EFFECT OF CROPPING SYSTEMS ON THE OCCURRENCE OF FUNGAL AND BACTERIAL DISEASES OF LEGUMES IN WESTERN KENYA

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DECLARATION

This is my original work and has not been submitted for the award of a degree in any other University.

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DEDICATION

I dedicate this thesis to my entire family for their love and support. I thank you all.

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LIST OF ABBREVIATIONS

AEZ	Agro-ecological zone
ANOVA	Analysis of variance
CABI	Commonwealth Agricultural Bureau International
CBB	Common bacterial blight
CFU	Colony forming units
CV	Coefficient of variation
GIS	Geographical Information Systems
ISTA	International Seed Testing Association
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
KARI	Kenya Agricultural Research Institute
KARLO	Kenya Agricultural and Livestock Research Organization
LSD	Least Significant Difference
NA	Nutrient agar
PDA	Potato dextrose agar
Ppm	parts per million
TSW	Thousandth seed weight
UoN	University of Nairobi

ABSTRACT

Bacterial and fungal diseases of legumes are a major constraint in legume production in western Kenya and persistently curtail optimal yields and quality of food legumes. This study aimed at determining the occurrence of fungal and bacterial diseases of these legumes and the contribution of seed quality to their occurrence, in diverse agro-ecological zones of western Kenya. The study was carried out during the short rains season (months of October, November and December) of 2013 in seven Counties with diverse agro-ecological zones. A total of 635 farms were sampled in the study covering both participating and non- participating farmers in the legume up-scaling projects in the area. A semi-structured questionnaire together with visual observations were used to obtain information on legume production practices, distribution, incidence and severity of common diseases of food legumes grown. Bean seed samples as well as plant tissues were collected from farmers for laboratory analysis. Geographical information system coordinates and elevation of each farm sampled were taken for the purpose of generating legume disease distribution and intensity maps. The collected seed samples were analyzed for purity, germination, bacterial and fungal contamination as outlined in International Seed Testing Association. Most of the legume farmers were small scale and allocated less than 0.1 Ha of land for legume production. Majority of the farmers intercropped legumes with other crops and planted local (landraces) legume varieties. There were 13 different bean varieties grown, with Rose coco and KK8 accounting for 23% and 22%, respectively. The most commonly grown legumes were common bean, cowpeas and groundnuts. The major diseases affecting all the legumes were common bacterial blight and root rots. Fungal and bacterial disease prevalence significantly ($P \leq 0.05$) varied in the different regions and agro-ecological zones (AEZ). There was however, no significant ($P \leq 0.05$) difference in disease intensity among farmers

participating and those not participating in the legume up scaling projects in the different regions. Most bean samples had the recommended percentage germination of 95% but low percentage purity of 74.1%. Of the germinated seedlings, 7% showed infection and most samples contained 12% of discoloured and shriveled seeds. Fungi isolated from the seeds were *Fusarium solani* and *Colletotrichum lindemuthianum* while *Xanthomonas campestris* pv *phaseoli* and *Pseudomonas savastanoi* pv *phaseolicola* were the main bacterial pathogens with infection levels of as high as 2000-3000 CFU/seed. There was significant ($P \leq 0.05$) variation in the frequency of fungal and bacterial pathogens populations among regions. The results of this study showed that there was a high prevalence of fungal and bacterial diseases of legumes due to cropping practices. Farm-saved bean seeds contained a high level of bacterial blight pathogen inocula due to continuous recycling of seed from previous cropping seasons. There is therefore, need to accurately monitor legume diseases and create awareness among farmers on use of disease-free seeds and application of appropriate agronomic practices to reduce the effects of seed-borne diseases.

