edition. Significant difference between treatments means were compared using standard error of difference of means at 5% level. Independent samples t-test was used to compare chemical properties between experiments and soil depths.

4.3 Results

4.3.1 Soil pH and cation exchange capacity (CEC)

The effect of crop rotations on soil pH (at 0-20 and 20-40 cm) was not significant in both experiment I and II, however, the average soil pH appeared to be slightly more acidic in experiment II compared to experiment I (Table 4.1). Similarly, crop rotations did not affect the cation exchange capacity (CEC) of the soil in both experiments, and the average soil CEC across the two depths (at 0-20 and 20-40 cm) did not appear to vary with experiments (Table 4.1).

4.3.2 Selected soil exchangeable cations calcium, magnesium, and sodium:

The effect of summer and winter crop rotations on soil exchangeable cations (Ca^{2+}, Mg^{2+} and Na^{+}) was not significant in both experiments across all soil depths. However, the soil cationic distribution showed a consistent pattern dominated by Ca^{2+}, followed by Mg^{2+} and Na^{+}, in both experiment I and experiment II (Table 4.2).

4.3.3 Soil Nitrate (NO_3^-)

The effect of summer and winter crop rotations on mean soil NO_3^- at 0-20 and 20-40cm depth was not significant in both experiments (Table 4.3). However, relatively high mean soil NO_3^- was recorded in experiment II compared to experiment I across the two depths (Figure 4.1 & 4.2).

4.3.4 Available phosphorus (P)

The mean soil P contents at 0-20 and 20-40cm depth were not significantly affected by summer and winter crop rotations in both experiment I and experiment II (Table 4.3) However, relatively higher mean soil P contents were recorded in experiment II (at 0-20cm) compared to experiment I (Figure 4.3).

4.3.5 Potassium (K)

The effect of crop rotations on mean soil exchangeable K^{+} was not significant (at 0-20cm and 20-40cm) in both experiments (Table 4.3).

Table 4.1. Effects of summer and winter crop rotations on soil pH and cation exchange capacity (CEC) in experiment I and experiment II.

Treatments	pH (KCl)	CEC (cmol$_c$ kg^{-1})
Experiment I		
0-20cm depth		
M-Mt-B	5.8	11.0
Ck-Mt-M	5.8	11.5
B-Mt-Cw	5.8	10.7
Cw-Mt-F	5.7	11.0
M-Mt-Mb	5.8	11.1
F-Mt-M	5.6	10.2
P-value	**ns**	**ns**
LSD	0.25	2.65
CV (%)	1.50	15.01
20-40cm depth		
M-Mt-B	5.7	9.5
Ck-Mt-M	5.8	11.2
B-Mt-Cw	5.8	10.4
Cw-Mt-F	5.6	10.8
M-Mt-Mb	5.8	11.2
F-Mt-M	5.8	10.1
P-value	**ns**	**ns**
LSD	0.18	1.25
CV (%)	2.01	3.80
Experiment II		
0-20cm depth		
M-Mt-B-Ck	5.7	9.9
Ck-Mt-M-Ck	5.6	11.8
B-Mt-Cw-Ck	5.8	10.8
Cw-Mt-F-Ck	5.6	11.2
M-Mt-Mb-Ck	5.5	10.5
F-Mt-M-Ck	5.4	11.7
P-value	**ns**	**ns**
LSD	0.34	2.12
CV (%)	2.32	11.75
20-40cm depth		
M-Mt-B-Ck	5.5	7.0
Ck-Mt-M-Ck	5.9	9.5
B-Mt-Cw-Ck	5.7	9.2
Cw-Mt-F-Ck	5.7	11.1
M-Mt-Mb-Ck	5.5	9.0
F-Mt-M-Ck	5.7	10.5
P-value	**ns**	**ns**
LSD	0.40	1.70
CV (%)	2.50	8.90

ns = not significant, ***** Significant at 5% ($P<0.05$), **CV** = Coefficient of variation, **LSD** = Least Significant Difference, **M-Mt-B** = Maize-Mustard-Bambara, **Ck-Mt-M** = Chickpea-Mustard-Maize, **B-Mt-Cw** = Bambara-Mustard-Cowpea, **Cw-Mt-F** = Cowpea-Mustard-Fallow, **M-Mt-Mb** = Maize-Mustard-Mung bean, **F-Mt-M** = Fallow-Mustard-Maize. **M-Mt-B-Ck** = Maize-Mustard-Bambara-Chickpea, **Ck-Mt-M-Ck** = Chickpea-Mustard-Maize-Chickpea, **B-Mt-Cw-Ck** = Bambara-Mustard-Cowpea-Chickpea, **Cw-Mt-F-Chickpea** = Cowpea-Mustard-Fallow, **M-Mt-Mb-Ck** = Maize-Mustard-Mung bean-Chickpea, **F-Mt-M-Ck** = Fallow-Mustard-Maize-Chickpea.

Table 4.2. Effects of summer and winter crop rotations on soil exchangeable Ca^{2+}, Mg $^{2+}$,and Na^{+} at 0-20 and 20-40 cm in experiment I and experiment II.

Treatments	Ca^{2+} (mg kg $^{-1}$)	Mg $^{2+}$ (mg kg $^{-1}$)	Na^{+} (mg kg $^{-1}$)
Experiment I			
0-20cm depth			
M-Mt-B	1334.6	469.3	48.8
Ck-Mt-M	1329.6	469.6	44.0
B-Mt-Cw	1290.6	456.3	45.0
Cw-Mt-F	1325.0	480.3	44.3
M-Mt-Mb	1344.3	473.7	45.6
F-Mt-M	1215.6	441.3	47.0
P-value	**ns**	**ns**	**ns**
LSD	2.07	4.66	145.24
CV (%)	14.37	7.90	8.40
20-40cm depth			
M-Mt-B	1131.3	425.3	44.6
Ck-Mt-M	1317.7	483.3	49.0
B-Mt-Cw	1260.6	452.3	45.0
Cw-Mt-F	1245.3	463.7	43.6
M-Mt-Mb	1336.0	479.0	42.3
F-Mt-M	1255.3	449.6	49.6
P-value	**ns**	**ns**	**ns**
LSD	3.10	4.30	5.62
CV (%)	10.50	8.21	5.90
Experiment II			
0-20cm depth			
M-Mt-B-Ck	1281.3	433.3	49.3
Ck-Mt-M-Ck	1426.0	497.0	49.0
B-Mt-Cw-Ck	1294.3	479.3	49.6
Cw-Mt-F-Ck	1305.0	483.6	50.0
M-Mt-Mb-Ck	1242.3	455.3	47.3
F-Mt-M-Ck	1417.3	502.6	48.0
P-value	**ns**	**ns**	**ns**
LSD	8.07	9.66	45.24
CV (%)	14.37	7.9	15.4
20-40cm depth			
M-Mt-B-Ck	932.6	316.0	50.0
Ck-Mt-M-Ck	1132.0	410.0	53.0
B-Mt-Cw-Ck	1098.3	410.6	48.0
Cw-Mt-F-Ck	1258.3	413.6	51.3
M-Mt-Mb-Ck	1057.3	399.3	45.3
F-Mt-M-Ck	1200.3	416.6	50.0
P-value	**ns**	**ns**	**ns**
LSD	9.10	13.30	15.62
CV (%)	18.50	10.21	9.90

ns = not significant, ***** Significant at 5% ($P<0.05$), **CV** = Coefficient of variation, **LSD** = Least Significant Difference, **M-Mt-B** = Maize-Mustard-Bambara, **Ck-Mt-M** = Chickpea-Mustard-Maize, **B-Mt-Cw** = Bambara-Mustard-Cowpea, **Cw-Mt-F** = Cowpea-Mustard-Fallow, **M-Mt-Mb** = Maize-Mustard-Mung bean, **F-Mt-M** = Fallow-Mustard-Maize. **M-Mt-B-Ck** = Maize-Mustard-Bambara-Chickpea, **Ck-Mt-M-Ck** = Chickpea-Mustard-Chickpea, **B-Mt-Cw-Ck** = Bambara-Mustard-Cowpea-Chickpea, **Cw-Mt-F-Chickpea** = Cowpea-Mustard-Fallow, **M-Mt-Mb-Ck** = Maize-Mustard-Mung bean-Chickpea, **F-Mt-M-Ck** = Fallow-Mustard-Maize-Chickpea.

Table 4.3. Effects of summer and winter crop rotations on soil NO_3-, P and K^+ in experiment I and experiment II at 0-20 and 20-40 cm.

Treatments	NO_3^- (mg kg $^{-1}$)	P (mg kg $^{-1}$)	K^+ (mg kg $^{-1}$)
Experiment I			
0-20cm depth			
M-Mt-B	43.8	8.0	101.3
Ck-Mt-M	42.3	8.3	133.3
B-Mt-Cw	41.6	7.3	116.3
Cw-Mt-F	45.6	8.5	96.3
M-Mt-Mb	39.4	9.0	112.3
F-Mt-M	44.7	6.7	93.6
P-value	**ns**	**ns**	**ns**
LSD	2.07	4.66	145.24
CV (%)	14.37	7.91	8.40
20-40cm depth			
M-Mt-B	45.1	3.0	77.3
Ck-Mt-M	42.5	3.3	114.3
B-Mt-Cw	42.1	4.3	91.3
Cw-Mt-F	45.2	3.0	146.0
M-Mt-Mb	39.7	4.3	174.7
F-Mt-M	45.1	4.0	85.0
P-value	**ns**	**ns**	**ns**
LSD	3.10	4.30	5.62
CV (%)	10.50	8.20	5.91
Experiment II			
0-20cm depth			
M-Mt-B-Ck	61.5	7.0	96.3
Ck-Mt-M-Ck	58.5	7.3	140.7
B-Mt-Cw-Ck	58.9	8.3	79.0
Cw-Mt-F-Ck	64.7	10.7	120.3
M-Mt-Mb-Ck	58.8	13.7	133.0
F-Mt-M-Ck	60.7	9.0	101.7
P-value	**ns**	**ns**	**ns**
LSD	4.43	5.66	73.08
CV (%)	4.09	16.51	21.39
20-40cm depth			
M-Mt-B-Ck	64.2	2.0	56.7
Ck-Mt-M-Ck	60.4	3.3	71.3
B-Mt-Cw-Ck	60.6	2.7	57.0
Cw-Mt-F-Ck	62.9	5.3	104.0
M-Mt-Mb-Ck	59.9	5.7	104.7
F-Mt-M-Ck	62.3	3.7	93.7
P-value	**ns**	**ns**	**ns**
LSD	6.51	2.55	6.53
CV (%)	6.80	8.40	14.80

ns = not significant, ***** Significant at 5% ($P<0.05$), **CV** = Coefficient of variation, **LSD** = Least Significant Difference, **M-Mt-B** = Maize-Mustard-Bambara, **Ck-Mt-M** = Chickpea-Mustard-Maize, **B-Mt-Cw** = Bambara-Mustard-Cowpea, **Cw-Mt-F** = Cowpea-Mustard-Fallow, **M-Mt-Mb** = Maize-Mustard-Mung bean, **F-Mt-M** = Fallow-Mustard-Maize. **M-Mt-B-Ck** = Maize-Mustard-Bambara-Chickpea, **Ck-Mt-M-Ck** = Chickpea-Mustard-Maize-Chickpea, **B-Mt-Cw-Ck** = Bambara-Mustard-Cowpea-Chickpea, **Cw-Mt-F-Chickpea** = Cowpea-Mustard-Fallow, **M-Mt-Mb-Ck** = Maize-Mustard-Mung bean-Chickpea, **F-Mt-M-Ck** = Fallow-Mustard-Maize-Chickpea.

