EVALUATION OF COWPEA RUST (Uromyces phaseoli) ON GROWTH AND YIELD OF SELECTED IMPROVED COWPEA (Vigna unguiculata (L.) Walp) GENOTYPES IN TWO CROPPING SYSTEMS IN WESTERN KENYA

BY

WABWAYI NDALIRA

BSc. In Agriculture (Egerton University)

A RESEARCH THESIS SUBMITTED TO THE SCHOOL OF POST-GRADUATE STUDIES IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS OF THE AWARD OF THE DEGREE OF MASTERS OF SCIENCE IN AGRONOMY (CROP PROTECTION) OF THE SCHOOL OF AGRICULTURE AND NATURAL RESOURCE MANAGEMENT

KISII UNIVERSITY

MARCH, 2021
DECLARATION AND RECOMMENDATION

DECLARATION BY THE CANDIDATE

I hereby declare that this research thesis is my original work and has not been presented for award of a degree or diploma in this university or any other university.

WABWAYI NDALIRA ________________________________

MAN19/50016/15 Signature Date

Department of Crop and Soil Sciences,
School of Agriculture and Natural Resource Management.

RECOMMENDATION BY THE SUPERVISORS

This research thesis has been submitted for examination with our approval as University supervisors.

DR. JUDITH ACHIENG ODHIAMBO, PhD ____________________________

School of Agriculture and Natural Resource Management,
Kisii University.

PROF. EVANS BASWETI, Ph.D ______________________________

School of Agriculture and Natural Resource Management,
Kisii University.
COPYRIGHT

All right are reserved. No part of this thesis or information herein may be reproduced, stored in a retrieval system or transmitted in any form or by any means such as electronic, mechanical, photocopying, recording or otherwise without the prior written permission of the author or Kisii University on that behalf.

©2021, Wabwayi Ndalira.
DEDICATION

This work is dedicated to my dear mother Esther Nasambu, my wife Beatrice Tenge and my daughters Angela, Julie and Gloria for their tireless effort to see me up to this stage. God bless you.
ACKNOWLEDGEMENTS

I am highly grateful to the Postgraduate School, for guidance and support during this undertaking. My heartfelt credit goes to my supervisors: Dr. Judith Achieng Odhiambo and Prof. Evans Basweti for their profitable time, endurance and continuous advice throughout the research period. Their benefaction in developing research purpose, inspirations, detailed discussions of the subject and encouragements are highly acknowledged. I would also like to appreciate staff members of Kenya Plant Health Inspectorate Service (KEPHIS) Kisumu for their support. My appreciation goes to the Kenya Agricultural Livestock Research Organization (KALRO) Kakamega and Alupe entirely especially Mrs. Christine Ndinya, Beatrice Mwenesi and Alice Were for their support during field work. Appreciation also goes to Kisii University for offering me chance, opportunity and facility to study in. I also appreciate NACOSTI who gave me the research permit without which I would have not come up with this report. Finally, I shall sincerely and humbly remain eternally grateful to my mother, siblings, relatives and friends for their help during the entire period of study.
ABSTRACT

Cowpea production is widespread among the peasant farmers of Western Kenya due to its vast environmental adaptation. Although, this crop is overwhelmed by cowpea rust (*Uromyces phaseoli* (Baarel Arth), an important pathogen, causing substantial economic yield losses and with limited management measures. This research, thus, evaluated cowpea rust disease incidence (DI) and severity (DS) on growth and yield of selected improved cowpea (*Vigna unguiculata* (L) walp) genotypes in two cropping systems in western Kenya. A research was conducted in Kenya Agricultural, Livestock Research Organization Alupe and Kakamega in two locations in Busia and Kakamega Counties respectively during short rains of 2018 and long rains of 2019. The experiment was laid in a Randomized Complete Block Design (RCBD) in split plot arrangement where cowpea genotype was a major treatment and cropping system the sub treatment. The cowpea genotypes consisted of four (4) selected improved genotypes namely Katumani 80 (K80), KVU 27-1, Tumaini, Dakawa and one local check, “Lwanda black eye” (Local) and two cropping systems; pure stand and intercropping with maize were evaluated. Data on growth, yield, disease incidence and severity were recorded. Data was subjected to Mixed model ANOVA using SAS and means separated using LSD (α =0.05). Similar trends were observed at both locations and seasons. The DI and DS were 50% and 39% respectively less in Dakawa and Tumaini compared to other genotypes with local and K80 being highly susceptible. On the other hand, DI and DS were 35% and 56% respectively less in pure stand cowpea compared to intercrop cowpea. Disease incidences and severity increased as time progressed in both Busia and Kakamega in all genotypes. The incidences and severity rose steadily from week 3 to week 12 but slightly dropped in week 15 which coincided with physiological maturity. Dakawa had 8% more leaves and 30% higher LAI than K80, local variety, Tumaini, and KVU 27-1 which were similar statistically. The results indicate that Dakawa cowpea genotype has potential resistance to cowpea rust and the conditions could be improved by planting cowpea in pure stand.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECLARATION AND RECOMMENDATION</td>
<td>ii</td>
</tr>
<tr>
<td>COPYRIGHT</td>
<td>iii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>iv</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>v</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>vi</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>x</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF PLATES</td>
<td>xii</td>
</tr>
<tr>
<td>LIST OF APPENDICES</td>
<td>xiii</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS AND ACRYNOMYS</td>
<td>xv</td>
</tr>
<tr>
<td>CHAPTER ONE</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Background of the Study</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Statement of the Problem</td>
<td>5</td>
</tr>
<tr>
<td>1.3 Justification</td>
<td>6</td>
</tr>
<tr>
<td>1.4 Objectives of the Study</td>
<td>8</td>
</tr>
<tr>
<td>1.4.1 Overall objective</td>
<td>8</td>
</tr>
<tr>
<td>1.4.2 Specific objectives</td>
<td>8</td>
</tr>
<tr>
<td>1.5 Hypotheses</td>
<td>9</td>
</tr>
<tr>
<td>1.6 Assumption of the Study</td>
<td>9</td>
</tr>
<tr>
<td>1.7 Delimitation of the Study</td>
<td>9</td>
</tr>
<tr>
<td>1.8 Limitation of the Study</td>
<td>10</td>
</tr>
<tr>
<td>1.9 Conceptual Framework</td>
<td>10</td>
</tr>
<tr>
<td>1.10 Definition of Terms</td>
<td>11</td>
</tr>
<tr>
<td>CHAPTER TWO</td>
<td>12</td>
</tr>
<tr>
<td>2.0 LITERATURE REVIEW</td>
<td>12</td>
</tr>
</tbody>
</table>
2.2 Global Cowpea Production ................................................................. 12
2.3 Environmental Conditions that Influence Growth and Yield of Cowpea ................................................................. 13
2.4 Potential Yields and Actual Yields to Define Yield gaps of Cowpea ................................................................. 15
2.5 Economic Importance of Cowpea Production ................................................................. 17
2.6 Cropping System in Cowpea Production ................................................................. 18
2.7 Abiotic and Biotic Stresses Limiting Cowpea Production ................................................................. 23
  2.7.1 Cowpea rust as a major biotic stress in cowpea production ................................................................. 24
2.8 Biology and Etiology of Cowpea Rust ................................................................. 25
2.9 Yield Losses Attributed to Cowpea Rust Infection ................................................................. 26
2.10 Cowpea Genotypes ................................................................. 27
2.11 Research Gaps ................................................................. 28

CHAPTER THREE .................................................................................... 31

3.0 MATERIALS AND METHODS ................................................................. 31

3.1 Geographical Description of the Study Area ................................................................. 31
3.2 Research Design ................................................................. 31
3.3 Data Collection Procedure ................................................................. 32
  3.3.1 Cowpea rust disease incidence ................................................................. 33
  3.3.2 Cowpea rust disease severity ................................................................. 33
  3.3.3 Growth parameters ................................................................. 34
  3.3.4 Yield and yield component parameters ................................................................. 34
3.4 Data Analysis and Presentation ................................................................. 35
  3.4.1 The experimental model used ................................................................. 35
  3.4.2 Statistical analysis ................................................................. 36

CHAPTER FOUR .................................................................................... 37

4.0 RESULTS AND DISCUSSION ................................................................. 37

4.1 RESULTS ................................................................. 37
  4.1.1 Weather and Baseline Soil Characteristics during Study Period ................................................................. 37
  4.1.2 Influence of Cowpea Genotype on Plant Height, Number of Leaves, Leaf Area Index, Disease Incidence and Disease Severity ................................................................. 39
4.1.3 Influence of Cropping System on Cowpea Rust Disease Incidences, Severity, Number of Leaves and Leaf Area Index ................................................................. 42
4.1.4 Yield and Yield Components of Different Cowpea Genotypes ......................................................... 43
4.1.5 Influence of Cropping System on Yield and Yield Components .......................................................... 45
4.1.6 Cowpea Rust Disease Incidence and Severity Progression with Growth Stages Disease Incidence (DI) ................................................................................................................. 47
4.1.7 Influence of Interaction of Genotype and Cropping System on Disease Incidence and Severity .......................................................................................................................... 49
4.1.8 Influence of Interaction of Genotype and Cropping System on Cowpea Yield and Yield Components ...................................................................................................................... 51

4.2 DISCUSSION ........................................................................................................................................ 55

CHAPTER FIVE .......................................................................................................................................... 64

5.0 CONCLUSION AND RECOMMENDATIONS ....................................................................................... 64

5.1 CONCLUSIONS .................................................................................................................................... 64

5.2 RECOMMENDATIONS .......................................................................................................................... 66

REFERENCES ............................................................................................................................................. 67

APPENDICES ............................................................................................................................................. 90
LIST OF TABLES

Table 1: Top world production of cowpea in 2012 (Metric tons) ........................................... 13
Table 2: World cowpea leaf production in 2016 (Faostat 2017) ............................................. 13
Table 3: Soil physical and chemical classification Kakamega and Busia ................................. 39
Table 4: Influence of cowpea variety on cowpea plant height, number of leaves, rust
incidences (DI), severity (DS) and Leaf Area Index (LAI) in Busia ..................................... 41
Table 5: Influence of cowpea genotype on cowpea plant height, number of leaves, rust
disease incidences (DI), disease severity (DS) and Leaf Area Index (LAI) in Kakamega ......................... 41
Table 6: Influence of cropping system on plant height, number of leaves, cowpea rust
incidences (DI), severity (DS) and Leaf Area Index (LAI) in Busia ........................................... 42
Table 7: Influence of cropping system on plant height, number of leaves, cowpea rust
incidences (DI), severity (DS) and Leaf Area Index (LAI) in Kakamega ................................. 43
Table 8: Influence of cowpea genotype on number of pods per plant, leaf weight and
grain yield in Busia ......................................................................................................................... 44
Table 9: Influence of cowpea genotype on number of pods per plant, leaf weight and grain
yield in Kakamega ......................................................................................................................... 45
Table 10: Influence of cropping system on the number of pods per plant, leaf weight and
grain yield in Busia ......................................................................................................................... 46
Table 11: Influence of cropping system on the number of pods per plant, leaf weight and
grain yield in Kakamega ......................................................................................................................... 46
LIST OF FIGURES

Figure 1: Conceptual framework of the study ................................................................. 10

Figure 2: Monthly cumulative rainfall (mm) and average air temperatures (°C) for
Kakamega during study period .................................................................................... 38

Figure 3: Monthly cumulative rainfall (mm) and average air temperatures (°C) for Busia
during study period .................................................................................................... 38

Figure 4: Progression of disease incidence on cowpea genotypes in Busia and Kakamega. .......................... 48

Figure 5: Progression of disease severity on cowpea genotypes in Busia and Kakamega . 49

Figure 6: Influence of Interaction of genotype and cropping system on disease incidence
and severity in Busia ..................................................................................................... 50

Figure 7: Influence of interaction of genotype and cropping system on disease incidence
and severity in Kakamega ............................................................................................ 50

Figure 8: Influence of interaction of genotype and cropping system on number of pods
per plant in Busia .......................................................................................................... 51

Figure 9: Influence of interaction of genotype and cropping system on number of pods
per plant in Kakamega ................................................................................................ 52

Figure 10: Influence of the interaction between genotype and cropping system on leaf
weight in Busia .............................................................................................................. 53

Figure 11: Influence of the interaction between genotype and cropping system on leaf
weight in Kakamega .................................................................................................... 53

Figure 12: Influence of the interaction between genotype and cropping system on grain
yield in Busia ............................................................................................................... 54

Figure 13: Influence of interaction between genotype and cropping system on grain yield
in Kakamega ................................................................................................................ 55
LIST OF PLATES

Plate 1: Cowpea rust infestation on K80 Busia (a) and Kakamega (b) and Tumaini genotype at week 4 (x)........................................................................................................ 47

Plate 2: Cowpea rust tolerant Dakawa genotype at Busia (c) and Kakamega (d) and susceptible local (e). ............................................................................................................... 47

Plate 3: Cowpea rust tolerant Tumaini (f), KVU 27-1 moderately resistant (g) and Susceptible K80 (h) at Busia........................................................... 47
LIST OF APPENDICES

Appendix 1: Analysis of Variance on the effect of Cowpea Rust on Number of Leaves at Busia
Appendix 2: Analysis of Variance on the effect of Cowpea Rust on Number of Leaves at Busia
Appendix 3: Analysis of Variance on the effect of Cowpea Rust on Plant height at Kakamega
Appendix 4: Analysis of Variance on the effect of Cowpea Rust on Number of Leaves at Kakamega
Appendix 5: Analysis of Variance on the effect of Cowpea Rust on Disease Severity at Kakamega
Appendix 6: Analysis of Variance on the effect of Cowpea Rust on Disease incidences at Kakamega
Appendix 7: Analysis of Variance on the effect of Cowpea Rust LAI at Kakamega
Appendix 8: Analysis of Variance on the effect of Cowpea Rust on Disease Severity at Busia
Appendix 9: Analysis of Variance on the effect of Cowpea Rust on Disease incidences at Busia
Appendix 10: Analysis of Variance on the effect of Cowpea Rust on Leaf Area Index at Busia SR
Appendix 11: Analysis of Variance on the effect of Cowpea Rust on Number of pods per plant at Busia
Appendix 12: Analysis of Variance on the effect of Cowpea Rust on leaf biomass kg ha⁻¹ at Busia
Appendix 13: Analysis of Variance on the effect of cowpea rust on grain yield (kg ha⁻¹ at Busia
Appendix 14: Analysis of Variance on the effect of Cowpea Rust on Number of pods per plant at Kakamega
Appendix 15: Analysis of Variance on the effect of Cowpea Rust on leaf biomass kg ha\(^{-1}\) at Kakamega