CHAPTER ONE: INTRODUCTION

1.1 Legume production in Kenya

Legumes belong to the *Fabaceae* family and are grown agriculturally for food, animal feed and generation of cash (Mhango *et al*., 2013). In Kenya, food legumes are the second most grown grains after maize (Muthomi *et al*., 2007). They are usually intercropped with cereals like maize, cassava, sorghum and millet, where the legumes are the minority crops while the cereals are the majority (Tsubo *et al*., 2003; Hauggard-Nielsen *et al*., 2007). In Western Kenya, food legumes are grown mainly as a source of food and an income generating crop by the resource poor farmers (Ojiem, 2006). Legumes are rich sources of proteins, which is approximately 18–25%, with soy bean having the highest percentage of protein content about 35-43% (Tharanathan and Mahadevamma, 2003). In addition, use of legumes as intercrops has been shown to have numerous benefits to the soil including controlling erosion, reducing water and nutrient loss, weed control and increasing nutrient access to the plants (Giller, 2001; Shapiro and Sanders, 2002; Adu-Gyamfi *et al*., 2007; De groote *et al*., 2010). The common food legumes grown in western Kenya are soy bean (*Glycine max*), common bean (*Phaseolus vulgaris*), green grams (*Vigna radiata*), groundnuts (*Arachis hypogaea*), lablab (*Lablab purpureus*), cowpeas (*Vigna unguiculata*), garden pea and Bambara nuts.

Food legume production however, is affected by pests and diseases and poor soil fertility due to poor farming practices (Akibode and Maredia, 2011). Legume diseases contribute to the total global food production losses due to plant disease, estimated at 10% (Strange and Scott, 2005). Lack of inputs like clean seeds, chemicals and fertilizers are also a major challenge for the small scale farmer (Kimiti *et al*., 2009). Farmers, therefore, rely on informal channels of obtaining seeds like keeping some from previous seasons, local exchanges among themselves or buying

from local markets (Karavina *et al*., 2008). Most fungal and bacterial diseases are seed borne and farmers reusing their own farm saved seeds, encourages pathogen build up in the seeds and soils which discourages breaking of disease cycles (Buruchara, 1990; Scott *et al*., 2003; Rubyogo *et al*., 2007). Management strategies like crop rotation are no longer applicable due to continous cropping brought about by diminishing land sizes due to a high population growth density. This encourages persistence of diseases and pests and a decrease in soil fertility due to depletion of soil nutrients (Brenam, 1998). Environmental factors such as elevation, humidity and precipitation and disease resistance affect the occurrence of pests and diseases (Bernardi, 2001; Fininsa and Tefera, 2006; Asch and Huelsebusch, 2009). Efforts to come up with resistant cultivars are usually hindered by incapacity to develop cultivars with multiple diseases resistance genotypes.

1.2 Problem statement

Food legumes play an important role both in nutrition and generation of income (Mwang'ombe *et al*., 2007). However, output of food legumes in western Kenya is hindered by diseases and pests, low soil fertility due to continous cropping with a lack of organic and inorganic inputs (Buruchara, 1990; Scott *et al*., 2003; Okalebo *et al*., 2006; Rubyogo *et al*., 2007) and unfavorable weather conditions which has resulted in low productivity, poor rural livelihood and poverty rates that are among the highest in Kenya (Giller *et al*., 2011). Clean certified seeds are important since most of the legume pathogens are seed borne (Narayan and Ayodha, 2013; Fourier, 2002). Seed borne diseases result in poor crop establishment and consequently huge crop losses (Dawson and Bateman, 2001; Islam *et al*., 2009).

1.3 Study justification

Legumes are a contributing food crop towards food security in Kenya's 67% food insecure population (World development indicators, 2014). They are the second most cultivated grains in Kenya after maize and other cereals (Muthomi *et al*., 2007). They play an important role in alleviating malnutrition in resource- poor households, since they are not only a cheap source of concentrated protein, but also of slow release carbohydrates, vitamins and minerals (Tharanathan and Mahadevamma, 2003). Legume diseases contribute to decreased yields and affect the storability and marketability of these legumes (Mwang'ombe *et al*., 2007). In addition, there is a lack of efficient seed systems that enables accessibility by the farmers (Tripp, 2003; Rubyogo *et al*., 2007). This study therefore, aimed at establishing the relationship between farming practices, environmental conditions and seed quality to the occurrence and distribution of fungal and bacterial diseases affecting legumes in western Kenya. It also aimed at establishing how Geographical Information Systems (GIS) technology can be applied in timely management of these diseases by mapping their distribution in the region. In establishing the relationships between these parameters, farmers will be well prepared and advised on better cropping practices and disease patterns and breakout which would allow timely and manageable interventions. The information will also lead to adoption of improved legume technologies and better management of legume diseases and consequently improved food security.