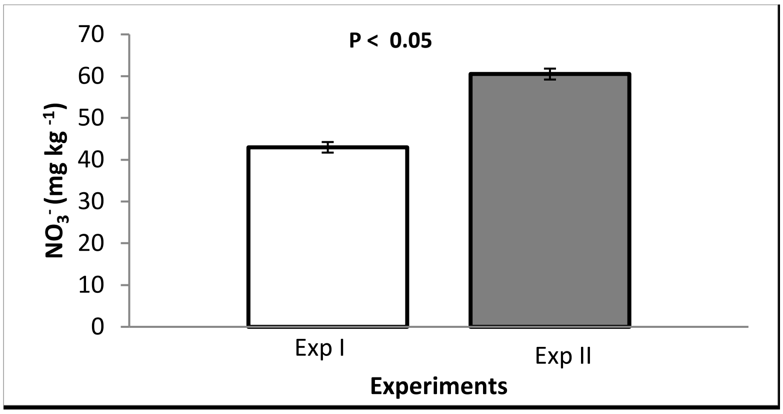


Figure 4.1. Comparison of mean soil NO_3^- between experiment I and II at 0-20cm soil depth using t-test.

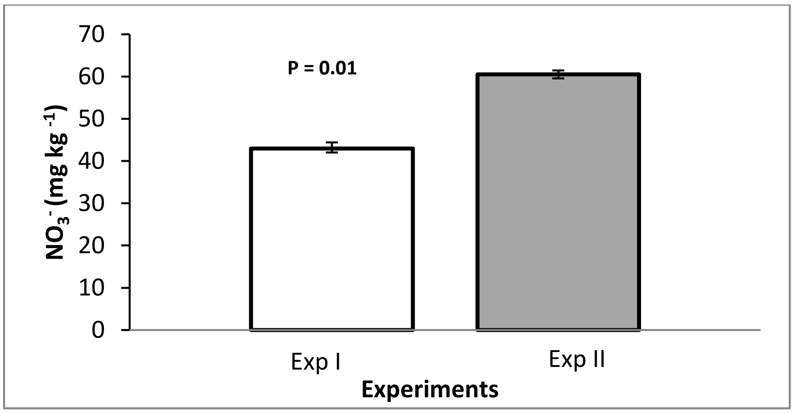


Figure 4.2. Comparison of mean soil NO_3^- between experiment I and II at 20-40cm soil depth using t-test.

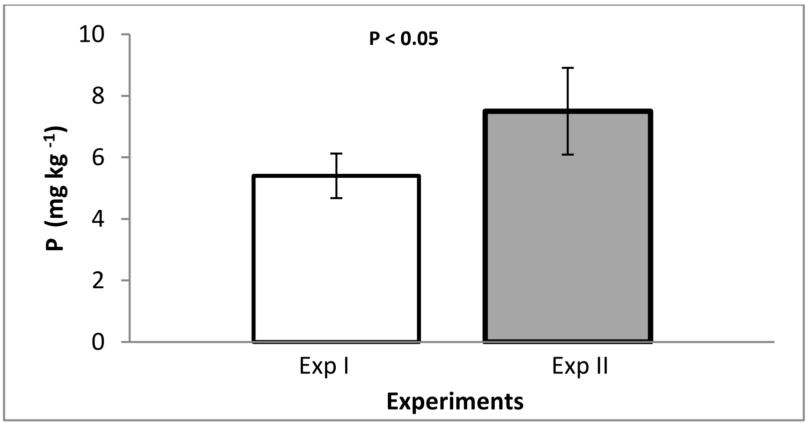


Figure 4.3. Comparison of mean soil P between experiment I and II at 0-20cm soil depth using t-test.

4.4 Discussion

4.4.1 Soil pH

Summer and winter crop rotations had no significant effect on soil reaction at 0-20cm and 20-40cm depth in both experiments. Soil pH values exhibited temporal dynamics; the mean soil pH ranged from 5.00 to 5.92 in both experiments across the two depths (Table 4.1). According to rating of Foth and Ellis (1998), these pH values were classified as acidic to moderately acidic. The non-significant effect of the rotations on soil pH in this study may probably be because the effects of crop rotation on soil pH tend to be long-term and are unlikely to be observed during the first few years of rotation. For example, Rosa *et al*. (2009) and Bassegio *et al.* (2015) also found no significant effect of crop rotation on soil pH within 2-4 years. In a long-term (8 years) field experiments to determine the effect of tillage and crop rotation on soil chemical properties, Neugschwandtner *et al.* (2014) reported an increase in soil pH with depth from 0 to 20 cm and was attributed to soil organic matter accumulation in the top layers of the soil which had a buffering effect. On the other hand, in a study to compare the effect of six 2-year rotations (2003 -2005) involving two genotypes each of cowpea and soybean, a natural bush fallow and maize on soil microbial and chemical properties and yield of subsequent maize, Yusuf *et al*. (2009) reported slightly higher soil pH, soil N, and organic carbon in soybean-maize rotation compared to fallow-maize and continues maize. The low soil pH values in the current study may be due to the nature of the soil; the study area is generally characterized by acidic soil (pH of around 5) in nature (Soil classification Working Group, 1991). Although the pH values appeared to be relatively lower at 0-20cm in comparison to 20-40cm depth, an independent t-test was carried out to compare the mean pH across the two depths and there was no statistical difference. The relatively low pH values in this study could be attributed to the on-going decomposition (mineralization) of high quantity (3 crops) of crop biomass, and agrees with the finding of Hulugalle and Weaver (2005) that a decrease in soil pH is among the short term changes of soil properties that result from the production of organic acids during the decomposition of crop residues and microbial respiration. During decomposition the carbon dioxide (CO_2) produced by decaying organic matter reacts with water in the soil to form a weak acid called carbonic acid. Moreover, Helyar and Porter (1989) stated that legumes can decrease soil pH through increase in soil organic carbon, N-fixation, and subsequent oxidation of such organic N. Nevertheless, the observed soil pH levels are within reported ranges (5-8); Behera *et al.* (2008) noted that productive soils general have a pH between 5 and 8. However, excessive soil acidity reduces crop growth and yield, and the need for liming to increase soil pH is advocated.

4.4.2 Soil CEC

The effect of crop rotations on mean cation exchange capacity (CEC) was not significant in both experiments across the two depths (0-20 and 20-40cm); the average mean soil CEC was analysed to be 10.75 and 10.19 cmol$_c$ kg^{-1} in experiment I and II respectively (Table 4.1). Following Hazelton and Murphy (2007), the rating of CEC greater than 40 cmol$_c$ kg^{-1} was considered as very high, 25 to 40 cmol$_c$ kg^{-1} as high, 12 to 25 cmol$_c$ kg^{-1} as medium, 6 to 12 cmol$_c$ kg^{-1} as low, and less than 6 cmol$_c$ kg^{-1} as very low therefore, soils of the current study area could be regarded as low (15-25 cmol$_c$ kg^{-1}) CEC. The non-significant effect in soil CEC can partially be attributed to non-significant difference in soil pH. For many soils, the CEC is dependent upon the pH of the soil and organic matter (McKenzie *et al*., 2004). The electrical charge of some of the soil components that contribute to the CEC is affected by the pH of the soil. At low pH more H^+ ions are attached to the colloids and they push the other cations from the colloids and into the soil water solution. Similar results have been reported previously by number of researchers. Evaluating two soil tillage systems under different crop rotations (sun hemp (*Crotalaria juncea L.*), pigeon pea (*Cajanus cajan*), velvet bean (*Mucuna pruriens*), sorghum (*Sorghum bicolor*) and fallow), Cunha *et al.* (2011) identified no crop rotation treatment effect on soil CEC. Moreti *et al.* (2007) and Nascimento *et al*. (2003) also reported no significant effect of crop rotation on soil CEC. Contrast to our findings, Degu *et al*. (2019) investigated the effect of crop rotations and conservation practice on selected soil physicochemical properties, and they reported a significant effect of crop rotation on soil CEC and were attributed to high accumulation of organic matter. This is in line with the findings of Crouse (2018) that soil CEC is influenced by organic matter and clay content. Organic matter has negatively charged sites which attract and hold on to cations and when soil particles are negatively charged, they attract and hold on to cations (positively charged ions) increasing the soil CEC. Hence the soil CEC may be increased over years through the addition of organic matter. However, the results of the current study were expected since soil CEC is an inherent soil characteristic and is difficult to alter significantly over a short period of time.

4.4.3 Selected soil exchangeable cations:

Summer and winter crop rotations had no significant effect on selected soil exchangeable cations [calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^+)] in both experiments across all soil depths (0-20 and 20-40cm). This may partially be attributed to the non-significant effect of summer and winter rotations on mean soil CEC due to low soil pH (Table 4.1). The exchangeable calcium, magnesium, sodium and potassium are associated with soil CEC (Rayment and Higginson 1992; McKenzie *et al*., 2004), as it indicates the capacity of the soil to retain these cations. However, as soils become more acidic these cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) are replaced by H^+, Al^{3+} and Mn^{2+}, which affect soil fertility (McKenzie *et al.,* 2004). Therefore, increasing the soil pH (i.e. decreasing the concentration of H^+ cations) will increase this variable charge, and therefore also increases the cation-exchange capacity. Similarly, Bassegio *et al.* (2015) evaluated the short-term changes in soil chemical properties for different crop rotations and management of crop residues and they reported no significant changes in Ca^{2+} and Mg^{2+} under different crop rotations and management of crop residues. Although the analysis of variance revealed no significant difference the cationic distribution in both experiments showed a dominance of Ca^{2+}, followed by Mg^{2+} and Na^+ ; 52 – 64.5% of the soil EC was occupied by Ca^{2+}, 32 – 41.4% by Mg^{2+} and 1.4 – 3.3% by Na^+ across 0-20cm and 20-40cm depths (Table 4.2). Soil CEC saturated to about 65 - 80% calcium, 15-20% magnesium, 4% potassium, and 1% to 5% sodium are suitable to grow strongest, healthiest, and most nutritious crops (Graham, 1959; Dontsova, and Norton, 2002). Based on the results of the current study, Ca^{2+} was within the desired range, Mg^{2+} proportion exceeded the optimum range (15-20%) and though sodium is not required for plant growth, it was non-toxic. In an experiment to investigate the ideal soil base ratios, Dontsova and Norton (2002) concluded that so long as calcium was the dominant cation, the soil produced a better yield.

4.4.4 Nitrate (NO_3^-)

Nitrogen is an essential nutrient in crop production and deficiencies can result in substantial yield losses. Nitrogen is available to plants as either ammonium (NH_4^+) or nitrate (NO_3^-) ions. Nitrate concentration in soil is a good indicator of available nitrogen to plants (Griffin *et al.,* 2009). Summer and winter crop rotations did not significantly affect soil NO_3^- in both experiments across the two soil depths (Table 4.3). However, greater mean soil NO_3^- was recorded in experiment II compared to experiment I across the two depths (Figure 4.1 & 4.2). The greater mean soil NO_3^- in experiment II compared to experiment I may be attributed to higher crop residues inputs with increasing crops in the rotation system. Crop residues could be the main source of soil NO_3^- in the current study (Dolan *et al.,* 2006). Nitrate (NO_3^-) is a naturally occurring form of nitrogen in soil and is formed during the nitrification process (Tzanis *et al.,* 2009). Plants take up nitrogen compounds through their roots and when they die the nitrogen compounds in the organic matter re-enter the soil through decomposition. The decomposition produces ammonia, which can then go through the nitrification process and produce NO_3^- (Tzanis *et al.,* 2009). Leguminous crops and their crop residues make major contributions to the soil organic matter pool, thereby providing enhanced potential for N availability (Schwenke *et al.,* 2002). In this study, chickpea residues could've made a greater contribution in soil NO_3^- in experiment II. Crop residues from non-leguminous crops in the rotation also contain N, but in relatively small amounts compared to legumes. Moreover, greater mean soil NO_3^- in experiment II could also likely be due to biological nitrogen fixation by chickpea. Legume crops such as chickpea are capable of fixing nitrogen gas into ammonia (Bakšienė *et al.,* 2009; Namvar *et al.,* 2011), the fixed ammonia can then go through the nitrification process and produce NO_3^- (Tzanis *et al.,* 2009) thus, high soil NO_3^- in experiment II. The increase in soil NO_3^- in the current study will highly benefit the succeeding summer crops and reduce the input cost for farmers.