Appendix 16: Analysis of Variance on the effect of Cowpea Rust on Grain yield kg ha\(^{-1}\) at Kakamega
LIST OF ABBREVIATIONS AND ACRONYMS

AFFA- Agriculture, Fisheries and Food Authority
ANOV- Analysis of Variance
CaO- Calcium Oxide
Cm- Centimeters
OECD- Organization for Economic Cooperation and Development
RCBD- Randomized Complete Block Design
FAOSTAT- Food and Agriculture Organization of the United Nations
IITA- International Institute of Tropical Agriculture
MoA- Ministry of Agriculture
MgO- Magnesium Oxide
MT- Metric tons
NPK- Nitrogen Phosphorus Potassium
LER- Land Equivalent Ratio
LM2- Low mid altitude
UM2- Upper mid altitude
LA1- Leaf Area Index
SAS- Statistical Analysis System
NACOSTI- National Commission for Science, Technology and Innovation
CHAPTER ONE

1.1 Background of the Study

Cowpea (*Vigna unguiculata* (L.) Walp) is a dicotyledonous leguminous herb from the Fabaceae family and sub-family, Fabiodeae (Verdcourt, 1970; Marechal et al., 1978). It is widely grown in the mid and lowland altitude dry savannas of Sub-Saharan Africa occasionally as pure cultivar but usually intercropped with cereals such as millet and sorghum (Agbogidi, 2010). Cowpea (*Vigna unguiculata* (L.) Walp is also mostly grown as a grain in Asia, North and South America, but also as a leaf vegetable and fodder crop. The production of cowpea is more common among the subsistence smallholder farmers due to its wide ecological habitation and tolerance to several biotic and abiotic strains that includes pests, diseases and drought. It is an essential food source and is evaluated as an important source of protein for more than 200 million people in sub-Saharan Africa and among the top ten fresh leafy vegetables in China (OECD, 2015).

Cowpea as a crop has significant contribution to the occupation and living standards of millions of relatively poor people in low-income countries of the Sub-Saharan Africa (FAO, 2002). It however also complements the low-quality cereal or root and tuber protein crops consumed regularly in tropical countries of Africa (Kitch et al., 1998; Karikari and Molatakgosi, 1999). The cowpea grains constitute 23-25% protein and 50-67% starch dry matter bases on average (Quin, 1997). From a single plant several products such as green leaves, immature pods, immature and mature seeds can be harvested. Discreet and decisive awareness to cowpea would assist approximately 850 million people in the world with high occurrence of undernutrition in less developed countries of Africa (FAO, 2006).
Cowpea has many ecological benignant attributes normally non-food related. It is an effective biological nitrogen fixing, drought and heat-resilient leguminous crop (Saidi et al., 2010). Cowpea crop is either planted as a pure crop or intercropped with other crops such as leaf vegetables, maize, finger millet, sorghum, beans, pigeon peas, bananas and others in many African countries, (Bittenbender et al., 1984; Singh et al., 1997). However whether in pure crop or intercrop, spreading indeterminate cowpea genotype serves as a ground cover thus, smothering weeds as well as protecting soil against erosion and soil moisture losses. Additionally, various cowpea genotypes stimulates suicidal germination of the *Striga hermonthica* seed, a parasitic weed that infests cereals with noxious effects (Quin, 1997).

World cowpea production was estimated to be 5.72 million tons of which Africa producing 5.42 million tons; East Africa with 0.52 million tons and Kenya produces about 122,682 tons (FAO, 2013). In Kenya, production potential is estimated at 1.6 tonha\(^{-1}\), indicating there is a huge yield gap in cowpea grain production. The situation is worse for Western Kenya where yields are much lower than the average 0.53 tonha\(^{-1}\)(MoALF, 2015). However several limiting factors are considered to sustainably grow cowpea. Understanding constricting factors at crucial growing stages highly matters in any farming system. For example, influence of severe drought in relation to phenology and extreme night temperatures as it influences flowering, podding and seed development are shown out as among the major cowpea production curbs (Padi, 2004). Furthermore, vulnerability to some of insect pests and diseases is farther important factor limiting continuous and sustainable cowpea production. Innumerable agronomic assessment trials were so far conducted to develop cowpea genotypes that would fetch high grain yield regardless of
stressing factors in place. The agronomic evaluations have pointed out that cowpea genotypes bred in one agro-ecology of the world usually cannot perform well in other agro-ecology (Padi, 2004).

Singh et al (1997) reported diseases, insect pests and parasitic weeds as the key vital factors responsible for low cowpea yield in Nigeria and the same could explain the low cowpea yields in Kenya. However, to narrow down the yield gap between actual and potential yield is a bottleneck that needs to be solved by both researchers and development stakeholders. Reducing of the yield gap via scientific research and development efforts can also result into boosting of nutrition, income and environmental safety among households through reduced pressure on land. Moreover limited statistics is available on the impact of biotic constraints especially cowpea rust (*Uromyces phaseoli*) on growth and yield of cowpea in Kenya.

Cowpea rust which appeared in the late 1990s has been identified as a big threat to cowpea production in East Africa particularly in Kenya and other regions worldwide (Allen et al., 1998). Cowpea rust occurs widely in Kenya and cowpea cultivars released usually lose their resistance within a short period of time. Genotypes with high incidence of resistance have to be bred constantly to replace the ones that are becoming susceptible and those already susceptible. Farmers apply fungicides several times within a growing season to obtain a clean crop which has been proved not to be economical due to small land size.

Use of appropriate cropping system has been proven to provide numerous environmental benefits as well as contribute to pest and disease management (Ding et al., 2015). Research indicates that planting cowpea in pure stand yields more than intercrop (Francis, 1986). Despite the higher yields from pure stand cropping system, land is limiting in western
Kenya and this compels farmers to adopt alternative cropping systems like intercropping system, which entails growing two or more crops simultaneously on the same piece of land at the same time or season. It is a traditional farming system that is common among subsistence farming communities. Even though many crops are intercropped, legume intercropping is widespread as legumes have the ability of biological nitrogen fixing (Vanlauwe et al., 2016). Also intercropping increases yield per unit area as well as increase in economic output as compared to pure stand cropping system. In addition, it is generally conceived that one element of an intercropping system may act as a barrier or buffer against the proliferation of biotic causing pathogens within the intercropping arrangement (Henrik and Peeter, 1997). For instance, intercropping maize-cowpea has been found to manage the stem borer population in maize to low levels (Henrik and Peeter, 1997). In other instances, the canopy in the intercropping arrangement may create a favourable microclimate for the proliferation, infection and spread of disease-causing pathogens. Thus, the influence of intercropping on the degree of infestation and spread of diseases have yielded varied results (Boudreau, 2013). For instance, intercropping maize with groundnuts has been found to increase rust incidence and severity due to canopies of the intercrop components increasing relative humidity and lowering temperature creating conducive environment for fungal disease outbreak (Msuku and Edje, 1980).

Sustainable cropping system is achieved when the cropping system design is based on the most important crops for particular region. Since maize is a key food crop in most Kenyan region especially western Kenya, development of sustainable cropping system for management of cowpea rust disease which is built around maize production is necessary.
It is further worth noting that for instance, there is no specific modest mitigation measure to prevent rust infection particularly in different agro-ecological regions (Mensah et al., 2018). However, there is a need to bridge cowpea yield gap in order to improve households’ food and nutrition, income as well as protecting the environment. Therefore, the main reason of the research is to evaluate the occurrence of cowpea rust and its performance impact on improved cowpea genotypes in maize-cowpea intercrop in upper mid-altitude and low altitude agroecosystems in Western Kenya.

1.2 Statement of the Problem

Major foliar fungal diseases of cowpea include brown rust (*Uromyces phaseoli*), Cercospora leafspot, web blight and Septoria leafspot. Cowpea rust is important restraint to cowpea production in western Kenya (KALRO, 2013). Crop loss of 18 -50 % has been reported as a result of cowpea major pest and diseases (Marley, 2013). Brown rust is capable of causing yield losses of between 18 to 100% in humid and tropical zones (Kimani et al., 2002; Monda et al., 2003). The current intervention strategies have not offered a long lasting solution. Farmers in the region are still cultivating late maturing, low yielding and rust susceptible varieties (Saidi et al., 2007). Moreover, the available cowpea genotypes are grown broadly without taking into account their suitability and adaptability to the conditions prevailing in different agro-ecological zones (Karikari and Molatakgesi, 1999) and are generally of low yield potentials of between 102-239 kg/ha (Kimiti et al., 2009).

This situation locks the expected benefits of cowpeas to poor households in terms of improving family nutrition, income, and improved soil fertility (Singh et al., 2003). Although numerous studies have revealed existence of genetic variability among cowpea
genotypes, there is limited published information on cowpea genotypes resistant to cowpea rust among the varieties common in western Kenya. The existence of cowpea lines from ICRISAT and Kenya Agriculture Livestock Research Organization (KALRO) that show potential tolerance to cowpea rust could offer a solution to farmers in Western Kenya, however they are less understood by farmers and their tolerant levels to cowpea rust are not documented. Therefore, the current research aimed to understand the impact of cowpea rust on growth, development and yield of improved cowpea genotypes beside the suitable cropping system to be adopted by farmers in western Kenya.

1.3 Justification
Cowpea is vulnerable to a wide range of biotic pathogens, which causes economic yield losses of all the growth stages of the crop. Reports on cowpea rust incidence in East Africa indicate that the disease is becoming important in Kenya especially in western part due to weather vagaries (Owade et al., 2020). However, little or no data is available on the occurrence and spread of the disease among cowpea genotypes under different agro-ecological zones.

According to KALRO Report (2013), some farmers have knowhow on the insect pest management methods but have little knowledge of managing cowpea diseases. The most commonly applied control measure against biotic stresses is by using synthetic pesticides whose intensive and indiscriminate application in agriculture has yielded many problems to the environment. The problems consist of water, soil, air, animals and food pollution; poisoning of farmers; eradication of non-target organisms; and preference of fauna and flora towards tolerance to certain pesticides (Nidhi and Trivedi, 2002).
The usage of resistant/tolerant crop genotypes is the most economical, easiest, and safest way of crop disease management (Agrios, 2005). It is therefore beneficial to give suitable research attention to finding cowpea genotypes tolerant to rust so as to minimize losses caused by the disease in a way that will not bear threat to the environment, human and beneficial organisms. Cowpea can be planted as pure crop or intercrop. Research indicates that planting cowpea in pure stand yields more than intercrop (Francis, 1986). It is believed that in intercropping arrangement, single elemental crop usually act as a barrier or buffer against the infestation, spread and distribution of biotic pathogens within the arrangement. For instance, the stem borer is managed to low levels when intercropping maize-cowpea (Henrik and Peeter, 1997). However, findings of Msuku and Edje (1980) indicated that intercrop of maize-cowpea and groundnuts increases rust incidence and severity due to canopies of the intercrop components increasing relative humidity and lowering temperature conditions favourable for disease development and spread. Also, Chemeda and Jonathan (2001) reported that maize-sorghum intercrop fields scored higher maize rust epidemics than sole cropped fields. Despite the higher yields from pure stand, land is limiting in western Kenya and this compels farmers to adopt intercrop regardless of the negative impact of the intercrop on cowpea crop growth and yield.

Therefore, this research sought to demonstrate the best option between pure stand and intercrop as regards cowpea rust incidences and severity on growth, yield and yield components. This is important in order to guide farmers on yield potential of cowpea in their locations and what should be done to arrive at the target yields from genotypes. This will also assist breeders and regulators to identify and recommend specific genotypes for specific agro- ecological zones in the study areas and beyond.
Despite the fact that cowpea leaves, immature pods and grains are the most important parts consumed to alleviate possible food and nutritional insecurity in poor African Countries Owade et al., (2019), they are still affected by cowpea rust. The vegetable is however very rich in iron and vitamin A whose deficiencies are prevalent in sub-Saharan Africa (Owade et al., 2019). In Kenya Farmers grow cowpea both as leafy vegetable and as well as grain legume crop (Maundu, 1997). Muthoni and Nyamongo (2010) in their founding recorded that cowpea pure-crop stands are however now commonly grown for urban market for commercial leafy vegetable consumption. It is therefore important to provide farmers with tolerant or resistant genotypes to overcome the damages caused by the aforementioned cowpea rust which is the reason for investigation of this research.

1.4 Objectives of the Study

1.4.1 Overall objective

To evaluate cowpea rust \((Uromyces phaseoli)\) incidences, severity and crop performance of improved cowpea genotypes in a maize-cowpea intercropping system in two varying agro-ecosystems in western Kenya.

1.4.2 Specific objectives

1. To evaluate the incidence and severity of cowpea rust disease among selected cowpea genotypes in two cropping systems in western Kenya.

2. To assess the effect of cowpea rust disease on growth and yield of selected cowpea genotypes in two cropping systems in western Kenya.

3. To examine the effect of cropping system on cowpea rust disease incidences and severity in two agro-ecological zones in western Kenya.
1.5 Hypotheses

1. There is no significant difference in disease incidence and severity among the selected cowpea genotypes in two cropping systems in western Kenya.

2. There is no significant difference on the effect of cowpea rust on the growth and yield of selected cowpea genotypes in two cropping systems in western Kenya.

3. The significant effect of cropping system on cowpea rust incidences and severity will not differ in pure crop stand and intercropped farming arrangement in in western Kenya.

1.6 Assumption of the Study

The study was based on the following assumptions; Cowpea rust spores accumulation is prevalent in the study areas and cause significant economic yield loss to the varieties planted by farmers in Western Kenya. The selected improved cowpea genotypes vary in their resistance / tolerance to cowpea rust and local variety is susceptible though adapted to Busia and Kakamega counties. Cowpea is grown in both Kakamega and Busia counties and both areas are prone to rust incidences although rainfall vary. Cowpea is either grown as intercrop or monocrop in the two agro-ecological zones and it is mainly intercropped with maize. Cowpea rust naturally infects the genotypes. Five percent of smallholder farmers will access research findings through Kenya Agricultural, Livestock Research Organization and extension agents through multi-sectorial stakeholder platforms.