1.4 Objectives

The main objective was to determine the effect of cropping systems, environmental conditions and seed quality on the occurrence of fungal and bacterial diseases of legumes in western Kenya.

The specific objectives were:

i. To determine the occurrence of fungal and bacterial diseases affecting legumes under diverse farming practices and agro-ecological zones of western Kenya.

ii. To determine the contribution of seed quality on the occurrence of fungal and bacterial diseases of common bean in diverse farming practices and agro-ecological zones of western Kenya.

1.5 Hypotheses

i. There is a correlation between farming practices and environmental conditions and the occurrence of fungal and bacterial diseases of legumes in western Kenya.

ii. Quality of seeds contributes to the occurrence and severity of fungal and bacterial diseases of common beans in western Kenya.

CHAPTER TWO: LITERATURE REVIEW

2.1 Legume production practices in western Kenya

In western Kenya, legumes are grown mainly for food and as a source of income (Mwang'ombe *et al*., 2007; Mhango *et al*., 2013) and are usually intercropped with maize or other cereals, a cropping practice common with small-scale farmers in the tropics. Intercropping is the practice of growing more than one crop simultaneously in alternating rows of the same field. Typically, cereal crops such as maize (*Zea mays*), millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*) are the major crops, whereas legume crops such as beans (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), pigeonpea (*Cajanus cajan*) and soybean (*Glycine max*) are the associated crop types (Tsubo *et al*., 2001). The choice of grain legumes by farmers is mainly influenced by factors like cash generation ability, palatability and high yield levels (Maobe *et al*., 1998). Intercropping has many benefits to the farmer including a reduction in farm inputs, diversification of diet, addition of cash crops, reduced labor cost, and reduced risk of crop failure (Hauggard-Nielsen *et al*., 2007).

Most farmers plant legumes twice a year during the long rains and short rains season (Jaetzold *et al*., 2006) using their own kept seeds from the previous seasons (Buruchara 1990; Scott *et al*., 2003; Rubyogo *et al*., 2007) and a few use cattle manure ammendment while most lack the inputs (Kimiti *et al*., 2009). Cattle manure is not sufficient since it is only available to 50% of households in smallholder farming systems and is limited to cattle owners (Mugwira and Murwira, 1997). Most farmers rely on cultural methods for control of diseases like weed control, deep ploughing of debris, crop rotation and minimizing of movement when the fields are wet (Allen *et al*., 1998).

2.2 Fungal and bacterial diseases affecting legumes in Kenya

2.2.1 Common bacterial blight

This is a fungal disease that is caused by *Xanthomonas campestris* pv. *phaseoli* and *X. campestris* pv. *phaseoli* var. *fuscans* affecting almost all legumes. The disease is destructive during high rainfall, humidity and temperature (25-35˚C) with maximum development occurring at 28˚C and results in yield and quality losses (Saettler, 1991; Gilbertson and Maxwell, 1992; Akhavan *et al*., 2013). It affects all legumes and yield losses have been reported to vary between 22% and 45% (Yoshii, 1980). Symptoms appear as water soaked lesions on the underside of leaves. Leafs pots enlarge and merge to form large brown irregular lesions surrounded by a narrow yellow zone. Spots may coalesce, and yellowing becomes more general. The stem may rot at the first node where cotyledons were attached and cause the plant to break. Infected pods have circular, water-soaked areas that often produce yellow masses of bacterial ooze. Later, spots dry and appear as reddish-brown lesions. Pod infection often causes discoloration, shriveling and bacterial contamination of seeds; however, some seed may appear healthy (Buruchara *et al*., 2010). Common blight bacteria survive between bean crops in association with seed, bean debris, and weeds (Mkandawire *et al*., 2004). Effective bacterial blight disease management involves use of genetic resistance (Miklas *et al*., 2003; Fourier *et al.*, 2011) in addition to the use of certified seed, crop rotation, and field sanitation .