4.4.5 Available phosphorus (P)

Phosphorus is an essential element classified as a macronutrient because of the relatively large amounts required by plants (Fernando *et al.,* 2002). Summer and winter crop rotations had no significant effect on soil available P contents across 0-20cm and 20-40cm soil depths in both experiments (Table 4.3). However, an independent samples t-test was carried out to compare mean soil P between experiment I and II. The results revealed a significant difference of soil P between experiments; greater soil P contents were recorded in experiment II at 0-20 cm depth. In contrast, there was no significant difference at 20-40cm depth. The greater soil P contents in experiment II can be attributed to the availability of superphosphate fertilizer that was applied during planting. When phosphorus fertilisers are applied, only 5–30% of phosphorus applied as fertiliser is immediately available to plants in the year of application. The rest is stored in soils in varying degrees of availability, and some lost via run-off, leaching or soil erosion (Tirado, and Allsopp, 2012). The relatively high soil P contents at 0-20cm may also be due to residue retention, and organic matter builds up. Plants take up the inorganic phosphate from the soil, and when the plant dies, it decays and the organic P is returned back to the soil (Zibilske *et al.,* 2002). Moreover, leguminous crop secretes organic acid and Arbuscular mycorrhiza fungi (AMF) from the root and increases the availability of P (Jenkins *et al.,* 2015). The non-significant difference on mean soil P contents at 20-40cm depth may be attributed to crop extraction. Chickpea have a high P uptake and has the ability to extract P from deeper soil profile because of its vigorous tap root system. On average, chickpea removes 6.5 kg ha^{-1} P (Pulse Australia, 2015), as it requires adequate phosphorus availability to achieve their full yield potential and fix atmospheric N (Muhammad *et al.,* 2012). The results of the current study imply that the inclusion of chickpea in a rotation is a good opportunity to utilize soil P reserves, mainly due to exudation of organic acids, ions ad phosphatases (Li *et al*, 2007) and helps to distribute phosphorus from deep within the soil profile to the soil surface, where plant roots have better access to them (Marschner, 1990). Based on the rating by FSSA (2003), the optimum amount of P (Bray-1) should be between the critical levels of 8-15 mg kg^{-1}. From the results of the current study, most P values were below the optimum P levels for crop yield and soil fertility. However, South African soils are generally deficient in phosphorus which is one of the most essential macronutrients for growth and root development (Smit, 2011; Tirado, and Allsopp, 2012). Therefore, P fertilizer should be applied according to the crop removal to secure the grain yield and crop productivity. The retained P at 0-20cm depth will be largely available for future plant uptake after the decomposition of plant residues.

4.4.6 Available potassium (K^+)

The effect of crop rotations on mean soil exchangeable K^+ was not significant across the two depths (0-20 and 20-40cm) in both experiments (Table 4.3). Although the K^+ values appeared to decrease with soil depths, an independent t-test was carried out to compare soil K^+ between 0-20 and 20-40cm depths and revealed no significant difference. There was also no significant difference of soil K^+ between experiments. The variation in crop residues did not significantly differ in soil K^+ and this may imply that K^+ remains retained in the crop residues. In production systems characterized by an absence of a fallow period between crops (plant harvest-plant system), K^+ remains absorbed in plant tissue for long periods of time and is thus protected from erosion and leaching losses (Ferreira *et al*., 2011). Contrary to the results of the current study, Sichone and Mweetwa (2018) reported a significant effect of crop rotations on soil K^+, in a study conducted to determine the impacts of a four years maize-cowpea rotation on soil properties under conservation farming, and was attributed to crop residue retention which led to a gradual build-up of organic matter in the soil. Assessing nutrient cycling by cover crops in cerrado soil, Boer *et al.* (2007) found K^+ to be the most accumulated, with levels reaching around 417 kg ha^{-1} in pearl millet. Similarly, Bassegio *et al.* (2015) also reported higher levels of potassium after harvesting than at the start (prior to planting) of the study. Although the analysis of variance revealed no significant difference on soil exchangeable K^+ the reported levels were still above the critical value of 41 mg K kg^{-1}. Chickpea has a high soil K-extraction capacity and ability to exploit deeper soil layers and thus is an important crop for the sustainability of agricultural production system, both in terms of minimizing K losses and improving its availability in the soil.

4.5 CONCLUSIONS

Summer and winter crop rotations did not significantly affect soil pH, CEC, exchangeable cations (Mg^{2+}, Ca^{2+} and Na^+), NO_3^-, P and K^+ in both experiments. However, greater soil NO_3^- and P values were reported in experiment II compared to experiment I, suggesting that summer and winter crop rotations may in the long-term improve soil fertility. It might, however, be necessary to consider supplemental application of lime to increase the soil pH due to acidifying effect from decomposition.

CHAPTER 5; RESIDUAL EFFECT OF SUMMER AND WINTER CROP ROTATIONS ON SELECTED SOIL BIOLOGICAL INDICATORS.

5.1 INTRODUCTION

The global decline in biodiversity has generated concern over the consequences for ecosystem functioning and services. Recently, research on the soil biological community and its function in the agricultural production system has received increasing attention (Liao *et al.*, 2018). Biological attributes could reflect ecosystem processes such as crop productivity, the regulation of decomposition, nutrient cycling and protection against soil-borne pathogens (Wagg *et al., 2014;* Ding *et al.,* 2018). Indeed, an active and diverse soil biota is important for maintaining crop productivity and soil quality.

Several studies have shown that agricultural practices including the tillage regime, fertilization, monoculture, summer fallow, crop residue management, biomass burning, and plant protection schemes have significant influences on soil microbial communities and composition, and hence soil biological properties (Hartmann *et al.,* 2015; Liao *et al.*, 2018; Ding *et al.,* 2018). Cropping systems based upon diverse crop rotations are often characterized by enhanced soil quality, improved plant productivity, and sustained agricultural production. Inclusion of crops with high-residue and deep- or dense-rooting crops in rotational system is known to positively influence the soil biological diversity of an agroecosystem (Willson *et al*., 2001). In contrast, monoculture production systems lead to a decrease in faunal diversity (Poudel *et al.,* 2002), which results in a reduction of soil biota, both in biomass and diversity. Some farmers use bare fallow to regenerate their lands. Instead of recovering the soil food web, the soil organic matter is degraded further, and the lack of cover can result in severe erosion and runoff when the rains start after the dry season. Nevertheless, summer cereal and winter fallow is still the most common cropping system used in the semi-arid regions of the Limpopo Province, South Africa. This production system could be shifted to a positive organization for plant production and ecosystem sustainability by introducing a summer – winter chickpea crop rotation.

Although chickpea is currently not grown commercially in South Africa, a preliminary study has shown a huge potential of winter chickpea in the dry environment of Limpopo Province, South Africa (Thangwana and Ogola (2012). In this chapter, the effect of summer and winter crop rotations on soil biological indicators was investigated. It was hypothesized that summer and winter crop rotations will affect soil biological indicators.

5.2 Materials and methods

Full experimental details are given in chapter 3, but a brief summary is described in this section. The study is a component of a long-term summer and winter crop rotations. The field experiment was established in summer 2016/17 at the University of Venda, South Africa but the current study is based on two winter seasons i.e. 2017 and 2018. Experimental materials consisted of summer crops [maize (*Zea mays*), bambara groundnut (*Vigna subterranea*), cowpea (*Vigna unguiculata*), mung bean (*Vigna radiata*)], fallow and winter crops [chickpea (*Cicer arietinum*) - mustard (*Brassica rapa*)] and summer-winter crop rotation. The experiments were laid out in a randomized complete block design (RCBD) with three replicates. Although the experiment was established in 2016, soil sampling and analysis started only in 2018, therefore the represented soil data is for 2018. The current chapter is based on the residual effect of combination treatments consisting of summer and winter crop rotations on selected soil biological health indicator (see Figure 2a and 2b). Soil samples were collected prior to planting (experiment I) and after harvest (experiment II) at 0-20cm and 20-40cm depth in each plot during winter 2018 growing season. The soil auger was disinfected with 10% alcohol prior to sampling for soil biological health indicator. Fresh soil samples collected for selected soil biological indicators were placed in a cooler box with ice and kept at 0^{o}C in a freezer until analysis. Soil biological indicators that were analysed include soil active carbon (AC), organic carbon (OC), ammonium (NH_4^+) and potentially minerilisable nitrogen (PMN). Soil organic carbon was determined using the procedure of Walkley and Black (1934). Active carbon was quantified using the simplified Weil *et al. (*2003) method. Potentially minerilisable nitrogen (PMN) was quantified as per the Cornell University Soil Health Handbook (Gugino *et al.,* 2009). The NH_4-N was determined using the colorimetric method according to the laboratory method of soil and plant manual of Okalebo, Gathua and Woomer (2005). The soil laboratory data obtained were subjected to analyses of variance using the general linear model of Genstat 18th Edition. Significant difference between treatment means were compared using standard error of difference of means at the 5% level of significance. Independent samples t-test was used to compare the differences between experiments and soil depths.

5.3 Results

5.3.1 Soil potentially mineralizable nitrogen

The effect of summer and winter crop rotations on mean soil potentially mineralizable nitrogen was not significant however, the soil PMN appeared to be lower in 20-40cm compared to 20-40cm (Table 5.1).

5.3.2 Soil active carbon

Summer and winter crop rotations did not affect the active carbon of the soil in both experiments (Table 5.1). Mean soil active carbon did not appear to differ across the two soil depths (0-20 and 20-40cm). However, the soil active carbon appeared to be greater in experiment II (at 0-20cm) compared to experiment I (Table 5.1).

5.3.3 Soil organic carbon (OC)

Crop rotations did not affect the soil organic carbon (OC) in both experiment I and II (Table 5.1). The average soil OC across the two soil depths (0-20 and 20-40cm) did not appear to differ in both experiments. However, higher accumulation of soil OC was observed in experiment II compared to experiment I (Figure 5.1a & b).

5.3.4 Soil ammonium (NH_4^+)

The effect of summer and winter crop rotations on mean soil NH_4^+ was not significant in both experiments (Table 5.1) but on average, soil NH_4^+ was greater in experiment II compared to experiment I (Figure 5.2a & b).

Table 5.1. Effects of summer and winter crop rotations on soil PMN, AC, OC and NH_4^+ in experiment I and experiment II at 0-20 and 20-40 cm.

Treatments	PMN (mg kg $^{-1}$)	AC (mg kg $^{-1}$)	OC (%)	NH_4^+ (mg kg $^{-1}$)
Experiment I				
0-20cm depth				
M-Mt-B	0.16	2.1	3.3	1.5
Ck-Mt-M	0.12	2.1	2.4	1.8
B-Mt-Cw	0.08	2.1	2.5	1.9
Cw-Mt-F	0.06	2.1	2.6	1.7
M-Mt-Mb	0.14	2.1	2.8	1.8
F-Mt-M	0.06	2.1	3.3	2.1
P-value	**ns**	**ns**	**ns**	**ns**
LSD	0.214	0.02	0.18	1.02
CV (%)	8.641	055	3.35	8.42
20-40cm depth				
M-Mt-B	0.14	2.1	3.5	1.7
Ck-Mt-M	0.10	2.1	2.7	1.7
B-Mt-Cw	0.03	2.1	2.9	2.2
Cw-Mt-F	0.02	2.1	3.0	1.7
M-Mt-Mb	0.10	2.0	3.3	1.9
F-Mt-M	0.05	2.1	3.7	1.9
P-value	**ns**	**ns**	**ns**	**ns**
LSD	0.093	0.18	0.24	2.30
CV (%)	33.160	0.49	3.72	9.20
Experiment II				
0-20cm depth				
M-Mt-B-Ck	0.14	3.1	5.6	4.4
Ck-Mt-M-Ck	0.17	2.8	5.5	4.4
B-Mt-Cw-Ck	0.06	2.9	5.6	3.6
Cw-Mt-F-Ck	0.12	3.2	5.9	5.1
M-Mt-Mb-Ck	0.13	3.1	5.6	6.6
F-Mt-M-Ck	0.21	3.0	5.6	7.7
P-value	**ns**	**ns**	**ns**	**ns**
LSD	0.110	0.02	0.18	1.02
CV (%)	8.641	0.55	3.35	13.51
20-40cm depth				
M-Mt-B-Ck	0.07	2.8	5.7	5.6
Ck-Mt-M-Ck	0.08	2.9	5.5	3.3
B-Mt-Cw-Ck	0.09	2.9	5.7	5.7
Cw-Mt-F-Ck	0.09	3.2	5.4	3.6
M-Mt-Mb-Ck	0.17	3.4	5.5	3.1
F-Mt-M-Ck	0.07	3.4	4.9	2.7
P-value	**ns**	**ns**	**ns**	**ns**
LSD	0.171	0.18	0.57	2.39
CV (%)	6.801	0.68	9.19	8.51

ns = not significant, ***** Significant at 5% ($P<0.05$), **CV** = Coefficient of variation, **LSD** = Least Significant Difference, **M-Mt-B** = Maize-Mustard-Bambara, **Ck-Mt-M** = Chickpea-Mustard-Maize, **B-Mt-Cw** = Bambara-Mustard-Cowpea, **Cw-Mt-F** = Cowpea-Mustard-Fallow, **M-Mt-Mb** = Maize-Mustard-Mung bean, **F-Mt-M** = Fallow-Mustard-Maize. **M-Mt-B-Ck** = Maize-Mustard-Bambara-Chickpea, **Ck-Mt-M-Ck** = Chickpea-Mustard-Maize-Chickpea, **B-Mt-Cw-Ck** = Bambara-Mustard-Cowpea-Chickpea, **Cw-Mt-F-Chickpea** = Cowpea-Mustard-Fallow, **M-Mt-Mb-Ck** = Maize-Mustard-Mung bean-Chickpea, **F-Mt-M-Ck** = Fallow-Mustard-Maize-Chickpea.