1.7 Delimitation of the Study

The study sought to determine the influence of cowpea rust incidences on the selected improved cowpea genotype and local variety in two agro-ecological zones in Western Kenya. The study was delimited to Busia and Kakamega Counties.
1.8 Limitation of the Study
The study was limited to only two seasons and sites due to funding and logistic arrangements despite need to set experiments in other regions in western Kenya. Change in weather patterns is unpredictable and unavoidable.

1.9 Conceptual Framework
The experiment adopted a linear model where independent variables (cropping system, cowpea genotype with time) and their interaction influenced dependent variables (grain yield, green leaf biomass, cowpea rust incidences and severity, plant height, leaf area index and number of leaves (Figure1).

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Dependent variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cowpea genotype</td>
<td>Grain yield</td>
</tr>
<tr>
<td>Cropping System</td>
<td>Above ground biomass</td>
</tr>
<tr>
<td>Variables Interaction</td>
<td>Cowpea rust incidences</td>
</tr>
<tr>
<td></td>
<td>Cowpea rust severity</td>
</tr>
<tr>
<td></td>
<td>Leaf Area Index</td>
</tr>
<tr>
<td></td>
<td>Number of Leaves</td>
</tr>
<tr>
<td></td>
<td>Plant Height</td>
</tr>
<tr>
<td></td>
<td>Number of leaves</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intervening variables</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weeding</td>
<td></td>
</tr>
<tr>
<td>Pest control</td>
<td></td>
</tr>
<tr>
<td>Fertilizer application</td>
<td></td>
</tr>
<tr>
<td>Weather condition</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: Conceptual framework of the study
The influence of modifying / intervening variables which are basically crop management practices such as weeding, fertilizer application, pest management and weather conditions were minimized through replication and randomization.

1.10 Definition of Terms

Cowpea genotype: Refers to genetic makeup of cowpea varieties.

Cropping system: This is the type and sequence of crops grown and practices used for growing them.

Disease Incidences: Is the number of plants infected by a disease within a population during specific period.

Disease Severity: The percentage of plants affected by the disease.

Leaf Area Index: Refers to as the one sided green leave area per unit ground surface area.

\[ A = b \times L \times W \]

Where;

A = leaf area
b = leaf area factor=0.75
L = leaf length
W= maximum leaf width

Leaf Area Index (LAI) = \( \frac{A}{L \times W} \times 0.75 \) (Wiersma and Bailey, 1975).
CHAPTER TWO

2.0 LITERATURE REVIEW

2.2 Global Cowpea Production

In 2012, the leading cowpea grain producer was China, producing 16.7 Mt. (Table 1). The world’s cowpea leaf production as at 2016 was estimated at 6,991,174 tons (Table 2) of which 6,739,689 tons were from Africa, with East Africa offering 532,901 tons (Faostat, 2016). Kenyan yields remain exceedingly low, ranging from 150 to 500 kg ha\(^{-1}\) due to abiotic and biotic stresses, low yielding genotypes, and poor crop management practices (Karuma et al., 2008). In Kenya the area under cowpea is approximately 227,809 ha including the area under the kitchen gardens (Faostat, 2016). The crop which is commonly known as Kunde is mainly produced for the domestic market (Francis, 2017). The counties producing cowpea in Kenya are Kitui, Migori, Kakamega, Bungoma, Machakos, Makueni, Kisumu, Kilifi, Kwale, Siaya and Taraka Nithi. In 2014 the largest quantity of total hectares under cowpea leaf production was 24,431 ha with a production of 6,509,674 Mt (AFFA, 2014).
### Table 1: Top world production of cowpea in 2012 (Metric tons)

<table>
<thead>
<tr>
<th>S/N</th>
<th>Country</th>
<th>Metric tons (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Peoples Republic of China</td>
<td>16.7</td>
</tr>
<tr>
<td>2</td>
<td>India</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>United States of America</td>
<td>3.1</td>
</tr>
<tr>
<td>4</td>
<td>Nigeria</td>
<td>3.1</td>
</tr>
<tr>
<td>5</td>
<td>Kenya</td>
<td>0.025</td>
</tr>
</tbody>
</table>

**Source:** OECD (Organization for Economic Co-operation and Development) (2012)

### Table 2: World cowpea leaf production in 2016 (Faostat 2017)

<table>
<thead>
<tr>
<th>Region</th>
<th>Area harvested (ha)</th>
<th>Yield (kg ha⁻¹)</th>
<th>Production (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>12316878</td>
<td>567.6</td>
<td>6991174</td>
</tr>
<tr>
<td>Africa</td>
<td>12079473</td>
<td>557.9</td>
<td>6739689</td>
</tr>
<tr>
<td>East Africa</td>
<td>891848</td>
<td>522.2</td>
<td>465687</td>
</tr>
<tr>
<td>Kenya</td>
<td>227809</td>
<td>644.4</td>
<td>146807</td>
</tr>
</tbody>
</table>

**Source:** Faostat (2017)

### 2.3 Environmental Conditions that Influence Growth and Yield of Cowpea

Cowpea growth forms vary from bushy, trailing, erect, or climbing and mostly indeterminate in suitable environmental conditions. Leaves are trifoliate and are alternately arranged and they are dark green in nature. The primary leaves are opposite to each other and simple. The stems are slightly hairy, striate occasionally stained with purple (Aveling, 1999). Because of its ability to create a deep taproot system, cowpea is drought tolerant crop than mung bean or soybean. It thrives in sandy soils, is highly susceptible to extreme wet conditions, and performs poorly in water locked soils. It performs well in dry conditions and cultivated genotypes can mature only with less than 300 mm of rainfall.
Cowpea has potential to acclimatize well to semi-arid areas of the tropics than other leguminous crop, this is because of its ability to tolerate drought and warm weather conditions (Singh et al., 2003). It has distinct capacity to biologically fix atmospheric nitrogen in symbiotic manner and does well even in poor soils with low levels of phosphorus, more sand with 0.2% organic matter (Sanginga et al., 2000).

Also, due to its capability and ability to tolerate shading effect makes it compatible with cereals and other cash crops like cotton, coffee and sugarcane in an intercropping system (Singh and Emechebe, 1998). Additionally it has a robust growth and quick ground cover habit that assists in soil erosion control and undisturbed decomposing root exudes nitrogen-rich residues that enhance soil fertility and structure (Singh et al., 2003). Overall, in subsistence agriculture these attributes have made cowpea an important element especially the dry savannas of poor African Countries (Carsky et al., 2001).

Cowpea is tolerant to abiotic conditions that affect crop production like drought, high temperatures and biotic stresses as compared to other crops. Nevertheless, many cowpea genotypes are affected by high temperatures and drought particularly during growth and developmental stages of flowering. The reason is that cowpea genotypes tend to have slim range of adaptation as genotypes bred for one agro-ecological area normally are not prolific in other agro-ecological zone (Agyeman et al., 2014).

Nwofia et al., (2015) confirmed that late cowpea planting significantly enhanced the growth, development and yield of the cowpea crop than early season planting. Sangakkara (1998) evaluated the effects of seed characteristics, soil moisture at planting and the season of crop establishment on growth and yield parameters of cowpea as factors influencing the productivity of the crop. Growth and yield of cowpea plants grown from small seeds with a
high conductivity of their leachates were significantly lower than those grown from large seeds. Under moderate soil moisture levels, root growth of seedlings is mostly prominent, while low soil moisture content retard root growth by reducing dry weights and suppressing the development of laterals. High soil moisture stress levels usually affects shoot growth more than root growth. Cowpea yields higher during wet season and within a season, growth and yield are always higher in late planted crop than when the crop is planted early in the season.

2.4 Potential Yields and Actual Yields to Define Yield gaps of Cowpea

According to the Kenya Agricultural and Livestock Research Organization (2013) cowpea production in the country ranges between 320kg-720kg ha\(^{-1}\). However, farmers in Kenya can get up to 144kg ha\(^{-1}\) more of cowpeas by intensifying the crop population and are capable of harvesting up to 864kg ha\(^{-1}\), under recommended spacing of 75cm by 75cm with approximate seed rate of 53,333 seed ha\(^{-1}\) (Laban, 2017). The Cowpea mean yield in Uganda is at below 400 kg ha\(^{-1}\) (CCRP, 2012) and overall yield is estimated to be at 20,000 t yr\(^{-1}\), where by much production is accounted by Northern and Eastern regions of the country (FAO, 1997). The potential grain yield is high under sole cropping (1.5–3.0 t/ha), when the crop is applied with insecticide, however, in the West African sub-region the actual yields obtained are much lower estimated at an average of 250–300 kg/ha (Mortimore et al., 1997). According to Ajeigbe and Singh (2006), the low cowpea yields recorded are due to a number of biotic and abiotic stress factors and as well as lack of inputs. The maximum cowpea damage begins as from seedling to storage and the serious insect pests and diseases damages usually occur during flowering and podding stages of the cowpea crop (Ajeigbe and Singh, 2006). As a result, remarkable yield increase
sometimes up to tenfold have been achieved with management measures such as use of pesticides, fungicides which more often increases cost of production (Ajeigbe and Singh, 2006).

According to Karungi et al. (2000) application of insecticide once at budding, flowering and podding stages resulted in grain yield of 1,293 kg/ha while weekly application of insecticide throughout the crop growing season yielded 1,561 kg/ha compared to 268 kg/ha obtained when no insecticide was applied. In addition, Nabirye et al. (2003) revealed that blending cultural and chemical methods once each during budding, flowering, and podding stages was much more efficient, effective and profitable than chemical cowpea spray every week throughout the growing season.

Rusoke and Rubaihayo (1994) reported from the findings that cowpea crop had recorded a yield potential of up to 3000 kg/ha. Also, cowpea suffers severe damage of grain during storage due to the *Callosobruchus maculatus* (F) pest infestations. The bruchid inflicts permanent grain yield damage, where infestation starts at the field level through the storage (Opolot et al., 2006). This direct impact result to weight loss as well as lower grain quality making the seed not suitable for planting and human consumption (Singh and Jackai, 1985; Opolot et al., 2006).

Different pathogens affect different parts and stages of the crop growth, this includes bacteria, viruses as well as fungi (Allen, 1983). In the Leguminosae family, cowpea (*Vigna unguiculata*), lima bean (*Phaseolus lunatus*) and common beans (*Phaseolus vulgaris*) are known to be hosts of the scab disease and other fungal diseases (Singh and Allen, 1979). Other 40 fungi species are cowpea pathogens (Allen, 1983). One such fungal cowpea disease of economic importance is cowpea brown rust (*Uromyces phaseoli*).
Cowpea rust causes severe infections such as distortion and flower bud abortion (Singh and Allen, 1979). These damages reduce the photosynthetic surface area of the leaves. According to Singh and Allen (1979) the stem symptoms can be confused with anthracnose, however cowpea rust infestation infections on stem and leaves are tan-brown, and are more often circular.

Mbong et al., (2010) reported that cowpea rust can be seed-borne but also wind borne. It infests and attacks all plant parts at all growth stages (Emechebe, 1980) but heavily during flowering to podding stage. Primary inocula for infection are provided by an infected seed or plant material (Lin and Rios, 1985).

2.5 Economic Importance of Cowpea Production

Beside food importance of cowpea, the crop has additional social, economic and ecological benefiting attributes which are normally non-food related. It is drought and heat-resilient legume and efficient biological nitrogen fixing (Saidi et al., 2010). However, cowpea is either grown as pure crop or intercropped with several other crops like leaf vegetables, cereals, legumes, tubers, bananas and also others in most African countries (Bittenbender et al., 1984; Singh et al., 1997). The spreading indeterminate cowpea genotypes in intercropping farming arrangement, acts as a ground cover hence controlling soil erosion as well as smothering weeds. Several cowpea genotypes in addition, stimulates suicidal germination of Striga hermonthica seeds, which is a parasitic weed that normally infests cereals with noxious effects (Quin, 1997). Despite cowpea’s long history in agriculture, scientists are still discovering surprising new uses for it. For instant, Louis et al., (2018) were interested on potential use of cowpea as a trap for insect pests that would see a reduction in pesticide applications in agricultural systems.
2.6 Cropping System in Cowpea Production

Growing two or more crops simultaneously on same piece of land at the same period or season is a traditional farming module that is common with subsistence farms in less developed countries of tropical Africa, India and Latin America. This farming model is known as intercropping or mixed cropping, depending on whether the crops are grown in separate rows or mixed within a row (Facknath, 2000). Whereas many crops are intercropped, legume intercropping is widespread because legumes have the potential of biological atmospheric nitrogen fixing, hence an important factor in soil nitrogen improvement. The intercropping has the following benefits: increase in yield per land area and increase in economic output as compared to pure crop stands (AATF and NGICA, 2006). In spite of these benefits intercropping has been observed in some conditions to lower nodulation and biological atmospheric nitrogen fixation (Katayama et al., 1995).

Beside, legume yields tend to go down under intercropping because of light competition (Ofori and Stern, 1987). Intercropping legumes with cereal also create micro-climate which may favour diseases manifestation and development, (Margarida, 2013). For example, Chemeda and Jonathan (2001) observed that intercrop of maize-sorghum fields had higher maize rust disease than sole crop fields.

While the influence of intercropping on pest populations has received some attention, Allen (1982) relatively few research have been undertaken on the effects of cropping systems on pathogen. The most commonly reported effect of associated cropping on disease is that, incidence or severity is decreased in the intercrop relative to pure stand, (Msuku and Edje, 1980). In contrast other research findings suggested that disease incidences and severity may be greater in an intercrop than in pure stand. For instance, white mould Sclerotina sclerotiorum in beans was not influenced by maize association in
variety trials in Arusha during 1988 though, there were varietal differences in susceptibility (Waddington et al., 1990). The present research seeks to evaluate the influence of intercropping cowpea and maize on cowpea rust (*Uromyces phaseoli*) on selected improved cowpea genotypes in two cropping systems in Western Kenya.

Since maize is of such importance in Western Kenya, cropping systems have to be developed that are based on maize, but also include other crops that can contribute to human nutrition and improve soil fertility. The incorporation of legumes in the cropping system is often seen as an important option (Giller, 2001). Legume grains and stover are nutritious food and feed in terms of protein content and quality. At the same time their ability to biologically fix nitrogen from the air enables legumes not only to depend on soil N or even contribute to the soil N stock (Giller, 2001). Intercropping and rotations of maize with legumes is often found to increase yields and economic benefits of the cropping system as a whole (Giller, 2001).