2.2.2 Halo blight

The disease is caused by *Pseudomonas savastanoi* pv *Phaseolica* and *Pseudomonas syringae* pv *Phaseolica*. Common bean is the host crop. High humidity and cool temperatures are the predisposing factors (Fourier, 2002). The disease is characterized by greasy water soaked spots, visible on the underside of young leaflets which is later surrounded by green halo. The disease

can be systemic causing yellowing and death of new foliage. Small circular water soaked spots or streaks which develop a reddish discoloration can be seen on pods. Light cream or silver colored bacterial ooze associated with the spots can be observed. Can cause discoloration, shriveling and bacterial contamination of seeds, which is a major source of infection. Serious losses have been documented in Lesotho, Rwanda and Zimbabwe (Allen *et al*., 1998) while yield losses of 43% have been reported in experimental conditions (Fourier, 2002). Recommended control measures of halo blight include: cultural practices like deep ploughing, crop rotation, use of clean seeds, use of resistant varieties (such as GLP 92) and use of fungicides.

2.2.3 Anthracnose

Anthracnose is one of the most important diseases affecting legumes and is endemic in Africa, Australia, Asia and many countries in Latin America (Pastor-Corrales *et al*., 1995). The causal agent of anthracnose, *Colletotrichum lindemuthianum*, is an imperfect fungus that is highly variable pathogenically among different geographical regions (Sharma *et al*., 1999; Ansari *et al*., 2004). The fungus attacks a wide range of crops including legumes (common bean, soybean and cowpea) in subtropical and temperate regions (Bailey *et al*., 1992), mostly under cool and humid conditions (Buruchara *et al*., 2010). When infection occurs early in the growth cycle of susceptible cultivars, yield loss of up to 100% can occur (Fern´andez *et al*., 2000; Mohammed, 2013). Bean anthracnose is spread by rain splash of spores (Diggle *et al*., 2002) while the disease is transmitted from one season to another through infected seed (Yusuf and Sangchote, 2005; Mudawi *et al*., 2009; Wahome *et al*., 2011). The characteristic symptom include pod lesions that are sunken encircled by a slightly raised black ring surrounded by a reddish border (Hall, 1994). Control is by use of resistant cultivars and clean seed (Nkalubo *et al*., 2007).

2.2.4 Angular leaf spot

Angular leaf spot is caused by the imperfect fungus *Phaeoisariopsis griseola* (Sacc.) Ferr. (*Isariopsis griseola* Sacc.) which is highly pathogenically variable (Dmulira *et al*., 2014) and is found in more than 60 countries world-wide (Guzm´an *et al*., 1995). The common host crop is the common bean (*Phaseolus vulgaris* L.). Field symptoms are observed after flowering; leaf lesions are the most conspicuous, which start as small, brown or grey spots that develop into angular necrotic lesions delimited by vascular strands. Lesions eventually enlarge, coalesce and cause defoliation. Circular to elliptical red brown lesions can develop on pods and also browning of the stems (Boshoff *et al.*, 1996). Warm, moist conditions and abundant inoculum from infected plant residues and contaminated seed favor the development of the pathogen (Stenglein et al., 2003). Angular leaf spot can cause severe and premature defoliation resulting in shriveled pods, shrunken seeds and yield losses of up to 80% (Schwartz *et al*., 1981; Stenglein *et al*., 2003). Best control methods includes use of resistant cultivars, seed sanitation and crop rotation (Oblessuc *et al*., 2012; Chilagane *et al*., 2013)

2.2.5 Leaf rust

Leaf rust is endemic and severe in eastern and southern Africa and causes yield and quality reductions ranging from 18 to 100% in humid and tropical areas (Kimani *et al*., 2002; Monda *et al*., 2003). The disease has high virulence diversity (Arunga *et al*., 2012; Acevedo *et al*., 2013,). The host crops are common bean, cow pea, and soy bean. Cow pea rust is caused by *Phakopsora pachyrhizi* and *Phakopsora meibomiae* while soy bean and common bean rust is caused by *Uromyces appendiculatus.* The disease is favored by cool to moderate temperatures, high moisture content, infected plant debris and volunteer plants, cultural practices, late planting, herbicide damage, excess nitrogen or hail damage. Repeated disease cycles may occur at 10- to

14-day intervals under favourable conditions (Schwartz *et al.*, 2004). Symptoms include spores from the leaf spots that rub off, the leaf spots enlarge to form reddish brown pustules. Green pods can also be infected to form rust pustules (Mersha and Hau, 2008). Cultural practices like crop rotation, deep ploughing of infected debris, early planting are used to manage the disease including planting of resistant varieties.