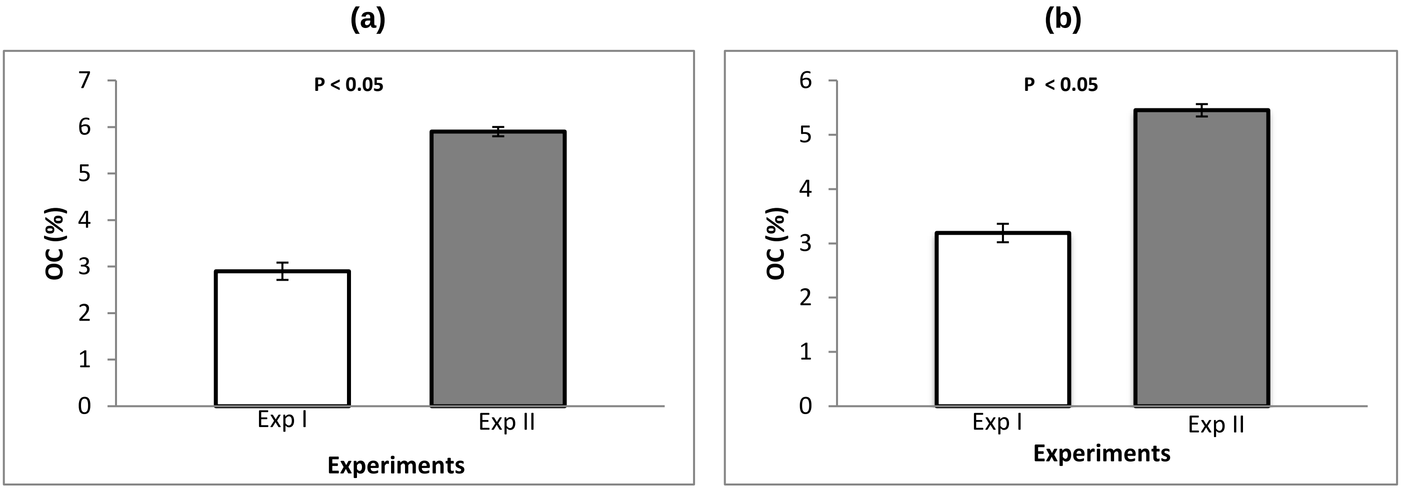


Figure 5.1. Comparison of mean soil organic carbon (OC) between experiment I and II at 0-20cm (a) and 20-40 cm (b) soil depth using t-test.

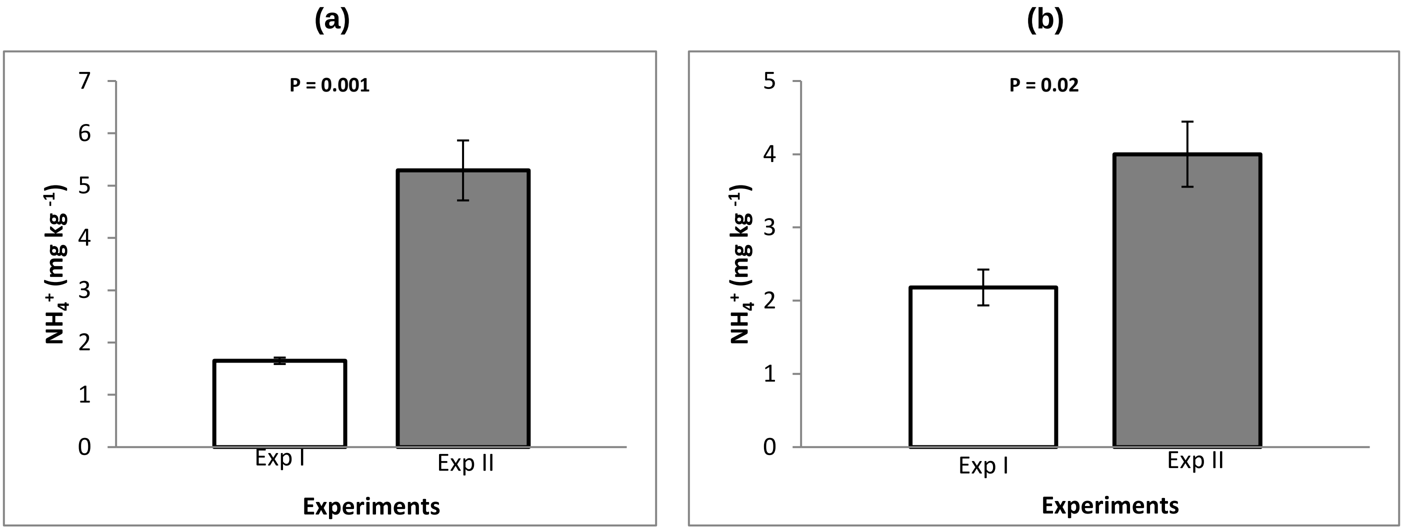


Figure 5.2. Comparison of mean soil ammonium (NH_4^+) between experiment I and II at 0-20cm (a) and 20-40 cm (b) soil depth using t-test.

5.4 Discussion

5.4.1 Potentially mineralizable nitrogen

Potentially mineralizable nitrogen is a combined measure of soil biological activity and available mineralized nitrogen (Moebius-Clune *et al*., 2017). In the current study, summer and winter crop rotations did not affect soil PMN in both experiments (Table 5.1). The non-significant difference on mean soil PMN in the current study may probably be because N mineralization is a complex long biochemical process. There is a 3 to 4-week period immediately after incorporation of leguminous residues when substantial N-mineralization occurs (Sarrantonio and Scott, 1988). In a study to evaluate the effect of particle organic matter on soil nitrogen mineralization under 5 years crop rotation system, Bu *et al*. (2015) reported a significant influence on soil PMN from rice-rapeseed (RR) crop rotation and was attributed to particulate organic matter. Although there is scarcity of studies on effects of crop rotation on soil PMN, in a meta-analysis conducted to review how conservation agriculture management practices affect PMN including N fertilizer application, cropping system diversity, and tillage system, Mahal *et al*. (2018) reported 46% higher PMN with increasing number of crops in the rotation and was associated with organic matter and crop residues addition (Mahal *et al*., 2018). This is in line with the findings of Willson *et al.* (2001) that plant residues that accumulate on the soil surface are important sources for mineralizable N. Many variables including organic matter, temperature, moisture, rainfall, and microbes can affect the mineralization of soil organic nitrogen. In the present study, the samples were derived from the same environment thus we propose the non-significant difference may be due to low soil microbial community in area of the current study. A study with a more prolonged period is recommended.

5.4.2 Soil Active carbon

Soil active carbon (AC) is an indicator of the small portion of soil organic matter that can serve as a readily available food and energy source for the soil microbial community (Moebius-Clune *et al.,* 2017). It is positively correlated with measures of biological activity (such as respiration) and microbial biomass, due to its role in providing available food and energy sources for the soil microbial community (Eisenhauer *et al.,* 2010; Moebius-Clune *et al.,* 2017). However, summer and winter crop rotations had no significant effect on soil AC in both experiments; the results showed a similar response (0-20 and 20-40cm) to treatments (Table 5.1). Further, there was no-significant difference on soil AC between experiment I and II (Table 5.1). Increased crop residues from summer and winter crop rotations was expected to increase soil active carbon, since organic matter storage in soil is directly related to the amount of C input through residue retention/incorporation and below-ground root biomass.

However, the results of the current study are comprehensible since crop rotations are less effective at improving soil properties in the short term. In general, it is often difficult to detect changes in soil organic matter following the implementation of new management practices in short term field experiments (Álvarez and Álvarez, 2000). However, the long-term effects of soil management practices on the size and activity of the microbial biomass have been found to be closely related to changes in total soil organic matter content (Franzluebbers and Arshad, 1996; Melero *et al*., 2009). This is likely because when a large population of soil microbes is fed plentifully over an extended period of time well decomposed organic matter builds up, thus, increasing the soil active carbon. However, soil organic matter is not sensitive to short-term changes of soil or crop management practices due to high background levels (Haynes, 2005). For example, Melero *et al*. (2009) reported significant higher mean AC between treatments in a long-term study (16 years) compared to short term study (3 years) from cereal-sunflower-legumes rotation under conservation tillage. Therefore, a study with a more prolonged period would provide useful insight, hence the importance of long-term studies.

5.4.3 Soil organic carbon

Crop rotations had no significant effect on mean soil organic carbon in both experiments (Table 5.1). However, significantly higher accumulation of soil organic carbon was observed in experiment II compared to experiment I at both 0-20 and 20-40cm depth (Figure 5.1a & b). In short-term studies, several authors have found an increase in organic carbon in the top layer in the first three years (Muñoz *et al.,* 2007). Labile soil organic carbon pools are the fine indicators of soil quality which influence soil function in specific ways (e.g., immobilization–mineralization) and are much more sensitive to change in soil management practices. The greatest accumulation of total organic carbon in experiment II may be associated with the high input of crop residues incorporated in the soil. Soil organic carbon are preserved in organic matter (Six *et al*., 2002)*,* thus the retention of more crop residues in the soil has been associated with an increase in organic carbon concentration. When organic residues are incorporated into the soil, soil organic matter accumulates in the soil aggregates thus increasing soil organic carbon (Horwath *et al.*, 2002). The results are in agreement with that of the study conducted by McDaniel *et al.* (2013), who reported that adding diverse crops and legumes in rotation compared to a monoculture increased soil carbon by 3.6% and total nitrogen by 5.3%. Similar results were reported by Anyanzwa *et al.* (2010). We speculate that contrast in results for the effects of crop rotation on soil OC in prior studies may be due to little crop diversity, low amount of organic materials applied to the soil and complete removal of the biomass from the field (Niklaus *et al.,* 2007). The results from the current study suggest that legumes should be included in a crop rotation and the residues must be incorporated in the soil to maintain soil carbon pools that will serve as source of energy which is needed in the reduction of atmospheric nitrogen and mitigating global warming

5.4.4 Soil Ammonium

The major proportion of soil nitrogen (N) resides in organic matter, but this N is continuously being mineralized into NH_4^+ and NO_3^- ions, the forms assimilated by plants. In the current study, soil ammonium (NH_4^+) was only significantly different between experiments; relatively higher mean NH_4^+ values were obtained in experiment II in comparison to experiment I (Figure 5.2). However, there was statistically no significant difference between treatments across the two soil depths (Table 5.1). The higher mean soil NH_4^+ in experiment II compared to experiment I may be due to return of crop (chickpea) residues with high N content to the soil. The nitrogen compounds found in the residues (residual N) and organic matter are broken down through decomposition, and this process releases nutrients, such as nitrogen (N), into the soil for plant uptake (Moebius-Clune *et al.,* 2017). Earlier, Danga *et al.* (2013) predicted the decomposition and N dynamics of two chickpea residues using NCSOIL model. They found 39.8 g kg^{-1} N in green manure chickpea residues and 7.8g kg^{-1} N in mature chickpea residues. Gan *et al.* (2011) reported an average C/N ratio of 17:1 in chickpea. A material with C/N ratio less than 24:1, like chickpea residue, would be much easier to be decomposed by the microorganisms, and results in the production of ammonium (Gan *et al.*, 2011). Soils with high levels of nitrogen-rich organic matter tend to have the highest populations of microbes involved in nitrogen mineralization.