Cowpea-maize intercropping in western Kenya seeks to improve wholesome total yields, food security, soil nutritional fertility and profitability of the maize cropping system which can therefore be seen as a form of sustainable agricultural intensification (SAI). The recently emerging paradigm of SAI was defined for the Sustainable Development Goals, with objective of increasing agricultural production sustainably for future food security improvement (SDSN, 2013).

Cropping systems designed within the SAI paradigm should also be resilient, meaning that they should be more tolerant to stress especially crop disease. This can result in diversification of cropping systems, development of disease resistant varieties. Building these resilient systems contributes to future food supply and thereby, food security can be
increased in changing environments. In many parts of Africa, the most successful intercropping systems are mixtures of species that are both temporally and spatially diverse (Francis, 1994). These systems are quite useful in agriculture since they can enhance soil fertility, out-compete weeds, and provide a varied supply of food and income to the farm family (Beets, 1990). The use of crops that are adapted to intercropping stress and optimum planting dates, crop densities, and spatial organization can contribute to yield increases. Intercropping systems make better use of available resources because the different crop species occupy slightly different niches (Willey, 1979; Dusa and Stan, 2013).

According to Francis (1994) a careful consideration of resource use by crop mixtures can help in understanding how to manage their components and design new and more environmentally sound systems. Such an evaluation would also help in designing more efficient resource use intercropping systems (Dusa and Stan, 2013). Intercropping systems have, for long, been discounted as backward and detrimental to real progress in agriculture (Francis, 1994). However, these systems gained more recognition (Rao and Mathuva, 2000) as potential contributors to substantial and sustainable increases in future food production (Tsubo et al., 2003). Crop mixtures are known to exploit a wider range of soil strata than do monocultures that have relatively uniform root structure and rooting habit/depth (Francis, 1994). The crops in a mixture may also have different nutrient requirements over time and thus complement each other in the uptake and use of soil nutrients. For instance legume and cereal intercrops are the best combination suitable at exploiting natural resources than pure crops of different crop species (Hauggaard-Nielsen et al., 2006). This is because leguminous crops can compensate their nitrogen demand
from atmospheric nitrogen fixation hence intercropping with cereals compete less for soil mineral nitrogen (Dusa and Stan, 2013). According to Eskandari (2012) there was a decrease of maize chlorophyll content as well as canopy temperature and increase of soil moisture content in an intercrop. Intercropping therefore maximizes degree of complementarities among elements and minimizes inter-species competition (Willey, 1979).

Adopting an intercropping system is a main and straight way of increasing diverseness of a biome, thereby allowing relationships between the different crop individuals among the genotypes (Yancey, 1994). Also temporal diversity is added in succeeding planting of different crop species in the same season or period (Mohammed, 2012). Several methods have been used to assess the benefit of intercropping depending on the need. However, one of the major tools for assessing intercropping system is the land equivalent ratio (LER).

\[ \text{LER} = \frac{\text{Y11} + \text{Y12}}{\text{Y11} + \text{Y12}} \]

Whereby, L1 and L2 are the LERs for the sole crops that is (cowpea and maize), Y11 and Y12 are the single crop yields in intercropping, YS1 and YS2 are the yields of sole crops. The partial LERs (L1 and L2) are the summation of the total LER for the intercrop (Kurata, 1986).

Admitting that all factors remain constant, the LER is estimated as the yield advantage achieved by growing two or more crops as an intercrop as compared to growing the same crops as a combination of isolate pure cropping (Yancey, 1994). In addition Land equivalent ratio therefore allows focusing, critically analyzing intercropping system merits that are beyond the aforementioned narrative of a diversification cropping pattern (Kurata, 1986). It evaluates and measures the levels of intercrop interruptions within a cropping system. Hypothetically, if the agro- ecological attributes of each crop in a combination are
very similar to the total LER should be 1.0 and for the partial LERs should be 0.5 for each. Moreover, Kurata, (1986) affirmed that a LER value of 1.0 showed no difference in yield between the intercrop and the combination of sole crop and any value greater than 1.0 indicates advantage for intercrop. In contradiction LER of less than 1.0 stipulates an advantage for intercropping. Land equivalent ratio of 1.2, for instance, stipulates that the area under monocrop would need to be 20% more than the area planted to intercrop for the two to produce the combined yield results (Mohamed et al., 2011). Land equivalent ratio has been used to determine the intercropping system merits (Yilmaz et al., 2008).

In developed and developing countries, legume-cereal intercrop plays critical role as far as subsistence crop production is concerned particularly during scarce water resource conditions (Dahmardeh et al., 2010). It modifies the abiotic and biotic characteristics of an agro-ecology and usually changes the life cycle of weed pests (Banik, 2006). A cropping system that lowers population of weed provides a weed suppressive platform upon which cultural weed management can be determined (Tsubo et al., 2005). Usually Cowpea is intercropped with cereals where it subscribes to the soil nutrient conservation (Carsky et al., 2001). In the coastal lowland of Kenya maize - cowpea intercrop or relay is practiced by more than 90% of subsistence farmers during main season (Saha et al., 1993).

The potential of legumes to fix atmospheric nitrogen via symbiosis with rhizobium bacteria gives them special value in low input agriculture (Saha et al., 1993; Giller, 2001). By incorporating cowpea into the cropping systems, farmers in the region have for long utilized biologically fixed nitrogen to maintain soil fertility but the yields have not stabilized. In the intercrop, single crops vary in how they utilize available resources either in form, temporal or spatial ensuring in their overall complementary and efficient
utilization of resources than when they are grown in pure cropping system, hence reducing the amount of weed population (Hauggaard-Nielsen et al., 2001). For instance, when intercropping pea and barley, Hauggaard-Nielsen et al., (2006) also recorded that there was an efficient increase in utilization of environmental resources for plant growth and a better competitive ability towards weeds as compared to pure cropping. Baumann et al., (2000) revealed that light resource is blocked from the weak component in intercrop thereby shortening the weed management period and retarding the growth and abundance of weed establishment. The apparent increase of intercrop potential competitiveness however makes them important for integration into the less in-put cropping systems in which alternative for chemical weed management are decreased or extinct (Szumigalski and Van Acker, 2005).

Yield increment, lodging resistance, soil conservation and weed suppression are one of the intercropping merits over pure cropping systems (Banik et al., 2006). Lithourgidis et al., (2006) stated that yield increased under intercropping than pure cropping system mainly due to effective utilization of resources such as water, light and nutrients than in pure cropping systems (Li et al., 2006). Specific facilitation or competition between crops normally happen when two crops are grown either intra and or intercropped (Zhang and Li, 2003). The key aspect affecting cereal yields in intercropping system is competition of resources as compared with pure cropping of cereals (Ndakidemi, 2006). Naresh et al., (2014) reported reduced canopy temperature in an intercrop of maize-wheat system.

2.7 Abiotic and Biotic Stresses Limiting Cowpea Production

There are numerous abiotic and biotic growth limitations to sustainably cultivate cowpea. Understanding the constricting factors during important growth stage highly matters in any
production system. For example, the influence of acute drought in relation to phenology and high night temperatures has shown to affect flowering, podding and seed development and are singled out to be among critical cowpea production constraints (Padi, 2004). Additionally, another vital factor limiting a supportive cowpea production is susceptibility to numerous pests.

The numerous agronomic research that have been conducted aims in developing cowpea genotypes which would yield more grain notwithstanding the stressing environmental factors. The most agronomic result trials as assessed and given by Padi (2004) have indicated that cowpea genotypes bred for one agro-ecological zone of the world usually do not perform very well in other region of an agro-ecological zone. How high and sustainable cowpea production system remains bottleneck to the research scientists which might be attained under biotic constraints particularly cowpea rust (Uromyces phaseoli).

### 2.7.1 Cowpea rust as a major biotic stress in cowpea production

Diseases like Uromyces phaseoli, mosaic virus, powdery mildew and bacterial blight are the crucial biotic stresses in the production and management of cowpea. Breeding high yielding genotypes which are resistant, tolerant to these diseases would be important achievement in crop development. Ferry (1990); Hall (2004) and Withanage (2005) however reported that though cowpea is both adaptive to favorable growing abiotic environment like resistant and tolerant to drought, extreme temperatures, and poor soils, biotic stresses impacts huge losses and are major factors behind why on-farm cowpea yields of traditional genotypes in Africa are double lower than potential yields. Consequently, improvement of cowpea genotypes that have resistance or tolerance to the biotic stresses would aggregate into impressive yield improvements. Because of climate
change, crops generally experience an upsurge of number of abiotic and biotic stress amalgamations, which seriously affect their growth, development and yield (Choudhary et al., 2016).

Because cowpea is widely grown by peasant farmers especially women who lack access to finance to purchase equipment for mechanizing pesticide application as well as protective gears to know how on the efficacy and safe use of pesticides, developing resistant cowpea genotypes is usually a desirable strategy of managing the diseases. Encounters from identification Survey on Cowpea insect Pests and Diseases in Uganda African Crop, Edema (1999) reported that in order to sustainably produce and expand cowpea production there is need to come up with an effective pest management plan as an important objective. Also concluded that though the crop insect pest losses were however not assessed, preliminary outcome showed that they were significant (Sabiti et al., 1994; Omono et al., 1995; Omono, 1996) and hence, requires intervention. It is conceived that future research would evaluate economic thresholds of pests with economic importance.

2.8 Biology and Etiology of Cowpea Rust

Fatokun et al., (2002) stated that the causal agent for cowpea brown rust is *Uromyces appendiculatus*. Highly susceptible lines can be almost completely defoliated by mid-flowering time so that yield loss is probably severe. The symptoms and diagnosis is that postules develop on both leaf surfaces releasing powdery, reddish- brown uredospores, the postules may be surrounded by yellow haloes, then by rings of secondary postules. The colour of postules becomes black as the pigmented teleutospore develops the aecidial (fruiting) stage occasionally causes a basal stem rust disease. *Uromyces phaseoli* is not seed- borne. However, Mbong et al., (2014) reported that cowpea rust can be seed borne
but also wind borne. The dispersal is favoured by foggy humid weather with dense dew and temperatures of 21-27°C. Uredospores are disseminated principally by wind, infected plant debris and volunteer plants, cultural management practices, late planting, herbicide damage, excessive nitrogen or hail damage. These are predisposing conditions favouring sporulation, infestation, spread and infection of cowpea rust. Repeated disease cycles occurs at 10 to 14-day intervals under favourable conditions, teleutospore play a role in the survival (Schwartz et al., 2005).

2.9 Yield Losses Attributed to Cowpea Rust Infection
Damages due to pests or diseases can lead to yield loss of greater than 90 % (IITA, 2003). Major foliar fungal diseases of cowpea include brown rust (Uromyces phaseoli), Cercospora leafspot, web blight and Septoria leafspot. Crop loss of 18 – 50 % was reported as a result of foliar diseases of cowpea (Marley, 2013). The crop is attacked by so many and largely numerous biotic and abiotic constraints making it highly susceptible at all stages of growth in unfavorable environments (Singh, 2005; Timko et al., 2007) but not excluding cowpea leaf brown rust which is endemic and very serious in eastern and southern part of Africa. However the disease also is considered to be important in the Southern Guinea savanna and rainforest regions of Western Africa and in mid altitude areas of Eastern Africa (Emechebe and Shoyinka, 1985). It causes economic yield losses ranging between 18 to 100% in humid and tropical regions (Kimani et al., 2002; Monda et al., 2003). The cowpea rust has high virulence diversity (Arunga et al., 2012; Acevedo et al., 2013). The disease alternative host crops are common bean, and soya bean.

Production of cowpeas in Kenya is, however, affected by many factors among which plant diseases constitute an important factor. These diseases reduce the quality and quantity of
the leaves and seeds considerably. More than ten diseases have been recorded on cowpeas in Kenya (Mukunya and Keya, 1978). Cowpea rust caused by *Uromyces phaseoli* is among the top five major diseases which are responsible for reducing crop grain yield appreciably. If the disease appears early, it completely defoliates the crop. Unfortunately very little work has been done on the cowpea rust in Kenya and therefore, no indication of the losses caused by the disease can be ascertained (Opio, 1979). Although the disease is of economic importance it has attracted little attention in East Africa and many parts of the world. Therefore, since cowpea rust is one of the major diseases of cowpea in Kenya, work of the basic nature has to be undertaken to help provide the knowledge needed to control it by use of resistant varieties in the breeding program. Opio (1979) from the findings of her study, suggested that breeding for disease resistance to cowpea rust in Kenya needs further investigation.

2.10 Cowpea Genotypes

**Katumani 80 cowpea variety**

This genotype is a dual-purpose cowpea that is suitable for both leaf and grain production. One of the key attribute of this important genotype is a semi-spreading habit. It also has elongated leaves with unique silvery midrib. It has purple blue flowers with ten white pigmented ivory like corollas. Immature seeds are green and turn white brown at maturity with interspersed faint red brown spots. The genotype is resistant to aphids and moderately tolerant to pod borers, thrips and leafhopper. In additionally, it is moderately tolerant to mosaic virus and fungal pathogens. Its yield potential range from 320-720 kg/acre or 800-1800 kg/ha (Karanja et al., 2008).
**Local (Lwanda black eye) cowpea variety**

This dual-purpose cowpea genotype that matures at 60-120 days. One of the special attributes associated with this variety is drought tolerance. It also does well in a vast range of soils. It is susceptible to cowpea rust (Karanja et al., 2008).

**KVU 27-1 cowpea variety**

This is a dual-purpose genotype grown for grain and leaf production with a semi-spreading attributes and indeterminate flowering pattern. It has pointed leaves and purple blue flowers while its grains are dark red in color. Potential yields of this variety range from 320-720 kg/acre. It has a moderate tolerant to thrips and aphids, leaf hoppers, and pod borers. It is also moderately resistant to mosaic virus and foliar fungal disease (Karanja et al., 2008).

**Tumaini cowpea variety**

Grows well at 0-1500m a.s.l, flowering at 48 day with cream grains, yield of 2.4 tha⁻¹. Resistant to CYMV, moderately resist to bacterial blight, moderately tolerant to Cowpea rust, from Tanzania (AVRDC, 2004).