2.2.6 Root rot complex

Root rots are common in all legume crops and are caused by different types of soil fungi (*Pythium* species, *Fusarium*, *Rhizoctonia*, *Sclerotium* and *Macrophomina phaseolina*) (Buruchara *et al*., 2010; Okoth and Siameto, 2010). They can occur individually or in a combination, in a root rot complex. Root rots are normally characterized by above ground symptoms such as poor seedling establishment, post emergence damping off, uneven growth ,premature defoliation of severely infected plants and decreased yields (Abawi and Ludwig, 2006; Muthomi *et al*., 2007; Schwartz *et al*., 2007). They are common in Africa including western Kenya where they are more prevalent usually in stressed crops from low soil fertility, high humidity, warm to high temperatures, high or low soil moisture, compacted soils, drought, acid soils or soils fertilized with ammonium fertilizers and those that are over cultivated (Abawi *et al*., 2006). Symptoms depend on causative organisms and also environmental conditions. Usually involves leaves turning yellow and dropping and symptoms generally are the same and causes total crop loss when severe up to 70% yield losses (Nzungize *et al*., 2012). Use of resistant cultivars is the most effective management method for root rot diseases in legumes (Alessandro *et al*., 2006). Other control measures include use of clean planting material, chemical seed dressing before planting, use of organic amendments, crop rotation, intercropping

and biological control (Lodha and Burman, 2000; Lokesha and Benagi, 2007; Muthomi *et al*., 2007).

2.2.7 Early and late blights

Early and late blights are common in groundnuts. Early leaf spot is caused by *Cercospora arachidicola* and occurs as early as 2 weeks after crop emergence. Lesions produced by this fungus are circular, dark brown on the upper surface with chlorotic (yellow) halos surrounding the darker lesions and a lighter shade of brown on the lower surface of the leaflets. Severe attacks can cause heavy defoliation and result in a large yield loss. Late leaf spot is caused by *Phaeiosariopsis personata* and occurs later in the season and has nearly circular lesions which are darker than those of early leaf spot. Late leaf spot does not normally affect yield reduction as severely as early leaf spot. On the lower leaf surface where most of the sporulation occurs, the lesions are black. Climate, micro-environments and method of irrigation have been reported to affect disease severity. Optimum temperatures of 25-31°C, high minimum (18-23°C) and maximum (31-35°C) temperatures and high humidity, as well as a late rainy season favour sporulation (Subrahmanyam *et al*., 1992). These diseases singly can cause loss in pod yield of more than 50% (Mcdonald *et al*., 1985; Waaliyar *et al*., 2000). Cultural practices (early planting and close spacing), have been used to control these diseases in groundnuts by small scale farmers (Montfort *et al*., 2004; Naab *et al*., 2009).

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2.2.8 Web blight

The disease is caused by *Rhizoctonia solani* and is spread by mycelia bridges between plants, rain-splashed sclerotia, infected soil debris (Ga´lvez *et al*., 1989) and airborne basidiospores (Cardenas-Alonso, 1989). The common host legume is the common bean and is favored by

humid weather with high to moderate temperatures. The characteristic symptoms include scalding of leaves which appear grey-greenish to dark brown. Pod infection appears light brown with irregular shaped lesions in young pods while mature pods appear dark brown, circular, lightly zonate and sunken with a dark border (Buruchara *et al*., 2010). The disease causes significant losses through the destruction of leaves and blemishes on seeds that reduce the market value of seeds (Godoy-Lutz *et al*., 1996). Cultural practices like, minimum tillage, crop rotation, wide spacing and use of fungicides are common practices for control for a lack of resistant cultivars (Gonzalez *et al*., 2012).

2.2.9 Cercospora leaf spot

Cercospora leaf spot, caused by *Cercospora cruenta* and *C. canescens,* causes severe leaf spotting and defoliation during the time of flowering and pod formation. The host legumes are cowpea, greengrams and soybean. *C. kikuchii* causes the disease in soybean and readily sporulates abundantly on infected plant tissue in high humidity and temperatures of 23-27°C (Murakishi, 1951). The pathogen can survive in infected seeds and in surface debris in the field for extended periods (Kilpatrick, 1956). Involvement of different species in causing cercospora leaf spot complicates characterization of species. Yield losses of 50% in severely diseased field have been reported (Pande *et al*., 2009). Since there is low level of resistance to cercospora leaf spot, the cultural practices and chemical control play an important role in its management. Field sanitation, crop rotation, destruction of infected crop debris, and avoiding collateral hosts near the crop may help in reducing the incidence (Pande *et al*., 2007).