Furthermore, the higher soil NH_4^+ in experiment II may also be attributed to biological nitrogen fixation by chickpea crops. It is well documented that soil NH_4^+ can often be improved by including legumes such as chickpea which are capable of biological nitrogen fixation in a rotation. Chickpea can fix 60–80% of its nitrogen requirement (SPG, 2016), amounting to 60–176 kg N ha^{-1}. Gan *et al. (*2010) reported that inoculated chickpea fixed up to 29% of N, averaging 18.3 kg N ha^{-1}. Tena *et al*. (2016) reported 51.5 to 67.9% N derived from the atmosphere and N fixed by chickpea. Soil ammonium (NH_4^+) concentrations depend on biological activities (Moebius-Clune *et al*., 2017). The results of the current study predicate that the high levels of soil NH_4^+ in experiment II indicate an increase in soil biological activity and microbial biomass. This is likely to explain an increase in soil NH_4^+ in the current study**.**

5.5 CONCLUSION

The selected soil biological indicators (PMN, NH_4^+, OC and AC) were not significantly affected by crop rotations across all soil depths (0-20 and 20-40cm). However, relative increases in soil organic carbon and NH4+ in experiment II were reported. Possibly, the crop residues added to the soil by chickpea crop might have influenced the soil organic carbon and NH_4^+. This indicates clearly the importance of chickpea in the summer and winter crop rotations, suggesting that the inclusion of legume in cropping system improves soil organic carbon and total soil nitrogen.

CHAPTER 6; EFFECTS OF SUMMER AND WINTER CROPS ON CROP PHENOLOGY AND GROWTH OF THE SUCCEEDING WINTER CHICKPEA.

6.1 Introduction

Chickpea is a crop with good potential for South African small-holder farmers and commercial cereal farmers. Currently, there's no commercial production of chickpea in South Africa, despites the high demand (FAO, 2016). Preliminary research has shown that chickpea is a promising winter crop in the Limpopo Province, South Africa (Thangwana and Ogola, 2012), however, thorough investigation of the adaptation and agronomic performance of chickpea is required before recommendations can be made for large- scale production.

Growth analysis is the most simple and precise method to evaluate the adaptation and agronomic performance of a crop. Growth is generally a function of environmental factors (such as temperature and solar radiation) and mineral nutrition, along with genotype and cropping systems (Anjum *et al.,* 2011). Crop characteristics which define potential yields include physiological and phenological traits. Growth analysis is one way to verify the crops adaptation to new environments, the competition between species, crops management effects and the identification of the productive capacity of different genotypes. It provides a considerable insight into adaptation of a crop as influenced by genotype and/or environment. Therefore, it is important to understand the growth dynamics of chickpea for development of suitable crop management practices.

Food production systems in the next decades need to adapt, to increase production to meet the demand of a higher population and changes in diets using less land, water and nutrients (Mathews *et al.,* 2011). In traditional production systems of South Africa, summer cereal – winter fallow is the most widely practised cropping system. However, planting the same crop year after year in the same field could encourage pests, diseases and weeds; and it can reduce the soil fertility and damage the soil structure. A more widespread use of cereal/legume rotations has been suggested as a means to sustainably meet increasing food demands. Several beneficial aspects are associated with crop rotation in comparison with monoculture cropping. Crop rotation is a key principle of sustainable agriculture because it improves the soil structure and fertility, and because it helps control weeds, pests and diseases, which is good management for long-term production. However, there is hardly any evidence in literature on summer-winter rotation in South Africa. The most commonly practiced cropping system practiced in the semi-arid regions such as the Limpopo Province, in South Africa, is winter fallow–summer maize (monoculture). Therefore, winter sowing of chickpea in rotation with summer crops has been proposed recently at the site of current study as a replacement of winter fallow (Thangwana and Ogola, 2012). This chapter assessed the effect of summer and winter crop rotations on crop phenology and growth of the succeeding chickpea. It was hypothesized that summer and winter crop rotations will affect crop phenology and growth.

6.2 Materials and method

Full experimental details are given in chapter 3, but a brief summary is described in this section. The study is a component of long-term summer- winter crop rotations. The field experiment was established in summer 2016/17 at the University of Venda, South Africa but the current study is based in two winter seasons i.e. 2017 and 2018. Experimental materials consisted of summer crops [maize (*Zea mays*), bambara groundnut (*Vigna subterranea*), cowpea (*Vigna unguiculata*), mung bean (*Vigna radiata*)], fallow and winter crops [chickpea (*Cicer arietinum*) - mustard (*Brassica rapa*)] and summer-winter crop rotation. The experiments were laid out in a randomized complete block design (RCBD) with three replicates. The current chapter is based on the residual effect of combination treatments consisting of summer and winter crop rotations on crop phenology and growth of chickpea. In the first experiment (2017) winter chickpea was succeeding first summer (2016/17) planting. In the second experiment (2018) chickpea succeeded 2 combination treatments consisting of (S1) first summer planting (2016/17) – (W1) first winter planting (2017/18) – (S2) second summer planting (2018/19). The treatment combinations are given in Figure 2a and 2b. Crop phenology was assessed by determining days to 50% emergence, flowering and podding, and crop growth was assessed by determining plant height, number of primary and secondary branches and canopy cover. Number of days to 50% emergence was determined by counting the number of days from sowing until 50% of the plants have emerged in each plot. The number of days to flowering was determined by counting the number of days from emergence until the day 50% of the plants in a plot had flowered at least one flower. The number of days to podding was determined by counting the number of days from emergence until 50% of the plants in a plot had at least one pod. Five plants in each plot were tagged for taking observations on plant height, primary and secondary branches. Number of primary and secondary branches was manually counted, while a ruler was used to measure plant height. Canopy cover was determined by measuring the proportion of intercepted radiation using the AccuPAR, model LP-80 ceptometer (Decagon Devices Ltd., Pullman, USA). All data obtained was subjected to analysis of variance (ANOVA) using the general linear model of Genstat 18th Edition. Significant differences between treatment means were compared using standard error of difference (SED) at the 5% level of significance. Independent samples t-test was used to compare the differences between experiments/ growing seasons.

6.3 RESULTS

6.3.1 Crop phenology

Summer and winter crop rotations did not affect number of days to 50% emergence, flowering and podding of chickpea in both 2017 and 2018 growing season. On average, the crop emerged 10 (2017) and 9 days (2018) after sowing (Table 6.1). There was no significant difference in number of days to 50% flowering in both 2017 and 2018 growing seasons (Table 6.1). However, the crop flowered earlier in 2017 compared to 2018 growing season; averaging 21 days and 33 days respectively (Figure 6.1). Similarly, the number of days to 50% podding did not differ across treatments in both 2017 and 2018 growing seasons (Table 6.1).

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Table 6.1 Residual effects of summer and winter crop rotations on days to 50% emergence, flowering and podding of the succeeding winter chickpea during 2017 and 2018 growing season.

YEAR	**2017**				**2018**		
Treatments	50% Emergence	50% Flowering	50% Podding	Treatments	50% Emergence	50% Flowering	50% Podding
Mr	10.0	21.3	68.7	M-Mt-B	9.3	32.7	63.7
Ck	10.3	21.3	69.7	Ck-Mt-Mr	9.3	32.3	62.7
B	9.0	20.0	65.0	B-Mt-Cw	10.7	32.7	64.7
C	9.7	20.7	68.7	Cw-Mt-F	9.3	34.0	64.0
M	11.3	22.3	68.0	M-Mt-Mb	8.7	32.7	62.0
F	11.0	22.0	70.0	F-Mt-M	9.3	32.7	63.0
P-Value	**ns**	**ns**	**ns**	P-Value	**ns**	**ns**	**ns**
LSD	1.47	1.62	4.95	LSD	2.06	6.71	1.87
CV (%)	7.92	4.1	3.63	**CV (%)**	12.02	11.24	1.63

ns = not significant, ***** Significant at 5% (P<0.05), **CV** = Coefficient of variation, **LSD** = Least Significant Difference. **Mr =** Maize rotational, **B** = Bambara, **Cw** = Cowpea, **M** = Maize permanent, **F** = Fallow. **Mr-Mt-B** = Maize rotational-Mustard-Bambara, **Ck-Mt-Mr** = Chickpea-Mustard-Maize rotation, **B-Mt-Cw** = Bambara-Mustard-Cowpea, **Cw-Mt-F** = Cowpea-Mustard-Fallow, **M-Mt-Mb** = Maize permanent-Mustard-Mungbean, **F-Mt-M** = Fallow-Mustard-Maize permanent.

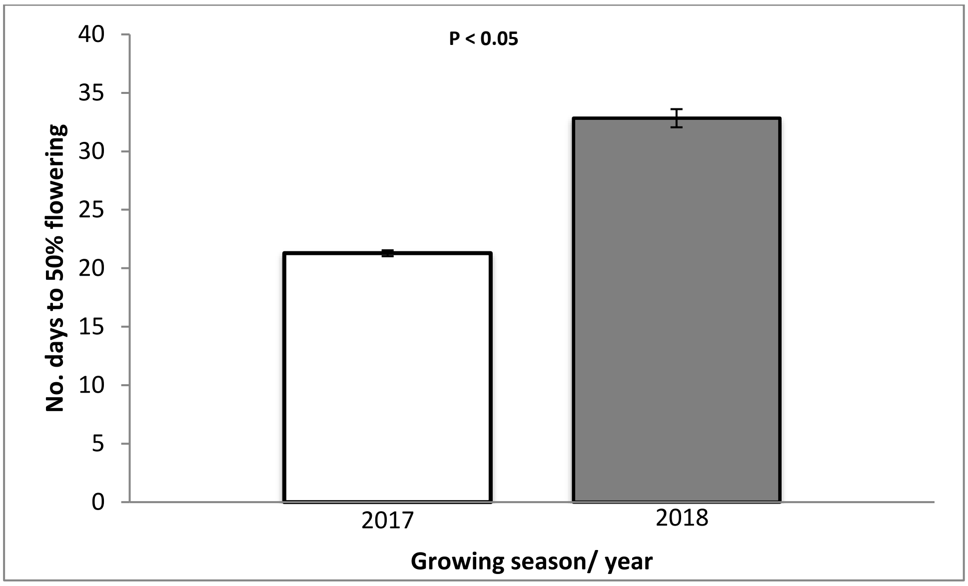

Figure 6.1. Comparison of mean number of days to 50% flowering between 2017 and 2018 growing seasons using t-test.

6.3.2 Crop growth

Primary and secondary branches

The analysis of variance revealed no significant effect of summer and winter crop rotations on the number of primary and secondary branches across all growing stages (14 -81 DAE) in both 2017 and 2018 growing season (Table 6.2 & 6.3). On average, the crop produced 2 primary branches per plant in both 2017 and 2018 growing seasons and produced 7 and 8 secondary branches in 2017 and 2018, respectively.

Plant height

The analysis of variance revealed no significant difference on mean plant height across all measurement dates in both 2017 and 2018 growing season (Table 6.4). However, the crop produced taller plants during 2017 growing season compared to 2018, averaging 70.69 and 60.47cm respectively at maturity (Figure 6.2).

Proportion of intercepted radiation

The analysis of variance revealed no significant difference on proportion of intercepted radiation (%) across all measurement dates both in 2017 and 2018 growing season (Table 6.5). However, mean proportion of intercepted radiation PAR increased with number of days after emergence (DAE) in both growing seasons.