**Dakawa cowpea variety**

It is resistant to Cowpea rust. From World vegetable Centre, Tanzania Dakawa Research Institute, Tanzania, AVRDC-RCA, (AVRDC, 2004).

**2.11 Research Gaps**

From the reviewed literature on cowpea genotypes and their resistance to cowpea diseases it is apparent that the local variety which is mainly planted in Western Kenya offers no solution to the current cowpea rust diseases. It is envisaged that introduction of K80, Tumaini, Dakawa and KVU 27-1 in Busia and Kakamega will probably yield more as they
have moderate resistance to fungal diseases and cowpea rust is one of the fungal diseases that causes economic yield loss.

Research has also shown that the yield reduction is attributed to farmers planting of local land races that are highly susceptibility to biotic and parasitic flowering plants like Striga (*Striga hermonthica*) and Alectra (*Alectra vogelii*) and have low yield potential (Musselman, 2019). This has been managed by development of improved genotypes which not only improves dry grain yield of cowpea production, but also green pods and leave yields (Lowenberg-DeBoer, 1995). Research has also indicated that the key constraint to cowpea production in Ghana is the high rate of pathogen infections and their related high management costs. Infections of cowpea rust caused by *Uromyces phaseoli* are the most severe and destructive. Approximately more than 2000 urediniospores of the pathogen presently are released daily during the dry spell, however there is no cost-efficient mitigation measure to prevent rust infection especially in different agro-ecological zones. Therefore, expertise of the severity of rust disease is highly important for quick control mediations. This research recommends the use of rust resistant genotypes as the cheapest, safest and most effective strategy to managing cowpea rust disease and consequently improve cowpea yield. Also serves as an environmentally safe and cost-effective disease management method (Theophilus et al., 2018).

The current research focused on cowpea genotype, cropping system and their interaction on cowpea growth, yield and yield components as affected by cowpea rust pathogen. Most researchers focus on cowpea genotype yield potential and or stability, soil fertility, fodder, intercropping patterns and agronomic practices but with little or scanty information on cowpea rust as relates to yield and yield components. Based on the illustrations from
Nigeria, Ghana and research conducted in other parts of Kenya, it was important to carry out an experiment in Western Kenya on cowpea rust incidences and severity on the selected cowpea genotypes to evaluate tolerant and susceptible ones. This would not only help to adopt tolerant and high yield genotype but also provide a cheap and environmentally friendly way of cowpea rust management. It would also provide information that would be disseminated to farmers in the region and beyond.
CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Geographical Description of the Study Area

The experiment was conducted in Kakamega and Busia Counties of western Kenya during low rains 2018 and rainy season 2019. In Kakamega the study was undertaken at the Kenya Agricultural, Livestock Research Organization (KALRO) Kakamega station (00°16.9' N, 034° 46.07'E). In Busia County, the experiment was conducted at KALRO Alupe station (00° 28.0N, 34° 07.00'E). The soil in Kakamega is classified as Ferralic-orthic acrisol (Jaetzold et al., 2007), deep, well drained highly weathered soil with inherently moderate fertility whereas the soil in Busia is very deep, dark red Orthic ferralsols and well drained, (Jaetzold et al., 2007). Both soils are poor in nutrients, thus require regular fertilization. Kakamega and Busia sites represent the Upper Midlands 2 (UM 2) and Low Midlands 2 (LM 2) respectively with an altitude of approximately 1585m and 1010m a.s.l respectively (Jaetzold et al., 2007). The two counties have generally cool wet climate receiving bimodal annual rainfall ranging between 1250mm-1750mm in Kakamega and 760mm -2000mm in Busia and temperature range of between 14°C -27°C in Kakamega and 19°C -31°C in Busia (Jaetzold et al., 2007). In both Counties, there is unpredictable rainfall and persistent mid-season dry spells, though not as much in Kakamega than Busia.

3.2 Research Design

The research design was Randomized Complete Block Design (RCBD) in split plot arrangement. The main plot factor was cowpea genotype (K80, KVU27-1, Dakawa,
Tumaini and Local landrace) while sub-plot factor was cropping system (pure stand or cowpea maize intercrop) resulting in a total of ten (10) treatment combinations with three replications. The Sub-plots measured 3 m wide and 5 m long and 1m in between the subplots. The experiment was conducted in short rains 2018 and long rains 2019.

Tillage was done manually using a hand hoe two (2) weeks before planting. Prior to planting composite soil samples were taken from each plot, analyzed using methods described in Anderson and Ingram (1993). Two cowpea seeds were planted manually at recommended standard spacing of 0.6 m x 0.1m in pure stand and 0.75m x 0.3m in intercrop respectively KARI (2000) resulting in 6 rows of cowpea plants in pure stand and 4 rows in intercrop. The plants were thinned to one plant per hole after emergence. Seeds were planted 2 cm deep resulting in a plant population of 166,667 and 44,444 plants ha\(^{-1}\) for pure stand and intercrop respectively. Prior to planting, Sympal (a fertilizer blend for legumes: NPK: 0:23:15 + 10 CaO + 4 S + 1 MgO, MEA ltd Kenya) 30 kg P and 30 kg K ha\(^{-1}\) was applied to offset possible P, K, Ca, S and Mg deficiencies. Fertilizer was applied in site band dug 5 cm deep and 10 cm away from cowpea planting lines at planting time and the experiment was kept weed free by manual weeding.

3.3 Data Collection Procedure

Soil samples were collected at the beginning of the study to determine baseline soil characteristics using methods described by Okalebo et al., (2002). Ten plants were randomly selected from a 1m\(^2\) quadrat within the net plot consisting of two middle rows in both intercrop and pure. On these plants, disease incidence, severity, plant height, number of leaves, Leaf Area Index was assessed at three weeks interval up to physiological
maturity. Destructive sampling was done at physiological maturity for both green leaf biomass and grain yield.

3.3.1 Cowpea rust disease incidence
A quadrate measuring 1m by 1m was cast ten times randomly in the net area to get the data on disease incidence in each site. The incidence was described as the proportion of rust infected plants to the total number of plants in the quadrate and was scored on a scale of 0-9 (Mayee and Datar, 1986);

0= No symptoms (No pustules): very resistant.
1= 1-10%, leaflet area covered with rust pustules: Resistant
3= 11-25%, leaflet area covered with rust pustules: Moderately resistant
5 = 26-50%; leaflet area covered with rust pustules: Moderately Susceptible
7 = 51-75%; leaflet area covered with rust pustules: Susceptible.
9 = > 75% leaflet area covered with rust pustules: Highly susceptible.

3.3.2 Cowpea rust disease severity
Disease severity was rated as a percentage of leaf area affected in the lower, mid and upper canopy of each of the plants under quadrat using 0-8 visual scale score method in which a rating of 0 = no disease, 1 = disease severity up to2.5%, 2 = disease severity 2.5-5%), 3 = disease severity 5-10%, 4 = disease severity 10-15%, 5 = disease severity 15-25%, 6 = disease severity 25-35%, 7= disease severity 35-67.5% and 8= disease severity 67.5-100%
. The midpoint value of each rating range was used to convert the rating to percent (Manandhar et al., 2016).
3.3.3 Growth parameters

**Plant height (cm)**

Plant height was measured on the ten randomly selected plants within the quadrat using measuring tape from soil surface to terminal/apical bud at three weeks’ interval after plant emergence up to physiological maturity.

**Number of leaves**

The leaf numbers were assessed by visual counting of all fully opened leaves on each randomly selected plant at an interval of three weeks after plant emergence (Agbogidi and Ofuoku, 2005).

**Leaf Area Index**

Leaf area measurements were taken at the same time with leaf count on the same plants. Leaf area (LA) was tabulated as the product of the length and breadth at the broadest point of the longest leaf multiplied by 0.75 (Jordan-Meille and Pellerin 2004). Leaf area index (LAI) was then calculated by dividing the LA by spacing after every three weeks after emergence (Wiersma and Bailey, 1975).

3.3.4 Yield and yield component parameters

**Number of pods per plant**

Number of pods was determined in the field by visual counting on a scale of 1 – 9 using the procedure of Egho (2009) at physiological maturity. The number of pods was then divided by the number of cowpea plants to get the number of pods per plant.
**Green leaf biomass**

Green leaf biomass was assessed at physiological maturity when 95% of the pods had changed colour to brown. Leaf biomass specimens were taken from all plots by plucking the mature leaves from each plant in the net area. Plants for biomass accumulation were randomly selected in an area of 0.6 m² within the net area. Fresh leaves were weighed using an electronic balance and the weight recorded (Woomer et al., 2011).

**Cowpea grain yield**

Pods were harvested at physiological maturity, 65 – 70 days after planting when pods turned yellow. Harvesting was done in the net plot that excluded the boarder rows and end plants in each sub-plot. The net area was 4 m x 1.8 m i.e. 7.2 m². Pods were harvested by hand and fresh weights of pods recorded. The pods were air dried to a constant weight and then shelled. The weight of the grains and empty pods were recorded separately. Grain yield in kg ha⁻¹ were standardized to 13 % storage moisture content.

**3.4 Data Analysis and Presentation**

**3.4.1 The experimental model used**

\[ Y_{ijk} = \mu + G_i + R_j + C_k + G_iC_k + \varepsilon_{ijkl} \]

- \( Y_{ijk} \) - Overall response of the genotypes at \( i^{th} \) genotype, \( j^{th} \) replicate and \( k^{th} \) cropping system
- \( \mu \) - The overall mean
- \( G_i \) - Effect due to the \( i^{th} \) genotype
- \( R_j \) - Effects due to \( j^{th} \) replicate (Block)
- \( C_k \) - Effect due to \( k^{th} \) cropping system
- \( G_iC_k \) - Interaction of \( i^{th} \) genotype, \( k^{th} \) cropping system
- \( \varepsilon_{ijkl} \) - Random error component due to \( i^{th} \) genotype, \( j^{th} \) replicate and \( k^{th} \) cropping system
3.4.2 Statistical analysis

In this study data was analyzed using inferential statistics. Short rains 2018 and long rains 2019 combined means was subjected to mixed model analysis of variance (ANOVA) using SAS 2012 at $P \leq 0.05$ level of significance and means were separated using least significant difference (LSD). This was to assess the effect of cowpea rust on released cowpea genotype in terms of disease incidences, severity, growth and yield parameters and their interaction.
CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 Weather and Baseline Soil Characteristics during Study Period

Generally, the study period was wet and humid as the recorded rainfalls and temperatures were higher than the long term averages for both the study locations. During the study period, the air temperature in Busia was 24°C and was two degrees higher than that in Kakamega (Figures 2 and 3). Busia also received cumulative rainfall of 1678mm which was 457mm less than amounts received in Kakamega. This variability was more pronounced in the second study season which under normal circumstances corresponds with the long rainy season. These results showed that Kakamega was more prone to cowpea rust infestation as it provided favourable warm humid environment for proliferation of fungi propagules.

Baseline soil analysis showed that soils were acidic at both sites with soil in Kakamega station having more nutrients (Table 3). Specifically soils in Kakamega were clay loam with 70% more Olsen P, four times more K, 2.5 times more percent nitrogen (% N), four (4) times more total percent carbon (Total C %) compared to sandy loam soils in Busia station.
Figure 2: Monthly cumulative rainfall (mm) and average air temperatures (°C) for Kakamega during study period

Figure 3: Monthly cumulative rainfall (mm) and average air temperatures (°C) for Busia during study period
The general soil texture for Kakamega site was clay loam while at Busia was sandy loam. The soil $\text{pH}$ for Kakamega was 5.4 and 5.7 at Busia which were classified as slightly acidic based on the critical value levels (Okalebo et al., 2002). Nitrogen content in the soil at Kakamega was 0.3% and 0.12% at Busia. The sites contained moderate levels of nitrogen, the available P was also low in both sites, however carbon was moderate at Kakamega and low at Busia in the soils as classified by Okalebo et al., (2002).

<table>
<thead>
<tr>
<th>Site</th>
<th>Soil Chemical Properties</th>
<th>Soil Physical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\text{pH}$</td>
<td>Olsen P (PPM)</td>
</tr>
<tr>
<td>Kakamega</td>
<td>5.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Busia</td>
<td>5.7</td>
<td>2.0</td>
</tr>
</tbody>
</table>

### 4.1.2 Influence of Cowpea Genotype on Plant Height, Number of Leaves, Leaf Area Index, Disease Incidence and Disease Severity

The two experimental sites of Busia and Kakamega represented different agro-ecological zones in western Kenya and experienced different weather conditions during the study seasons resulting in variability in the magnitudes of the variables measured and therefore data were analyzed separately for each site. On the other hand, there was no significant seasonal effect within study sites and therefore data was averaged across the seasons within each study site. The mixed model ANOVA showed that both the main effect of
genotype and that of cropping system on the number of leaves, disease incidence (DI), disease severity (DS) and leaf area index (LAI) were significant (P ≤ 0.05) at both sites.

In Busia, plant height measurements showed that local variety (74.7 cm), KVU 27-1 (76.3 cm), Dakawa (74.2 cm) and K80 (70.4 cm) were statistically similar but significantly different from Tumaini (69.7 cm) cowpea genotype. However, K80, KVU 27-1, Tumaini and local variety genotypes had statistically similar number of leaves and were 19% lower than Dakawa genotype (Table 4). Similar trend was observed in Kakamega where Dakawa genotype had a significant 16% more leaves than local variety. However, there was no significant difference in the number of leaves between Dakawa genotype and K80, Tumaini and KVU 27-1 genotypes in Kakamega. Leaf area index was also higher in Kakamega compared to Busia across all cowpea genotypes with the local variety recording the lowest LAI at both sites. The results showed that cowpea rust disease incidence was generally higher in Busia than in Kakamega across all cowpea genotypes. However, the opposite was observed for cowpea rust disease severity which was generally higher in Kakamega compared to Busia across all cowpea genotypes. This could be due to high humidity observed in Kakamega as a result of greater rainfall and low temperatures than in Busia. It is also worth noting that Dakawa genotype cowpea had the lowest disease incidence and severity at both Busia and Kakamega.

At Busia, the Dakawa cowpea genotype recorded 52% lower DI, 71% lower DS and 39% more LAI than K80 and Local variety genotypes (Table 4). The same genotype recorded 30% low DI, 33% DS and 22% more LAI than Tumaini and KVU 27-1. Similar trends were observed in Kakamega (Table 5). Specifically, Dakawa genotype recorded 55% lower DI, 28% lower DS and 29% higher LAI than K80 and local variety genotypes. The
same genotype recorded 18% lower DI and 25% more LAI than Tumaini and KVU 27-1. Although the results were not significant, DS was lower in Dakawa genotype than Tumaini and KVU 27-1.

Table 4: Influence of cowpea variety on cowpea plant height, number of leaves, rust incidences (DI), severity (DS) and Leaf Area Index (LAI) in Busia

<table>
<thead>
<tr>
<th>Variety</th>
<th>Plant height (cm)</th>
<th>Number of leaves</th>
<th>DI</th>
<th>DS</th>
<th>LAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>K80</td>
<td>70.4ab</td>
<td>17.8b</td>
<td>5.1a</td>
<td>3.1a</td>
<td>2.3c</td>
</tr>
<tr>
<td>Local variety</td>
<td>74.9ab</td>
<td>16.5b</td>
<td>5.2a</td>
<td>3.4a</td>
<td>2.2c</td>
</tr>
<tr>
<td>Tumaini</td>
<td>69.7b</td>
<td>17.2b</td>
<td>3.2b</td>
<td>1.3b</td>
<td>2.7b</td>
</tr>
<tr>
<td>KVU 27-1</td>
<td>76.3a</td>
<td>17.3b</td>
<td>3.3b</td>
<td>1.4b</td>
<td>2.9b</td>
</tr>
<tr>
<td>Dakawa</td>
<td>74.2ab</td>
<td>20.6a</td>
<td>2.3c</td>
<td>0.9b</td>
<td>3.2a</td>
</tr>
</tbody>
</table>

Means followed by the same lower-case letter (s) within the column are not significantly different (P ≤ 0.05).

Table 5: Influence of cowpea genotype on cowpea plant height, number of leaves, rust disease incidences (DI), disease severity (DS) and Leaf Area Index (LAI) in Kakamega

<table>
<thead>
<tr>
<th>Variety</th>
<th>Plant height (cm)</th>
<th>Number of Leaves</th>
<th>DI</th>
<th>DS</th>
<th>LAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>K80</td>
<td>70.2a</td>
<td>19.4ab</td>
<td>3.1a</td>
<td>5.7a</td>
<td>2.9b</td>
</tr>
<tr>
<td>Local variety</td>
<td>70.4a</td>
<td>17.5b</td>
<td>3.1a</td>
<td>5.4a</td>
<td>2.5b</td>
</tr>
<tr>
<td>Tumaini</td>
<td>68.4a</td>
<td>18.3ab</td>
<td>1.7bc</td>
<td>4.3b</td>
<td>3.2a</td>
</tr>
<tr>
<td>KVU 27-1</td>
<td>77.4b</td>
<td>18.3ab</td>
<td>2.1b</td>
<td>5.1ab</td>
<td>3.1ab</td>
</tr>
<tr>
<td>Dakawa</td>
<td>72.9a</td>
<td>20.4a</td>
<td>1.4c</td>
<td>4.1b</td>
<td>3.6a</td>
</tr>
</tbody>
</table>

Means followed by the same lower-case letter (s) within the column are not significantly different (P ≤ 0.05).
Means followed by the same lower-case letter (s) within the column are not significantly different ($P \leq 0.05$).

4.1.3 Influence of Cropping System on Cowpea Rust Disease Incidences, Severity, Number of Leaves and Leaf Area Index

Cropping system significantly influenced plant height, number of leaves, disease incidence, disease severity and leaf Area index in both Busia and Kakamega ($P \leq 0.05$). In Busia, cowpea plants were two times taller under intercrop than in pure stand (Table 6). However, the plants had three times more leaves in pure stand cowpea than intercrop cowpea. The results also showed that disease incidence and diseases severity were 28% and 50% respectively less in pure stand cowpea compared to intercrop cowpea, while leaf area index was 8% higher in pure stand cowpea compared to intercrop cowpea.

**Table 6: Influence of cropping system on plant height, number of leaves, cowpea rust incidences (DI), severity (DS) and Leaf Area Index (LAI) in Busia**

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Plant height (cm)</th>
<th>Number of Leaves</th>
<th>DS</th>
<th>DI</th>
<th>LAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure stand</td>
<td>42.4b</td>
<td>24.9a</td>
<td>1.36b</td>
<td>3.2b</td>
<td>2.8a</td>
</tr>
<tr>
<td>Intercrop</td>
<td>105.0a</td>
<td>9.9b</td>
<td>2.70a</td>
<td>4.5a</td>
<td>2.6b</td>
</tr>
<tr>
<td>LSD</td>
<td>3.5</td>
<td>1.60</td>
<td>0.29</td>
<td>0.52</td>
<td>0.17</td>
</tr>
<tr>
<td>CV%</td>
<td>14.7</td>
<td>28.3</td>
<td>24.5</td>
<td>22.6</td>
<td>20.7</td>
</tr>
</tbody>
</table>

Means followed by the same lower-case letter (s) within the column are not significantly different ($P \leq 0.05$).
The same trend was observed in Kakamega where intercropped cowpea plants were three times taller than pure stand cowpea plants (Table 7). As in Busia, the number of leaves was three times more in pure stand cowpea than in intercrop cowpea. Disease incidence and severity was 24% and 32% respectively less in pure stand cowpea compared to intercrop cowpea and leaf area index was 10% more in pure stand cowpea.

Table 7: Influence of cropping system on plant height, number of leaves, cowpea rust incidences (DI), severity (DS) and Leaf Area Index (LAI) in Kakamega

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Plant height (cm)</th>
<th>Number of Leaves</th>
<th>DI</th>
<th>DS</th>
<th>LAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure stand</td>
<td>39.7b</td>
<td>26.9a</td>
<td>4.5b</td>
<td>1.9b</td>
<td>2.8a</td>
</tr>
<tr>
<td>Intercrop</td>
<td>105.7a</td>
<td>10.7b</td>
<td>5.2a</td>
<td>2.8a</td>
<td>2.5b</td>
</tr>
<tr>
<td>LSD</td>
<td>5.1</td>
<td>1.8</td>
<td>0.6</td>
<td>1.9</td>
<td>0.1</td>
</tr>
<tr>
<td>CV%</td>
<td>25.6</td>
<td>25.2</td>
<td>24.4</td>
<td>28.7</td>
<td>27.5</td>
</tr>
</tbody>
</table>

Means followed by the same lower case letter (s) within the column are not significantly different (P ≤ 0.05).

4.1.4 Yield and Yield Components of Different Cowpea Genotypes

The cowpea genotype effect on yield and yield components were significant at both Busia and Kakamega experimental sites (P ≤ 0.05) as shown in table 8. In Busia, Dakawa and Tumaini were statistically similar and had five times, two times and three times more pods per plant, leaf yield and grain yield respectively compared to statistically similar K80 and local variety. Though KVU 27-1 had comparable leaf weight with Dakawa and Tumaini genotypes, it had statistically reduced number of pods per plant and grain weight as compared to the two genotypes. Similar trends were observed in Kakamega where Dakawa and Tumaini genotypes had three times, two times and three times more number of pods
per plant, leaf weight and grain weight respectively than K80 and Local variety (Table 9). As the case in Busia, KVU 27-1 had comparable leaf weight but lower number of pods and grain weight compared with Dakawa and Tumaini genotypes.

Table 8: Influence of cowpea genotype on number of pods per plant, leaf weight and grain yield in Busia

<table>
<thead>
<tr>
<th>Genotype</th>
<th>No. of pods per plant</th>
<th>Leaf weight (kg ha(^{-1}))</th>
<th>Grain Yield (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>K80</td>
<td>2.8 c</td>
<td>2443.2b</td>
<td>214.6b</td>
</tr>
<tr>
<td>Local variety</td>
<td>4.0c</td>
<td>2421.0b</td>
<td>241.3b</td>
</tr>
<tr>
<td>Tumaini</td>
<td>15.0a</td>
<td>4787.7a</td>
<td>563.5a</td>
</tr>
<tr>
<td>KVU 27-1</td>
<td>10.7b</td>
<td>3974.7a</td>
<td>346.0b</td>
</tr>
<tr>
<td>Dakawa</td>
<td>16.8a</td>
<td>4462.2a</td>
<td>727.0a</td>
</tr>
<tr>
<td>LSD</td>
<td>2.33</td>
<td>1546.2</td>
<td>191.6</td>
</tr>
<tr>
<td>CV%</td>
<td>19.6</td>
<td>24.8</td>
<td>26.8</td>
</tr>
</tbody>
</table>

Means followed by the same lower case letter(s) within the column are not significantly different (\(P \leq 0.05\))
Table 9: Influence of cowpea genotype on number of pods per plant, leaf weight and grain yield in Kakamega

<table>
<thead>
<tr>
<th>Genotype</th>
<th>No. of pods per plant</th>
<th>Leaf weight (kg ha(^{-1}))</th>
<th>Grain Yield (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>K80</td>
<td>4.3c</td>
<td>1744.8b</td>
<td>297.6b</td>
</tr>
<tr>
<td>Local variety</td>
<td>5.2c</td>
<td>1711.8b</td>
<td>209.2b</td>
</tr>
<tr>
<td>Tumaini</td>
<td>13.0a</td>
<td>3478.3a</td>
<td>519.5a</td>
</tr>
<tr>
<td>KVU 27_1</td>
<td>7.8b</td>
<td>2002.3b</td>
<td>298.2b</td>
</tr>
<tr>
<td>Dakawa</td>
<td>15.2a</td>
<td>2426.3ab</td>
<td>584.5a</td>
</tr>
<tr>
<td>LSD</td>
<td>2.57</td>
<td>1054.5</td>
<td>158.9</td>
</tr>
<tr>
<td>CV%</td>
<td>23.5</td>
<td>28.5</td>
<td>34.5</td>
</tr>
</tbody>
</table>

Means followed by the same lower case letter (s) within the column are not significantly different (P ≤ 0.05).

4.1.5 Influence of Cropping System on Yield and Yield Components

The main effect of cropping system on pods per plant, leaf and grain yields was significant at both Busia and Kakamega (P ≤ 0.05). In Busia (Alupe Station), pure stand cowpea plants had 58%, 39% and 38% more pods per plant, leaf yield and grain yield respectively compared to intercrop cowpea (Table 10). In Kakamega, cowpea plants planted in pure stand had 34%, 60% and 40% more number of pods per plant, leaf yield and grain yield compared to intercrop cowpea (Table 11).
### Table 10: Influence of cropping system on the number of pods per plant, leaf weight and grain yield in Busia

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>No. of pods per plant</th>
<th>Leaf weight (kg ha(^{-1}))</th>
<th>Grain Yield (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure stand</td>
<td>14.2a</td>
<td>4113.5a</td>
<td>503.1a</td>
</tr>
<tr>
<td>Intercrop</td>
<td>9.6 b</td>
<td>3121.9b</td>
<td>358.1b</td>
</tr>
<tr>
<td>LSD</td>
<td>1.5</td>
<td>961.2</td>
<td>120.9</td>
</tr>
<tr>
<td>CV%</td>
<td>19.6</td>
<td>24.8</td>
<td>26.8</td>
</tr>
</tbody>
</table>

Means followed by the same lower case letter (s) within the column are not significantly different (P ≤ 0.05)

### Table 11: Influence of cropping system on the number of pods per plant, leaf weight and grain yield in Kakamega

<table>
<thead>
<tr>
<th>Cropping System</th>
<th>No. of pods per plant</th>
<th>Leaf Weight (kg ha(^{-1}))</th>
<th>Grain Yield (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure stand</td>
<td>9.98a</td>
<td>2664.10a</td>
<td>440.70a</td>
</tr>
<tr>
<td>Intercrop</td>
<td>8.30a</td>
<td>1881.30b</td>
<td>322.90b</td>
</tr>
<tr>
<td>LSD</td>
<td>1.62</td>
<td>666.9</td>
<td>100.5</td>
</tr>
<tr>
<td>CV%</td>
<td>23.5</td>
<td>28.5</td>
<td>34.5</td>
</tr>
</tbody>
</table>

Means followed by the same lower case letter (s) within the column are not significantly different (P ≤ 0.05)
4.1.6 Cowpea Rust Disease Incidence and Severity Progression with Growth Stages

Disease Incidence (DI)

There was a progressive increase in the intensity of DI with advances in plant growth in all genotypes with higher incidences in local variety, K80 and KVU 27-1 at both Busia and Kakamega (Figure 4). The progression was linear and at flowering stage to podding (week 9-12), the incidences started to flatten with Dakawa and Tumaini showing less incidences compared to local and K80 which had high incidences (plate 1, 2 and 3).

Plate 1: Cowpea rust infestation on K80 Busia (a) and Kakamega (b) and Tumaini genotype at week 4 (x).

Plate 2: Cowpea rust tolerant Dakawa genotype at Busia (c) and Kakamega (d) and susceptible local (e).

Plate 3: Cowpea rust tolerant Tumaini (f), KVU 27-1 moderately resistant (g) and Susceptible K80 (h) at Busia
Figure 4: Progression of disease incidence on cowpea genotypes in Busia and Kakamega.

Disease Severity.

Disease susceptibility increases with age in all the cowpea genotypes at both Busia and Kakamega. The local variety, K80, and KVU 27-1 were highly susceptible compared to Tumaini and Dakawa at both Alupe and Kakamega (Figure 5). In Busia, Disease severity rose steadily from vegetative (week 3 and 6), flowering (week 9) to podding (week 12) but slightly dropped at week 15 (physiological maturity) across cropping system. A similar trend was also observed in Kakamega.
4.1.7 Influence of Interaction of Genotype and Cropping System on Disease Incidence and Severity

The mixed model ANOVA showed that the interaction effect of cowpea genotype and cropping system on disease incidence (DI) and severity (DS) was significant ($P \leq 0.05$). In Busia, both disease incidence and severity was significantly lowest in Dakawa cowpea variety planted as either pure stand or intercrop compared to other treatment combinations (Figure 6). Similar trend was observed in Kakamega (Figure 7).
Figure 6: Influence of Interaction of genotype and cropping system on disease incidence and severity in Busia

Figure 7: Influence of interaction of genotype and cropping system on disease incidence and severity in Kakamega
4.1.8 Influence of Interaction of Genotype and Cropping System on Cowpea Yield and Yield Components

The interaction effect cowpea genotype and cropping system with regards to number of pods per plant, leaf yield and grain yield was significant at both Busia and Kakamega (P ≤ 0.05). In Busia, the highest and comparable number of pods per plant was found in Dakawa and Tumaini plants planted as pure stand cowpea crops (Figure 8). The plants of Local variety, KVU 27-1 and K80 planted as intercrop had the lowest and comparable number of pods per plant. The same trend was seen in Kakamega where Dakawa and Tumaini plants planted as pure stand cowpea crops had the highest and comparable number of pods per plant (Figure 9). The lowest number of pods per plant was found in plants of KVU 27-1 planted as intercrop.