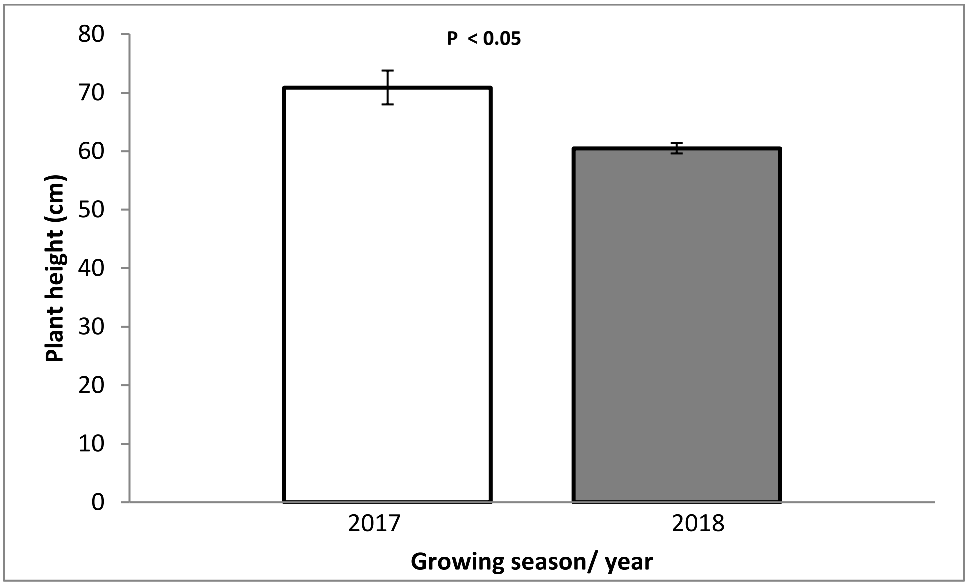

Figure 6.2. Comparison of mean plant height between 2017 and 2018 growing seasons using t-test.

Table 6.2. Residual effects of previous summer and winter crop rotations on primary branches (PB) of the succeeding winter chickpea at 14 – 81 DAE during 2017 and 2018 growing season.

YEAR	**2017**							**2018**					
Treatments	14 DAE (PB)	32 DAE (PB)	46 DAE (PB)	54 DAE (PB)	67 DAE (PB)	81 DAE (PB)	Treatments	14 DAE (PB)	32 DAE (PB)	46 DAE (PB)	54 DAE (PB)	67 DAE (PB)	81 DAE (PB)
Mr	1.00	2.00	2.00	2.33	2.33	2.33	M-Mt-B	1.00	1.33	1.33	2.00	2.00	2.00
Ck	1.00	2.00	2.00	2.00	2.00	2.00	Ck-Mt-Mr	1.00	1.33	1.00	2.00	2.00	2.00
B	1.00	2.00	2.00	2.00	2.00	2.00	B-Mt-Cw	1.00	1.00	2.00	2.66	2.33	2.33
Cw	1.00	2.00	2.00	2.33	2.33	2.33	Cw-Mt-F	1.00	1.00	1.66	2.66	2.33	2.33
M	1.00	1.66	1.66	1.66	1.66	1.66	M-Mt-Mn	1.00	1.00	1.33	1.66	2.00	2.00
F	1.00	1.66	1.66	1.66	1.66	1.66	F-Mt-M	1.00	1.00	1.33	2.33	2.66	2.66
P-Value	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	P-Value	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
LSD	0.79	0.54	0.54	0.54	0.54	0.66	LSD	0.79	0.54	0.74	0.85	1.08	1.08
CV (%)	27.93	15.78	15.78	18.25	18.25	18.25	**CV (%)**	27.93	26.83	34.99	21.21	26.83	26.83

ns = not significant, ***** Significant at 5% (P<0.05), **CV** = Coefficient of variation, **LSD** = Least Significant Difference. **Mr =** Maize rotational, **B** = Bambara, **Cw** = Cowpea, **M** = Maize permanent, **F** = Fallow. **Mr-Mt-B** = Maize rotational-Mustard-Bambara, **Ck-Mt-Mr** = Chickpea-Mustard-Maize rotation, **B-Mt-Cw** = Bambara-Mustard-Cowpea, **Cw-Mt-F** = Cowpea-Mustard-Fallow, **M-Mt-Mb** = Maize permanent-Mustard-Mungbean, **F-Mt-M** = Fallow-Mustard-Maize permanent.

Table 6.3. Residual effects of previous summer and winter crop rotations on secondary branches (SB) of the succeeding winter chickpea at 14 – 81 DAE during 2017 and 2018 growing season.

YEARS				**2017**							**2018**		
Treatments	**14 DAE**	**32 DAE**	**46 DAE**	**54 DAE**	**67 DAE**	**81 DAE**	**Treatments**	**14 DAE**	**32 DAE**	**46 DAE**	**54 DAE**	**67 DAE**	**81 DAE**
M	0.33	2.00	2.66	3.67	5.00	5.00	M-Mt-B	2.00	3.00	5.33	6.00	6.67	7.00
Ck	0	3.00	3.33	4.33	6.00	6.33	Ck-Mt-Mr	1.33	3.33	6.67	7.33	7.33	7.33
B	0.33	1.60	3.33	4.66	6.67	6.66	B-Mt-Cw	1.33	2.33	4.33	5.00	6.00	7.33
Cw	0	2.66	3.33	4.33	5.33	5.66	Cw-Mt-F	1.67	3.33	5.67	6.00	6.67	7.66
M	0.66	3.00	3.66	5.00	5.33	6.00	M-Mt-Mb	2.00	3.33	6.00	7.00	7.67	8.17
F	1.00	3.00	4.00	5.67	5.67	6.00	F-Mt-M	2.00	3.00	5.67	6.33	7.00	6.00
P-Value	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	P-Value	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
LSD	0.63	0.79	1.68	2.56	2.53	2.54	LSD	1.18	1.43	2.60	1.47	1.23	1.46
CV (%)	89.89	17.00	27.29	30.58	24.54	23.52	**CV (%)**	37.72	20.94	25.55	12.89	5.79	11.05

ns = not significant, ***** Significant at 5% (P<0.05), **CV** = Coefficient of variation, **LSD** = Least Significant Difference. **Mr =** Maize rotational, **B** = Bambara, **Cw** = Cowpea, **M** = Maize permanent, **F** = Fallow. **Mr-Mt-B** = Maize rotational-Mustard-Bambara, **Ck-Mt-Mr** = Chickpea-Mustard-Maize rotation, **B-Mt-Cw** = Bambara-Mustard-Cowpea, **Cw-Mt-F** = Cowpea-Mustard-Fallow, **M-Mt-Mb** = Maize permanent-Mustard-Mungbean, **F-Mt-M** = Fallow-Mustard-Maize permanent.

Table 6.4. Residual effects of previous summer and winter crop rotations on plant height (cm) of the succeeding winter chickpea during 2017 and 2018 growing season.

YEAR			**2017**				**2018**						
Treatments	**14 DAE PH**	**32 DAE PH**	**46 DAE PH**	**54 DAE PH**	**67 DAE PH**	**81 DAE PH**	**Treatments**	**14 DAE PH**	**32 DAE PH**	**46 DAE PH**	**54 DAE PH**	**67 DAE PH**	**81 DAE PH**
Mr	13.9	23.0	43.8	52.7	55.2	60.8	M-Mt-B	12.0	21.7	30.7	38.0	44.7	65.0
Ck	13.2	20.3	43.5	52.0	58.0	63.2	Ck-Mt-Mr	11.3	20.0	28.0	35.7	46.3	52.0
B	13.5	22.3	43.3	53.0	53.3	55.7	B-Mt-Cw	11.3	21.3	31.3	39.7	49.0	60.7
Cw	13.5	22.8	43.0	53.0	55.0	59.8	Cw-Mt-F	11.7	19.7	29.0	36.0	54.7	63.3
M	12.7	20.8	43.7	51.7	55.7	62.7	M-Mt-Mb	10.7	21.0	28.7	35.0	44.7	53.0
F	12.7	22.8	43.0	55.8	63.7	69.7	F-Mt-M	9.3	20.3	29.7	39.3	45.3	54.7
P-Value	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**P-Value**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
LSD	2.89	4.89	5.22	6.10	5.11	4.98	**LSD**	2.61	1.69	2.52	6.85	9.84	13.65
CV (%)	12.02	12.07	4.12	6.43	5.10	4.52	**CV (%)**	12.96	4.50	4.69	10.10	11.4	9.88

ns = not significant, ***** Significant at 5% (P<0.05), **CV** = Coefficient of variation, **LSD** = Least Significant Difference. **Mr =** Maize rotational, **B** = Bambara, **Cw** = Cowpea, **M** = Maize permanent, **F** = Fallow. **Mr-Mt-B** = Maize rotational-Mustard-Bambara, **Ck-Mt-Mr** = Chickpea-Mustard-Maize rotation, **B-Mt-Cw** = Bambara-Mustard-Cowpea, **Cw-Mt-F** = Cowpea-Mustard-Fallow, **M-Mt-Mb** = Maize permanent-Mustard-Mungbean, **F-Mt-M** = Fallow-Mustard-Maize permanent.

Table 6.5. Residual effects of previous summer and winter crop rotations on the (PAR) proportion of intercepted radiation (%) of the succeeding winter chickpea during 2017 and 2018 growing season.

YEAR	**2017**							**2018**					
Treatments	**14 DAE (PAR)**	**32 DAE (PAR)**	**46 DAE (PAR)**	**54 DAE (PAR)**	**67 DAE (PAR)**	**81 DAE (PAR)**	**Treatments**	**14 DAE (PAR)**	**32 DAE (PAR)**	**46 DAE (PAR)**	**54 DAE (PAR)**	**67 DAE (PAR)**	**81 DAE (PAR)**
Mr	34	50	67	74	92	87	M-Mt-B	19	47	52	59	62	81
Ck	39	53	55	72	83	88	Ck-Mt-Mr	13	49	58	66	71	82
B	44	48	53	79	81	81	B-Mt-Cw	13	46	50	61	62	78
Cw	32	59	50	66	86	88	Cw-Mt-F	17	51	53	62	74	87
M	38	55	55	77	90	84	M-Mt-Mb	18	57	62	65	82	91
F	44	65	67	78	89	97	F-Mt-M	18	49	54	64	77	84
Grand	38.4	55.3	61.1	74.2	86.9	97.6	Grand	16.8	50.5	55.5	63.3	71.8	84.9
P-Value	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**P-Value**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
LSD	23.33	17.04	35.51	21.18	11.65	16.69	LSD	27.81	16.92	17.92	18.54	21.81	14.92
CV (%)	22.96	16.9	31.69	15.10	7.4	9.883	CV (%)	32.7	18.04	17.75	16.45	16.65	8.90

. **ns** = not significant, ***** Significant at 5% (P<0.05), **CV** = Coefficient of variation, **LSD** = Least Significant Difference. **Mr =** Maize rotational, **B** = Bambara, **Cw** = Cowpea, **M** = Maize permanent, **F** = Fallow. **Mr-Mt-B** = Maize rotational-Mustard-Bambara, **Ck-Mt-Mr** = Chickpea-Mustard-Maize rotation, **B-Mt-Cw** = Bambara-Mustard-Cowpea, **Cw-Mt-F** = Cowpea-Mustard-Fallow, **M-Mt-Mb** = Maize permanent-Mustard-Mungbean, **F-Mt-M** = Fallow-Mustard-Maize permanent.

6.4 Discussion

6.4.1 Crop phenology

Successful germination and emergence are the primary requirements for good crop establishment. However, summer and winter crop rotations did not significantly affect the number of days to 50% emergence; the mean number of days to 50% crop emergence was almost similar in both years of the study (Table 6.1). The uniform germination can be attributed to availability of soil moisture during planting, as the plots were irrigated immediately after planting. Soil water content at sowing is an important determinant of seed emergence and early growth (Yusif *et al.,* 2016). There is enough evidence in literature that availability of water during planting can enhance germination which in turn would results in decrease in number of days to 50% emergence (Hosseini *et al*., 2009; Yusif *et al.,* 2016). Hosseini *et al*. (2009) conducted an experiment to assess the influence of different soil moisture contents (field capacity percentage basis) on emergence as well as early plant growth in twenty chickpea genotypes. Their experimental results revealed that the time to emergence was progressively delayed with a decrease in soil moisture (Hosseini *et al*., 2009). Moreover, in a long-term, summer and winter crop residues is more likely create a good soil structure which will improves soil moisture retention and ensures availability of water for germination of the seed. The crop residues will cover the soil surface and prevent the soil from drying or loosing soil moisture (soil moisture retention) and encourage early emergence. Early crop emergence will lead to good crop establishment and encourages biomass production.