![Figure 8: Influence of interaction of genotype and cropping system on number of pods per plant in Busia](image-url)
Similarly, in Busia plants of Dakawa and Tumaini genotypes planted in pure stand had the highest and comparable leaf yield compared to the plants of other genotypes grown as either pure stand crops or intercrops (Figure 10). Similar results were obtained in Kakamega where the highest leaf yield was found in Dakawa and Tumaini plants grown as pure stand crops (Figure 11). However, the lowest leaf yield was found in K80 and Local variety plants grown as intercrops.
Figure 10: Influence of the interaction between genotype and cropping system on leaf weight in Busia

Figure 11: Influence of the interaction between genotype and cropping system on leaf weight in Kakamega
The results from Busia showed that Dakawa and Tumaini cowpea genotypes planted as pure stand crops had highest and comparable grain yields while Local variety genotype planted either as pure stand or intercrop had the lowest grain yields (Figure 12). In Kakamega just like Busia, the highest and comparable grain yields was found in Dakawa and Tumaini cowpea genotypes grown as pure stand crops (Figure 13). However, the lowest and comparable grain yields were obtained from the other genotypes planted as either pure stand crop or intercrop.

Figure 12: Influence of the interaction between genotype and cropping system on grain yield in Busia
4.2 DISCUSSION

The discussion is based on the analysis of the means of each parameter for both SR 2018 and LR 2019. This was because the seasonal effects on the parameters measured were not significant and the data for each parameter was combined separately for each study site (Busia and Kakamega) with varied agro-ecological zone for further analysis. Data on weather during the study period as shown in figure 2 and 3 indicated above long term normal averages for both rainfall and temperatures for both Busia and Kakamega study sites. These conditions might have created warm humid microclimate that favoured the outbreak, proliferation and infection of rust fungi. This could have resulted in the finding that cowpea rust was prevalent in both the two study locations of Busia and Kakamega.
The higher rainfall (1800 mm p.a) and lower temperatures (20°C) in Kakamega (Figure 2) might have created higher relative humidity (Harrison et al., 1997; Lawrence, 2005) with low light intensities resulting in greater accumulation of cowpea rust fungi spores with high intensity of infestation and spread in Kakamega. While the low rainfall conditions (1000 mm p.a) and high temperature (24°C) in Busia could have inhibited the growth, development and spread of the cowpea rust fungi. The low temperatures and high rainfall in Kakamega created long periods of leaf surface wetness which has been shown to accelerate the development and growth of fungal pathogens (Dorrance et al., 2003; Gautam et al., 2013). The results are in confirmation with the findings that environments in humid agro-ecological regions are more conducive for the growth and development of fungal disease-causing agents (Adegbite and Amusa, 2008). According to research done by Adandonon et al., (2003) disease incidence of cowpea stem rot was greater in the south and central regions of Benin Republic than its Northern zone as a result of different amount of rainfall received by the two zones. The findings asserts with those of Mwang’ombe et al., (2007) who indicated that incidences and severity of angular leaf spot of common beans in Kenya is influenced by agroecology, geographical location and altitude. Also, the findings are in agreement by Kijana et al., (2017) who concluded that higher altitude areas increased angular leaf spot disease in beans than low altitude areas. Also, the results are in collaboration with the observation by Ddamulira et al., (2015) who confirmed that there was an increased fungal disease incidence and severity in the high and cool altitude zones of Uganda.

From the analysis of variance there was statistical difference in plant height and number of leaves in both Kakamega and Busia. K80, Dakawa and local genotype were statistically
similar but significantly different from KVU 27-1 and Tumaini. The higher heights and less number of leaves found in cowpea under intercropping could be as a result of shading conditions under Intercropping resulting in removal of dry matter production centre from leaves to stems promoting the stem elongation at the expense of leaves to obtain high amounts of light (Kermah et al., 2017; Gong et al., 2015; Ballare, 1999).

Low disease incidence and severity recorded by Dakawa (2.3 and 0.9) and Tumaini compared to K80 and Local variety, across the cropping system indicates that the genotypes had varied genetic compositions. Dakawa and Tumaini cowpea genotypes recorded the lowest damage by cowpea rust pathogen in both cropping system due to its inbuilt hereditary resistance towards the disease infestation, infection and damage over the other experimented genotypes. Also Singh (1999) similarly reported same superior characteristics that were expressed by IT90K-277-2 genotype over the other improved genotypes. Sharma and Franzmann (2000) reported that different genotypes have diverse response towards disease susceptibility and resistance because of their variations in the genetic makeup. Goenaga et al., (2008) also in his findings indicated that Cowpea genotypes showed varying yield potential when grown under severe virus infection because of their genetic diversity. Alsemaan et al., (2011) also appreciated the presence of genetic differences among Rosa damascene agreements used to increase the production of rose oil.

In terms of growth, it was found out that cowpea plants were generally taller with a mean height of 105 cm when intercropped and 42 cm when planted in pure stand. A similar trend was reported in the number of leaves in both sites. Specifically, greater positive of aforementioned parameters were recorded in Dakawa and Tumaini cowpea genotypes. The
competition for light, nutrients and space necessary for growth and development was high in intercrop than pure stand. Dry matter accumulation under intercrop was low as compared to sole crop, due to negative effect of shading resulting in reduced amount of light required to stimulate growth and yield components (Carr et al., 1998; Carruthers et al., 2000). Previous studies indicated that there was negative effect of shading on soybean growth and development because of close planting of maize causing severe shading and absorbed part of the light under maize-soybean relay-strip intercropping system, (Wu et al., 2007; Yang et al., 2014; Gao et al., 2015).

Cropping system significantly influenced disease incidence and severity in both Busia and Kakamega. The high disease severity in Kakamega could have resulted in concentrated efforts by plants in translocating growth molecules to the lateral development of more leaves rather than upward growth in order to compensate for the lost leaves due to rust fungi infestation (Chemeda and Jonathan, 2001). The lower number of pods per plant, leaf yield and grain yield observed in Kakamega could be as a result of the impacts of high disease severity in the same region (Chemeda and Jonathan, 2001). The disease incidence and severity were lower in Dakawa and Tumaini cowpea genotypes in both Busia and Kakamega. The same cowpea genotypes had generally higher leaf area index, leaf weight and grain weight compared to K80, local variety and KVU 27-1. This could be indication that plants that have less disease incidence and disease severity tend to translocate more nutrients and photosynthetic molecules to the growth and development of food reserves that finally serve as the yields and yield components (Bingham et al., 2014).

Larger and lesser disease infected leaves are known to increase surface area for photosynthesis resulting in high amount of biomass a plant produces (Balemi, 2009).
Ondieki (2011) observed that an increase in phosphate uptake increased leaf area and number of leaves and ultimate grain yields. The difference in disease incidence and severity between the genotypes may also have been due to genetic makeup of individual plants. Improved genotype such as Dakawa and Tumaini have hybrid vigour and ability to resist disease causing agents more efficiently than local and susceptible varieties like K80 among other abiotic stresses.

Cowpea genotypes that recorded low disease incidence rates also recorded low disease severity rates. Previous studies have also found a positive correlation between disease incidence and disease severity under similar conditions (Lawrence, 2005). The condition was more pronounced in the cropping system where intercrop cowpea exhibited significantly higher disease incidence rate and subsequently high disease severity scores compared to pure stand cowpea. Intercropping might have increased disease incidence in this situation than pure stand whose temperatures were high prompting high wind velocity, which is indeed what was observed during this experimental period. Accordingly, the microclimate in the intercropping might have caused the observed increase in disease incidences and severity in both sites as compared to pure stand. These findings are in agreement with research done in Kenya at Kabete and Thika on evaluation of intercropping beans with maize in Kenya on common bean angular leaf spot disease severity by Boudreau (2019). Similarly, Chemeda and Jonathan (2001) recorded high severity of maize rust disease in maize-sorghum intercrop than in pure crop. Mmbaga et al., (1996) reported that bean- maize intercrop influenced bean rust occurrence by affecting fungal spore dispersal, retention, and penetration infection efficiency. Msuku and Edje (1980) also observed that rust disease upsurge in the field was as a result of increased rust epidemic in
the maize-bean-groundnut intercrop due to high levels of relative humidity coming from canopies of maize-bean-groundnut favouring production of uredospore. Although this result contradicts the earlier findings that intercropping combinations results in decreased disease incidences and severity (Ihejirika, 2007; Boudreau, 2013), the intensified high relative humidity due to large plant canopy under intercropping environment has been found to increase fungal spore growth and development (Harrison et al., 1997). This could have resulted in high DI and DS in cowpea intercrop in our study. This is in agreement with Ofori and Stern (1987) who stated that yield advantage of sole crop over intercrop is explained by less disease incidences and severity besides favourable growing conditions. This is similar with findings by Pal et al., (1993) who recorded yield advantage of legume-cereal pure crop over intercrop. The yield advantage of pure crop against intercrop was ascribed to competition between the intercrop crops of maize-cowpea, (Bonny, 1990).

High rainfall resulted to increased relative humidity which prolonged periods of leaf surface wetness that created a microclimate environment which has been confirmed to accelerate the development, sporulation and infection of disease causing fungi (Gautam et al., 2013). This conforms to the report by Dorrance et al., (2003), that soil moisture and relative humidity favour fungal disease development. According to research done by Adandonon et al., (2003) disease incidence of cowpea stem rot was greater in the south and central areas of Benin Republic than its Northern zone as a result of different amount of rainfall received by each zone. In addition, the microclimate created under cowpea-maize intercrop canopy could have reduced wind velocity resulting in decreased air circulation hence prolonged aerial fungal spore accumulation and cowpea leaf wetness favouring cowpea disease incidence and severity. The results concurs with the those of Rothrock et
al., (1985) who indicated that the incidence and severity of Southern stem canker of soybean was more severely in soybean-wheat under double cropping than soybean monoculture. Disease incidence and severity negatively affected growth and yield determining parameters and the final yield. The same trend was reflected in the cropping system where cowpea under pure stand had more number of leaves, more pods per plant and hence higher leaf and grain yield than in the intercrop stand. Intercropping legume with cereal could create micro-climate which may favour disease manifestation and development with concomitant yield reductions in the affected crops (Margarida, 2013). Furthermore, other factors that prevails under intercropping such as minimum exposure to light that is essential for photosynthesis hence low dry matter accumulation, lodging on the ground due to shading that result into etiolation and weak stems Ofori and Stern, (1987); Yang et al., (2014) could exacerbate the effects and also result in limited plant development and productivity. This study is in confirmation with, Heitholt et al., (2005) who concluded out that abiotic and biotic stresses can reduce yield of crops such as moisture strain has been recorded to lower the yield advantage from closer row spacing in Kansas by more than 20%. The low disease incidence and severity in pure stand cowpea could have prompted leaf growth and development as a result of proper cell division and elongation in the meristematic tissues and hence better growth and yields components. An exponential progression of disease was observed upto week 9 after planting after which the disease incidence and severity flattened and starts reducing in all the cowpea genotypes and cropping systems at both Busia and Kakamega experimental sites. The intensity of progression was however low in Dakawa and Tumaini compared with local variety, K80.
and KVU 27-1. The low disease incidence at the initial vegetative stage (week 3 and 6) could be attributed to low fungal counts and spores during disease infection phase and to the vigorous growth and high immunity of the cowpea plants fighting the fungus. However as weeks progress the cowpea rust fungus multiplies due to prevailing suitable conditions. This finding is in conformity with research done by Kone et al., (2017), who found out that as disease progresses it suppresses plasticity and recovery rate of cowpea genotype. McCain and Hennen (1984) also found that younger leaves are immune to infection due to absence of well-developed stomata. On such leaves, the fungus fails to recognize stomata for infection to take place (Coutinho et al., 1994). The hydrophobic nature of young leaf surface may also hinder uredospore germination and penetration processes (Coutinho et al., 1994). The significant differences in the progression of disease incidence and disease severity along growth stages among cowpea genotypes indicated the varying tolerance and susceptibility among cowpea genotypes. The results is in accordance with Schneider et al., (1975) who showed that cowpea genotype has varying tolerance and susceptibility levels as time progresses upon cowpea rust infestation.

There was significant interaction effect of cowpea genotype and cropping system on plant height, number of leaves and Leaf Area Index, disease incidence and severity, number of pods per plant, leaf yields and grain yields. From this study it has been found out that there are potential cowpea genotypes that can resist or tolerate rust infestation in Western Kenya. Dakawa and Tumaini are the most recommended cowpea genotypes as they outperformed local, K80 and KVU27-1. It was also found that cowpea performance is also affected by prevailing weather conditions specifically temperature, relative humidity and rainfall regimes as influenced by altitude. Low altitude areas such as Busia have less infestation...
compared to higher altitudes like Kakamega. Intercropping maize with cowpeas causes micro-climate that lowers temperature, reduces wind velocity and increases relative humidity conditions favourable for cowpea rust proliferation.