The number of days taken from sowing to onset of flowering is an important growth parameter which influences productivity and adaptation of chickpea, particularly in rain-fed environments (Kumar and Abbo, 2001). In the current study, there was no significant difference on mean number of days to 50% flowering across all treatments in both 2017 and 2018 growing seasons, however, there was a significant difference between growing seasons/ years. According to the t-test, the crop flowered earlier in the year 2017 as compared to 2018 (Figure 6.1). The non-response of numbers of days to 50% flowering across treatments was not entirely due to summer and winter crop rotation, but due to other factors such as genetic attributes, photoperiod, the seasonal temperature profile and vernalization responses of the plant and nutrient availability (Roberts *et al*., 1985; Clarke, 2001; Thangwana and Ogola, 2012; Pulse Australia, 2015). The significant difference between growing seasons can be attributed to temperature. According to weather data (Table 3.1), 2017 growing season was warmer than 2018 growing season, with average temperature of 17.29 (2017) and 15.61°C (2018) in July which coincides with the flowering of chickpea.

Pods play a key role in encapsulating the developing seeds and protecting them from pests and pathogens. Summer and winter crop rotations had no significant effect on mean number of days to 50% podding in both 2017 and 2018 growing season (Table 6.1). The non-significant difference on mean number of days to 50% podding across treatments could be associated with no-response of numbers of days to 50% flowering. In legume crops, successful sexual reproduction and the ensuing development of pods and seeds depend on flowering. Pod formation/ production begin after the crop flowers have been pollinated. Although there was a yearly difference on number of days to 50% flowering (Figure 6.1), there was no significant difference on the number of days to 50% podding. The reason for no variation on crop phenology may be attributed to nutrient availability. Crop rotation requires long term to improve nutrient availability and consequently influence crop phenology.

6.4.2 Crop growth

Branches per plant are essential parameters of plant biometry and play an important role to achieve higher grain yield. However, summer and winter crop rotations had no significant effect on number of primary and secondary branches across treatments and in both 2017 and 2018 (Table 6.2). The non-significant difference on number of branches may be due to genetic attributes. Roy *et al.* (2016) reported that chickpea cultivars differed significantly with respect to number of branches per plant. There was also no significant difference between years (2017 & 2018) on number of branches despite the variation in weather conditions. On average, the crop produced two primary branches per plant in both years (Table 6.2). Summer and winter crop rotation had no significant effect on plant height across treatments in both 2017 and 2018 (Table 6.4), but there was a progressive increase in plant height with the advancement in age of crop (DAE) and the rate of progression in height was slow at late stages (54 DAE). However, an independent t-test revealed a yearly significant difference on plant height; the crop produced taller plants during 2017 growing season compared to 2018, averaging 70.8 and 60.4cm, respectively (Figure 6.2). There is a difference of 11.48 cm among the values and would have virtual effect on the plant height. The yearly mean plant height difference observed in the current study may be contributed to difference in weather conditions. According to weather data (Table 3.1), 2017 growing season was warmer than 2018 growing season. Although plant height is an inherited characteristic it is dependent upon the environmental conditions for its final expression. The variation in day and night temperatures experienced may have influenced the plant height resulting in the significant difference.

The proportion of intercepted radiation is one of the most important factors that influence crop development and provides the energy needed for fundamental physiological processes such as photosynthesis and transpiration. The proportion of intercepted radiation was not significantly affected by summer and winter crop rotations in both years (Table 6.5). Despite the variation in temperature there was no yearly difference on PAR. Crop canopy cover and dry matter accumulation in chickpeas is strongly influenced by environmental conditions and nutrient availability. Plant growth and development largely depend on the combination and concentration of mineral nutrients available in the soil. The no variation on crop growth in the current study can be attributed to no-significant effects of crop rotation on selected soil chemical properties and soil biological health indicators. The effects of crop rotation on soil nutrient availability are well documented but they manifest after a long period. However, the long-term use of crop rotation may likely improve soil fertility, increase soil aggregate stability, microbial and earthworm activity and soil water storage, and optimize the soil physical environment for crop growth.

6.5 CONCLUSION

Summer and winter crop rotations had no significant effect on number of days to 50% crop emergence, flowering and podding, primary and secondary branches, plant height and proportion of intercepted radiation. Crop rotation is known to positively influence soil nutrient availability and consequently affect crop growth. However, the effect of crop rotation on soil nutrient availability is unlikely to be observed during the first few years of rotation. These results suggest prolonged experiments.

CHAPTER 7: EFFECT OF SUMMER CROPS ON YIELD AND YIELD PARAMETERS OF THE SUCCEEDING WINTER CHICKPEA

7.1 Introduction

Crop rotation has been recognized to have positive influence on crop productivity. Numerous studies have shown greater grain yield obtained in crop rotation compared to monocultures (Sanginga *et al.,* 2002; Nel *et al.,* 2003; Caliskan *et al.,* 2013; Alam *et al.*, 2014). The yield increase associated with crop rotations has been attributed to improved soil fertility and structure. Most smallholder farmers in the semi-arid regions of the Limpopo province, South Africa are located in relatively low fertility soils consequently, resulting in low crop yield. The decline in soil fertility and low crop productivity has been attributed to monoculture without the use of either organic or inorganic fertilizers (Ramaru *et al.,* 2009). However, maize mono-cropping and winter fallow continues to be the main practice throughout the semi-arid regions of the Limpopo province. This traditional cropping system is considered unsustainable particularly for nitrogen availability. The low and declining soil fertility has led to renewed interest in crop rotation as an alternative practice for economically sustainable grain production. This practice is not only important in enhancing crop yields but also in maintaining the environment and addressing food insecurity.

The integration of a legume crop into this traditional cropping system has the potential to improve soil fertility and consequently increase yield. Chickpea is an important legume crop ranking second after dry bean (*Phaseolus vulgaris* L.) in the world (FAO, 2016). The crop can be cultivated in all sorts of cropping systems and rotated with other crops. The ability of chickpea to fix atmospheric N in a cropping system is a distinct benefit and has been attributed to nitrogen contribution to succeeding summer crops in the rotation and to improvements in soil properties (Beck, 1992; Garg and Chandel, 2011). The inclusion of chickpea in a rotation with cereal crops could help restore soil fertility and reduce incidence of weeds, diseases and pests (Namvar *et al.,* 2011). Chickpea has been introduced in South Africa as a new research project in response to persistent market demand and commercial interest (FAO, 2016). Preliminary research has shown that chickpea has the potential to be a high yielding winter crop in the Limpopo province, South Africa as a rotational crop (Thangwana and Ogola, 2012). The crop is likely to provide important economic advantages to smallholder farm households: it is a source of protein (an alternative to meat) and a source of cash-income and improves soil quality when grown as a break crop in cereal dominated farming systems. The purpose of the current chapter is to evaluate the effect of summer crops on grain yield and yield components of the succeeding winter chickpea.

7.2 Materials and methods

Full experimental details are given in chapter 3, but a brief summary is described in this section. The study is a component of long-term summer- winter crop rotations cropping system. The field experiment was established in summer 2016/17 at the University of Venda, South Africa but the current study is based on two winter seasons i.e. 2017 and 2018. Experimental materials consisted of summer crops [maize (*Zea mays*), bambara groundnut (*Vigna subterranea*), cowpea (*Vigna unguiculata*), mung bean (*Vigna radiata*)], Fallow and winter crops [chickpea (*Cicer arietinum*) - mustard (*Brassica rapa*)] and summer-winter crop rotation. The experiments were laid out in a randomized complete block design (RCBD) with three replicates. The current chapter is based on the residual effect of combination treatments consisting of summer and winter crop rotations on grain yield and yield components of chickpea. In the first experiment (2017) winter chickpea was succeeding first summer (2016/17) planting. In the second experiment (2018) chickpea succeeded 2 combination treatments consisting of (S1) first summer planting (2016/17) – (W1) first winter planting (2017/18) – (S2) second summer planting (2018/19). The treatment combinations are given in Figure 2a and 2b.

Grain yield and yield components of chickpea were determined at harvest maturity. All plants from four inner rows, in a sample area of 4m^2 were cut at ground level. The pods were manually removed from all the harvested plants and counted to determine number of pods per plant. The pods were manually threshed by hand, and the number of seeds per pod was determined. All the seeds were air-dried and weighed to determine the grain yield (kg ha^{-1}). The sub-samples of the seeds were used to determine 100 seed weight (100-SW). All data obtained were subjected to analysis of variance using the general linear model of Genstat 18th Edition. Significant differences between treatment means were compared using standard error of difference (SED) at the 5% level of significance. Correlation analyses for yield and yield components were also determined to assess the relationship between parameters. Independent samples t-test was used to compare the differences between experiments and soil depths.

7.3 Results

7.3.1 Grain yield and yield components

Summer and winter crop rotations had no significant effect on mean number of pods per plant, number of seeds per pod, 100 seed weight and grain yield in both 2017 and 2018 growing seasons (Table 7.1 & 7.2). However, the crop produced greater (by 21.7%) number of pods per plant in 2018 growing season compared to 2017, averaging 40.16 and 25.8, respectively (Figure 7.1 & 7.2). The number of seeds per pod did not appear to vary between treatments and experiments; on average, the crop produced one seed per pod across all rotation treatments in both 2017 and 2018. The mean 100 SW was also not significantly affected by summer and winter crop rotations in both 2017 and 2018 growing seasons. The crop produced higher grain yield in 2018 compared to 2017, 1654 kg ha^{-1} and 1319 kg ha^{-1} respectively (Figure 7.2), however, there was no significant difference between treatments in both experiments (Table 7.1 & 7.3).

Table 7.1. Residual effects of summer and winter crop rotations on grain yield and yield components of succeeding chickpea during 2017 growing season.

YEAR			**2017**		
Treatments	**Number of pods per plant**	**Number of seeds per pod**	**Pod-borer Damage (%)**	**100 Seed Weight (g)**	**Grain yield (kg ha^{-1})**
Mr	33.3	1.1	34.0	23.1	1129.3
Ck	17.9	1.5	50.0	21.3	1082.9
B	20.9	1.5	49.5	22.3	1112.8
Cw	20.6	1.3	40.3	21.9	1160.8
M	28.9	1.2	38.0	23.7	1549.5
F	33.3	1.1	39.3	24.7	1881.0
P-Value	**ns**	**ns**	**ns**	**ns**	**ns**
LSD	19.85	0.51	22.19	3.34	21.54
CV (%)	10.8	12.32	14.37	8.10	16.71

ns = not significant, ***** Significant at 5% (P<0.05), **CV** = Coefficient of variation, **LSD** = Least Significant Difference. **Mr =** Maize rotational, **B** = Bambara, Cw = Cowpea, **M** = Maize permanent, **F** = Fallow.

Table 7.2 Residual effects of summer and winter crop rotations on grain yield and yield components of succeeding chickpea during 2018 growing season.

YEAR	**2018**			
Treatments	**Number of pods per plant**	**Number of seeds per pod**	**100 Seed Weight (g)**	**Grain yield (kg ha^{-1})**
Mr-Mt-B	46.8	1.8	24.0	1778.4
Ck-Mt-Mr	48.5	1.4	21.8	1930.0
B-Mt-Cw	35.7	1.7	17.5	1521.0
Cw-Mt-F	35.7	1.3	20.0	1575.4
M-Mt-Mb	37.7	1.2	18.8	1682.8
F-Mt-M	36.4	1.5	21.5	1736.1
P-value	**ns**	**ns**	**ns**	**ns**
LSD	11.46	0.60	5.79	636.49
CV (%)	15.68	22.28	15.46	26.51

ns = not significant, ***** Significant at 5% ($P<0.05$), **CV** = Coefficient of variation, **LSD** = Least Significant Difference. **Mr =** Maize rotational, **B** = Bambara, **Cw** = Cowpea, **M** = Maize permanent, **F** = Fallow. **Mr-Mt-B** = Maize rotational-Mustard-Bambara, **Ck-Mt-Mr** = Chickpea-Mustard-Maize rotation, **B-Mt-Cw** = Bambara-Mustard-Cowpea, **Cw-Mt-F** = Cowpea-Mustard-Fallow, **M-Mt-Mb** = Maize permanent-Mustard-Mungbean, **F-Mt-M** = Fallow-Mustard-Maize permanent.