The study bridges the gap between farmers and researchers as well as breeders on appropriate cowpea genotypes to be planted in cowpea rust prone areas. It also provides an insight on the most suitable cropping system to be adopted considering the prevailing weather conditions and agro-ecological niche.
CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the current research, it is evident that cowpea genotypes significantly differed in plant height, number of leaves, leaf area index, disease incidence, disease severity, leaf weight, number of pods and grain weight in both Busia and Kakamega due to genetic factors and weather conditions. Specifically, higher disease severity, lower number of pods per plant, lower leaf and grain yields were recorded in Kakamega which experienced more rainfall and low temperatures that created high humid microclimate during the study period. Cowpea genotypes, Dakawa and Tumaini recorded low disease incidence and severity, more pod numbers per plant, higher leaf numbers and grain yields than local variety, K80 and KVU 27-1 at both Busia and Kakamega. Cropping system also significantly influences growth and yield components. Cowpea genotypes grown in pure stand arrangement were shorter, with lower disease incidence and severity, higher number of pods per plant, higher leaf and grain yields compared to those planted under intercropping arrangement due to several number of growth limiting factors which include minimum exposure to light that is essential for photosynthesis a function of dry matter accumulation, logging on the ground due to etiolation because of weak stems hence limited plant development and productivity in intercrop. This results is in conformation with, Heitholt et al., (2005) who reported out that abiotic and biotic stresses can reduce yield of crops for example there was yield decrease of up to more than 20% from closer spacing in
Kansas due to moisture stress. The higher heights and less number of leaves found in cowpea under intercropping could be as a result of shading conditions under intercropping resulting in removal of dry matter production centre from leaves to stems promoting the stem elongation at the expense of leaves to obtain high amounts of light (Kermah et al., 2017; Gong et al., 2015; Ballare, 1999). Dry matter accumulation under intercrop was low in comparison to pure crop, because of negative effect of shading resulting in reduced amount of light required to stimulate growth and yield components (Carr et al., 1998; Carruthers et al., 2000). Additionally, previous trials reported that the negative effect of shading on soybean growth due to close spacing of maize caused severe shading hence intercepting most part of the light under maize-soybean relay-strip intercropping system (Wu et al., 2007; Yang F et al., 2014; Gao R et al., 2015). Increase of dry matter accumulation and ultimate yield in sole crop compared to intercrop could be attributed to competition for water and nutrients under intercropping (Chemada, 1997). High disease incidence and severity in intercrop could be due to high relative humidity, long period of leaf wetness and low temperatures that favoured the pathogen infection. This is in agreement with Boudreau (1992) who acknowledged that intercropping normally lower temperature and wind velocity but increase relative humidity which could change disease development. Fininsa (2001) demonstrated that high humidity and leaf wetness favour many pathogens that infect more readily in moist condition for instance angular leaf spot and white mould whose levels are higher in intercrop of beans and maize than in sole crops. There was significant interaction of cowpea genotype and cropping system on disease incidence, severity, and leaf area index, number of pods, plant height, and number of
leaves, leaf weight and grain weight. Dakawa and Tumaini out-yielded the rest of the genotypes on growth and yield parameters with more potential under pure stand. Based on these results therefore it may be suggested that farmers adopt pure stand for more leaf and grain weight, however for intercropping purposes they can use Dakawa and Tumaini cowpea genotype as they have potential resistance to cowpea rust in both pure and intercrop.

5.2 RECOMMENDATIONS

Breeders to develop cowpea genotypes that has consistence in yield stability under pure or intercrop conditions to cater for small and land limited households in the study area and beyond. A research should be conducted on rust management through an integrated biological cowpea rust management on susceptible cowpea genotypes that have desirable characteristics. Further research to be conducted to evaluate other cropping systems beside the intercrop and sole cropping system that could be suitable with cowpea as a component as practices by farmers in the study location.
REFERENCES


Mohammed, S.A.A. (2012). Assessing the land equivalent ratio (LER) of two leguminous pastures (Clitoria and Siratro) intercropping at various cultural practices and fencing at Zalingei- Western Darfur State. Sudan ARPN. *Journal of Science and Technology* 2 (11), 1074 – 1080.


### APPENDICES

#### Appendix 1: Analysis of Variance on the effect of Cowpea Rust on Number of Leaves at Busia

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>185.64</td>
<td>1.57</td>
<td>0.0187</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>147454.73</td>
<td>1245.87</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>107.93</td>
<td>0.91</td>
<td>0.4051</td>
</tr>
<tr>
<td>Week</td>
<td>4</td>
<td>29050.94</td>
<td>245.46</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>269.81</td>
<td>2.28</td>
<td>0.0066</td>
</tr>
<tr>
<td>Variety*Week</td>
<td>16</td>
<td>36.81</td>
<td>0.31</td>
<td>0.00947</td>
</tr>
<tr>
<td>Variety<em>cropping system</em>Week</td>
<td>20</td>
<td>978.79</td>
<td>8.27</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

*Significant levels at P ≤ 0.05*

#### Appendix 2: Analysis of Variance on the effect of Cowpea Rust on Number of Leaves at Busia

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>20.95</td>
<td>0.85</td>
<td>0.04967</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>8403.78</td>
<td>341.22</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>117.14</td>
<td>4.76</td>
<td>0.0107</td>
</tr>
<tr>
<td>Week</td>
<td>4</td>
<td>2185.25</td>
<td>88.73</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>36.03</td>
<td>1.46</td>
<td>0.02193</td>
</tr>
<tr>
<td>Variety*Week</td>
<td>16</td>
<td>18.31</td>
<td>0.74</td>
<td>0.00431</td>
</tr>
<tr>
<td>Variety<em>cropping system</em>Week</td>
<td>20</td>
<td>331.42</td>
<td>13.46</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

*Significant levels at P ≤ 0.05*
### Appendix 3: Analysis of Variance on the effect of Cowpea Rust on Plant height at Kakamega

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>428.62</td>
<td>1.24</td>
<td>0.2982</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>227418.13</td>
<td>655.33</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>3.13</td>
<td>0.01</td>
<td>0.991</td>
</tr>
<tr>
<td>Week</td>
<td>4</td>
<td>10622.53</td>
<td>30.61</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>550.23</td>
<td>1.59</td>
<td>0.1807</td>
</tr>
<tr>
<td>Variety*Week</td>
<td>16</td>
<td>120.82</td>
<td>0.35</td>
<td>0.9909</td>
</tr>
<tr>
<td>Variety<em>cropping system</em>Week</td>
<td>20</td>
<td>665.78</td>
<td>1.92</td>
<td>0.0144</td>
</tr>
</tbody>
</table>

Significant levels at $P \leq 0.05$

### Appendix 4: Analysis of Variance on the effect of Cowpea Rust on Number of Leaves at Kakamenga

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>49.61</td>
<td>1.13</td>
<td>0.3448</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>12535.85</td>
<td>285.29</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>303.30</td>
<td>6.9</td>
<td>0.0013</td>
</tr>
<tr>
<td>Week</td>
<td>4</td>
<td>471.96</td>
<td>10.74</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>59.60</td>
<td>1.36</td>
<td>0.0251</td>
</tr>
<tr>
<td>Variety*Week</td>
<td>16</td>
<td>11.46</td>
<td>0.26</td>
<td>0.0098</td>
</tr>
<tr>
<td>Variety<em>cropping system</em>Week</td>
<td>20</td>
<td>75.40</td>
<td>1.72</td>
<td>0.0357</td>
</tr>
</tbody>
</table>

Significant levels at $P \leq 0.05$
Appendix 5: Analysis of Variance on the effect of Cowpea Rust on Disease Severity at Kakamega

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>25.96</td>
<td>20.08</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>40.60</td>
<td>31.4</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>7.29</td>
<td>5.64</td>
<td>0.0043</td>
</tr>
<tr>
<td>Week</td>
<td>4</td>
<td>41.67</td>
<td>32.23</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>4.29</td>
<td>3.32</td>
<td>0.0122</td>
</tr>
<tr>
<td>Variety*Week</td>
<td>16</td>
<td>0.39</td>
<td>0.3</td>
<td>0.0096</td>
</tr>
<tr>
<td>Variety<em>cropping system</em>Week</td>
<td>20</td>
<td>0.24</td>
<td>0.19</td>
<td>0.005</td>
</tr>
</tbody>
</table>

***Significant levels at P ≤ 0.05

Appendix 6: Analysis of Variance on the effect of Cowpea Rust on Disease incidences at Kakamega

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>14.19</td>
<td>3.02</td>
<td>0.0196</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>22.75</td>
<td>4.84</td>
<td>0.0292</td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>29.93</td>
<td>6.37</td>
<td>0.0022</td>
</tr>
<tr>
<td>Week</td>
<td>4</td>
<td>116.24</td>
<td>24.75</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>0.26</td>
<td>0.05</td>
<td>0.0094</td>
</tr>
<tr>
<td>Variety*Week</td>
<td>16</td>
<td>0.94</td>
<td>0.2</td>
<td>0.0097</td>
</tr>
<tr>
<td>Variety<em>cropping system</em>Week</td>
<td>20</td>
<td>1.02</td>
<td>0.22</td>
<td>0.0099</td>
</tr>
</tbody>
</table>

Significant levels at P ≤ 0.05
### Appendix 7: Analysis of Variance on the effect of Cowpea Rust LAI at Kakamega

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>666.71</td>
<td>3.33</td>
<td>0.0119</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>108327.25</td>
<td>541.78</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>489.49</td>
<td>2.45</td>
<td>0.0897</td>
</tr>
<tr>
<td>Week</td>
<td>4</td>
<td>4944.97</td>
<td>24.73</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>584.43</td>
<td>2.92</td>
<td>0.0229</td>
</tr>
<tr>
<td>Variety*Week</td>
<td>16</td>
<td>77.01</td>
<td>0.39</td>
<td>0.0084</td>
</tr>
<tr>
<td>Variety<em>cropping system</em>Week</td>
<td>20</td>
<td>618.15</td>
<td>3.09</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Significant levels at $P \leq 0.05$

### Appendix 8: Analysis of Variance on the effect of Cowpea Rust on Disease Severity at Busia

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>37.68</td>
<td>46.11</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>67.54</td>
<td>82.64</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>3.56</td>
<td>4.36</td>
<td>0.0153</td>
</tr>
<tr>
<td>Week</td>
<td>4</td>
<td>90.83</td>
<td>111.15</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>12.51</td>
<td>15.3</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Variety*Week</td>
<td>16</td>
<td>1.43</td>
<td>1.74</td>
<td>0.0506</td>
</tr>
<tr>
<td>Variety<em>cropping system</em>Week</td>
<td>20</td>
<td>0.68</td>
<td>0.83</td>
<td>0.00687</td>
</tr>
</tbody>
</table>

Significant levels at $P \leq 0.05$
### Appendix 9: Analysis of Variance on the effect of Cowpea Rust on Disease incidences at Busia

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>50.12</td>
<td>18.75</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>69.22</td>
<td>25.9</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>8.97</td>
<td>3.35</td>
<td>0.039</td>
</tr>
<tr>
<td>Week</td>
<td>4</td>
<td>248.95</td>
<td>93.15</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>15.76</td>
<td>5.9</td>
<td>0.0003</td>
</tr>
<tr>
<td>Variety*Week</td>
<td>16</td>
<td>4.02</td>
<td>1.5</td>
<td>0.0133</td>
</tr>
<tr>
<td>Variety<em>cropping system</em>Week</td>
<td>20</td>
<td>2.53</td>
<td>0.95</td>
<td>0.0529</td>
</tr>
</tbody>
</table>

Significant levels at $P \leq 0.05$

### Appendix 10: Analysis of Variance on the effect of Cowpea Rust on Leaf Area Index at Busia SR

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>554.11</td>
<td>18.29</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>140.17</td>
<td>4.63</td>
<td>0.0339</td>
</tr>
<tr>
<td>Replicate</td>
<td>2</td>
<td>105.05</td>
<td>3.47</td>
<td>0.0351</td>
</tr>
<tr>
<td>Week</td>
<td>4</td>
<td>4591.26</td>
<td>151.57</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>188.48</td>
<td>6.22</td>
<td>0.0002</td>
</tr>
<tr>
<td>Variety*Week</td>
<td>16</td>
<td>35.43</td>
<td>1.17</td>
<td>0.0305</td>
</tr>
<tr>
<td>Variety<em>cropping system</em>Week</td>
<td>20</td>
<td>43.02</td>
<td>1.42</td>
<td>0.0131</td>
</tr>
</tbody>
</table>

Significant levels at $P \leq 0.05$
### Appendix 11: Analysis of Variance on the effect of Cowpea Rust on Number of pods per plant at Busia

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>239.12</td>
<td>63.48</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>1.20</td>
<td>0.32</td>
<td>0.00787</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>10.62</td>
<td>2.82</td>
<td>0.0507</td>
</tr>
</tbody>
</table>

Significant levels at $P \leq 0.05$

### Appendix 12: Analysis of Variance on the effect of Cowpea Rust on leaf biomass kg ha$^{-1}$ at Busia

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>7531485.88</td>
<td>4.73</td>
<td>0.0075</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>7374529.20</td>
<td>4.63</td>
<td>0.0438</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>1231720.28</td>
<td>0.77</td>
<td>0.5552</td>
</tr>
</tbody>
</table>

Significant levels at $P \leq 0.05$

### Appendix 13: Analysis of Variance on the effect of cowpea rust on grain yield (kg ha$^{-1}$) at Busia

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>263844.20</td>
<td>10.47</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>157687.50</td>
<td>6.26</td>
<td>0.0211</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>23502.17</td>
<td>0.93</td>
<td>0.0404</td>
</tr>
</tbody>
</table>

Significant levels at $P \leq 0.05$
Appendix 14: Analysis of Variance on the effect of Cowpea Rust on Number of pods per plant at Kakamega

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>14.19</td>
<td>3.02</td>
<td>0.0196</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>22.75</td>
<td>4.84</td>
<td>0.0292</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>0.26</td>
<td>0.05</td>
<td>0.0094</td>
</tr>
</tbody>
</table>

Significant levels at P≤ 0.05

Appendix 15: Analysis of Variance on the effect of Cowpea Rust on leaf biomass kg ha-1 at Kakamega

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>3215482.03</td>
<td>4.19</td>
<td>0.0126</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>4595036.03</td>
<td>5.99</td>
<td>0.0237</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>348839.20</td>
<td>0.46</td>
<td>0.0067</td>
</tr>
</tbody>
</table>

Significant levels at P≤ 0.05

Appendix 16: Analysis of Variance on the effect of Cowpea Rust on Grain yield kg ha-1 at Kakamega

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>4</td>
<td>155885.70</td>
<td>8.95</td>
<td>0.0003</td>
</tr>
<tr>
<td>Cropping system</td>
<td>1</td>
<td>103958.53</td>
<td>5.97</td>
<td>0.0239</td>
</tr>
<tr>
<td>Variety*cropping system</td>
<td>4</td>
<td>8260.20</td>
<td>0.47</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Significant levels at P≤ 0.05