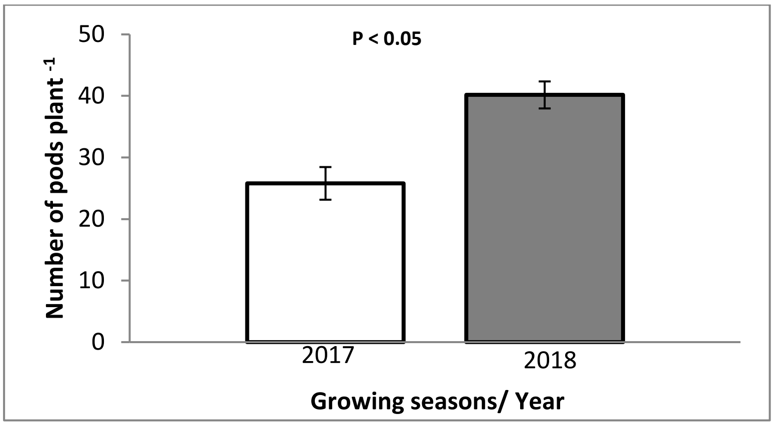

Figure 7.1. Comparison of mean number of pods per plant between 2017 and 2018 growing seasons using t-test.

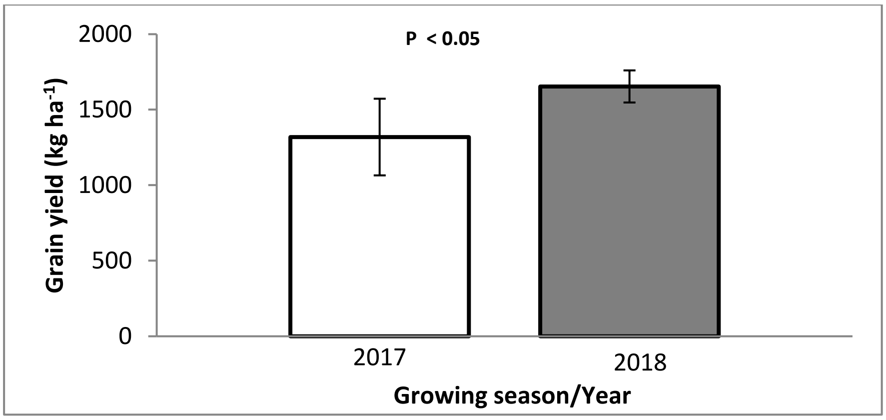

Figure 7.2. Comparison of mean grain yield between 2017 and 2018 growing seasons using t-test.

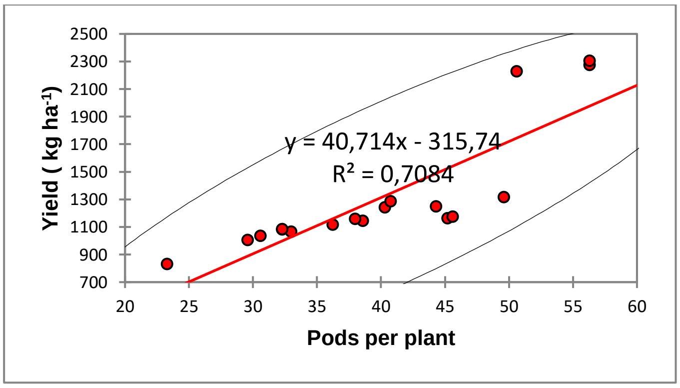

Figure 7.3 Relationship between grain yield and pods per plant of succeeding chickpea for 2018 winter season

7.4 Discussion

The stability of yield is an important characteristic to be considered when judging the value and sustainability of a cropping system. In the current study, summer and winter crop rotations had no significant effect on mean number of seeds per pod, number of pods per plant, 100 seed weight, and grain yield in both 2017 and 2018 growing seasons. However, the independent t-test revealed a statistical difference on grain yield between growing seasons; greater grain yield was obtained in 2018 growing season compared to 2017 growing (Figure 7.2). The significant difference of grain yield between experiments was not entirely due to summer and winter crop rotation but was associated with the number of pods per plant. Correlation analysis showed a positive correlation between number of pods per plant and grain yield (Figure 7.3). This is in line with results of Thangwana and Ogola (2012), they reported greater (13.3%) grain yield with desi than kabuli type and was associated with greater number of pods per plant. The number of pods per plant and seeds per pod have been reported the source of yield (Aytac and Kinaci, 2009). The variation in grain yield across growing seasons associated with a similar variation in number of pods per plant. The crop produced higher number of pods per plant in 2018 compared to 2017. Lower number of pods per plant obtained in 2017 could be attributed to pod borer damage; the crop was damaged by pod borer during podding stage in 2017 growing season. It is estimated that major biotic and abiotic stresses reduce at least 50% realizable potential yield of chickpea in the major production regions of the world (Ryan, 1997). Much of these losses occur at flowering and podding time. Therefore, spraying for pod borer after flowering is advocated; to prevent yield losses. There was no significant difference on mean number of seeds per pod; on average, the crop produced 1 seed per pod both in 2017 and 2018 growing season. The yield increase associated with crop rotations has been attributed to increased nitrogen supply, improved soil water availability, soil nutrient availability, soil structure, soil microbial activity and weed control, decreased insect pressure and disease incidence, and the presence of phytotoxic compounds and/or growth-promoting substances originating from crop residues have also been identified as contributing factors (Karlen et al., 1994). The results of the current study were not unexpected, because the effects of crop rotation on soil properties and crop productivity tend to be long-term and are unlikely to be observed during the first few years of the rotation. In a long term (40 years) field experiments to determine the effect of crop rotation and fertilization on maize and wheat yields and yield stability, Berzsenyi *et al*. (2000) reported greater grain yield of maize and wheat compared to monoculture. Greater grain yields were obtained in crop sequences after leguminous crops and also after non-leguminous crops and this beneficial effect has been attributed to availability of extra nitrogen and other rotational effect (Berzsenyi *et al*., 2000).

7.5 CONCLUSSION

Summer and winter crop rotations had no significant effect on mean grain yield, number of pods per plant, number of seeds per pod and 100-SW of chickpea in both growing seasons (2017 & 2018). Grain yield and number of pods per plant were only significantly different between growing seasons however treatments did not play a role. Despite the no-response, all the reported grain yield values were within the optimum grain yield for chickpea crop. Therefore, these results suggest that chickpea can be an important winter rotational crop, and highly be integrated into summer cereal-winter fallow cropping system in the semi-arid regions of Limpopo province, South Africa.

CHAPTER 8: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

8.1 General discussion

The use of crop rotation can provide sustainability for an agricultural production system by improving soil fertility and increasing nutrient use efficiency. Crop rotation generally results in increased organic matter content compared to continuous cropping or fallow. Soil organic matter influences biological activity, serves as a nutrient reservoir, and impacts soil aggregation. Furthermore, crop rotation gives various nutrients to the soil and also mitigates the build-up of pathogens and pests that often occurs when one species is continuously cropped and can also improve soil structure and fertility by alternating deep-rooted and shallow-rooted plants. However, crop rotation requires time in preparing fields for crop ahead and requires additional equipment’s. Aside from different types of equipment’s, crop rotation also requires a set of skills and knowledge. Moreover, certain climates and locations are more favourable for monocultures because there are certain crops that cannot grow well in a specific type of temperature and soil conditions.

Summer cereal (maize) and winter fallow is a mostly practiced cropping system in the semi-arid regions of South Africa, however, this has caused significant loss of organic matter and depletion of nutrient reserves in soils overtime. Consequently, crop yields are often low. Crop rotation systems have been shown to improve soil fertility and crop nutrient absorption efficiency, thus increasing the production potential through nutrient cycling. Therefore, this study was conducted to examine the effect of summer and winter crop rotations on crop productivity of chickpea and selected soil chemical and soil biological indicators. The specific objectives of the study were to assess the residual effect of summer and winter rotations on:

(i) Soil chemical properties and biological indicators

(ii) Crop phenology, growth and yield of succeeding winter chickpea

The statistical analysis revealed no significant effect of summer and winter crop rotations on crop productivity (phenology, growth and yield) of chickpea and selected soil chemical properties and biological indicators. The no-response on chemical and biological indicators of the soil was not beneficial in terms of crop productivity. However, the results of the current study were not unexpected, because the effects of crop rotation on crop productivity and on soil properties tend to be long-term and are unlikely to be observed during the first few years of the rotation. Although there were hardly any differences between treatments, there were significant differences between soil depths, experiments and years/growing seasons.

Greater soil NO_3^- , NH_4^+, P and organic carbon were obtained in experiment II compared to experiment I and was attributed to high crop residues input. Relatively higher soil P was obtained at 0-20cm compared to 20-40cm depth. Lower P at 20-40cm could be explained by lack of deep incorporation of organic matter to lower depth as the crop residues were incorporated with manually operated hand hoe. Thus, farmers need to incorporate crop residues deep in the soil after the crops have been harvested. In addition, greater soil NO_3^- and NH_4^+ in experiment II is also likely due to biological nitrogen fixation by chickpea. This is in line with the study of Gan *et al. (*2010) that inoculated chickpea fixed up to 29% of N. Therefore, this result suggests that the inclusion of a legume crop in a crop rotation can improve soil fertility and benefit resource poor farmers.

Generally, there were no clear effects of treatments on crop growth, grain yield and yield components, however, 2018 growing season resulted in higher productivity in comparison to 2017. In contrast, the crop produced taller plants and flowered earlier in 2017 compared to 2018 growing season. The results reported in the current paper demonstrated that the variation in weather parameters between years is one of the main causes of seasonal variation in chickpea productivity. The variation in grain yield across seasons was associated with a similar variation in number of pods per plant. Several studies have associated the higher grain yield with higher number of pods per plant (Aytac and Kinaci, 2009; Thangwana and Ogola, 2012). However, all the grain yield values recorded in the present study were within the average commercial seed yields reported for chickpea. The study findings clearly indicate the possibility of including chickpea as winter crop in the summer cereal and winter fallow and can gradually restore some of the organic matter lost in fallow systems. A study with a more prolonged period would provide useful insight. Thus, further research is needed to clarify the effect of summer and winter crop rotation.

8.2 General conclusion

The results of this research showed no clear effects of treatments on crop productivity and selected soil chemical and biological indicators. However, there was statistical difference between depths, experiments and growing season/year. Overall, greater soil NO_3^- , NH_4^+, P and organic carbon were obtained in experiment II compared to experiment I. Greater soil NO_3^- , NH_4^+, P and organic carbon recorded in experiment II will likely enrich the soil nutrients for succeeding summer crops that follow in the rotation and consequently increase the yield. This is likely to be beneficial to cash-constrained farmers who cannot afford to buy commercial fertilizers for cereal production. Crop phenology and growth were not significantly affected by summer and winter crop rotations, and treatment did not play a role in this regard. Grain yield values recorded in the current study compare favourably with the average commercial grain yields reported for chickpea. This suggests that summer – winter cropping systems may be a key to meet the ever-growing demand for food and to address the increasing concern of environmental quality. However, the non-significant difference across treatments reinforces the need for long-term experiments to assess the sustainability of this cropping system to reach a more reliable conclusion.

8.3 Recommendation

- Although there were no clear treatment effects on crop productivity, soil chemical properties and soil biological indicators, the study shows that there is need for long-term experiments to assess the sustainability of cropping systems.
- Most soil chemical and biological properties remained relatively constant. Therefore, these temporal dynamics emphasize the need for research on long-term effects on soil properties and crop productivity.
- Quantification of N –fixation in future studies.
- Gross margin analysis to assess the cost-benefit ratio of the various cropping systems.

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