2.2.10 Powdery mildews

Powdery mildew disease is caused by the obligate biotrophic fungi *Erysiphe polygoni*, which develops throughout the legume shoot, including leaves, stems, petioles and pods (Trabanco *et al*., 2012). It is favored by warm temperatures, low humidity and shade (Valenzula and smith, 2002). This disease usually occurs and develops under cool air temperature (approximately 18–24° C), but disease development and progression may stop when temperatures are greater than 30°C (Grau, 2006). It affects all legumes and the most obvious symptom is a powdery white fungus on the surface of infected parts (Sinclair, 1999). Other symptoms can range from chlorosis, green islands, rusty spots, defoliation or severe combination of these symptoms, depending on the type of cultivars. Infection occurs primarily in the lower leaves but can occur on the upper leaves when conditions are favorable resulting in high losses. According to Gonçalves *et al.*, (2002), Soybean crop widely affected by the disease, had estimated yield losses of between 30 and 40%.

2.2.11 Ascochyta leaf spot

Ascochyta leaf spot infection is caused by the fungus *Phoma exigua var. exigua*, *Ascochyta phaseolorum* and disease progression occur from 5° to 25 °C with an optimum temperature of 16-20 °C, and a minimum of 6 hours of leaf wetness. Disease severity increases with the increase in relative humidity (Trapero-Casas and Kaiser, 1992). Cloudiness and prolonged wet weather favour rapid development and spread of the disease (Tivoli and Banniza, 2007). The symptoms involve large dark grey to black spots that later become zonate with concentric rings around the spot. Stems when infected the nodes are blackened and premature leaf drop may occur. Pod infection can result into formation of cankers and results in seed infection. The pathogen survives on infected or contaminated seeds and infected plant debris (Gossen *et al*., 2011).

Integrated disease management including cultural methods, fungicides and use of resistant genotypes are the effective methods of control (Pande *et al*., 2009).

2.3 Factors affecting occurrence and severity of legume disease

The occurrence and severity of legume diseases is affected by several factors. Environmental conditions such as temperatures, elevation, humidity and precipitation play a big role on how often and severe the diseases and pests occur (Bernardi, 2001). Different kinds of pathogens can grow, thrive and cause disease whenever favorable temperatures, rainfall and altitude are available.

The quality of seeds also affects the occurrence of these diseases as many of the bacterial and fungal pathogens are seed-borne (Allen *et al*., 1998; Narayan and Ayodha, 2013). These seed borne pathogens can cause enormous crop losses; reduction in plant growth and productivity of crops (Allen *et al*., 1998; Dawson and Bateman, 2001; Islam *et al*., 2009). In addition, farmers lack the knowledge and accessibility of clean certified seeds and therefore rely on their own seed retained from harvest season to season (Buruchara 1990; Rubyogo *et al*., 2007). This results in huge crop losses, reduction in plant growth and productivity of crops (Dawson and Bateman, 2001; Islam *et al*., 2009).

Most farmers practice continuous cropping, a common practice due to diminishing land sizes and changing socio-economic conditions, this encourages persistence of pathogens and decreases soil fertility resulting in low crop yields (Breman, 1998; Nambiro, 2008). Fertility status of the land, coupled by the incidence and severity of pests and diseases, dictate how often these legumes are incorporated in the cropping systems (Akibode and Maredia, 2011).

There is the lack of resistant cultivars resistant due to legumes being attacked by a complex of diseases and therefore difficult to come up with resistant cultivars to all the diseases. Moreover,

seed companies concentrate on the legumes that are more profitable in terms of cash and less effort is put on those traditional crops that are a source of food security to most of the resource poor farmers in the small holder farming systems (Tripp, 2003; Rubyogo *et al*., 2007).

2.4 Role of seed in spread of legume diseases

Seed is the most important input in crop production and therefore healthy seeds are the most important in ensuring maximum crop output (Diaz *et al*., 1998). Majority of plant pathogens are seed-borne which results in poor crop establishment and therefore low yield (Dawson and Bateman, 2001; Islam *et al*., 2009). Legume seed production is affected by both fungal and bacterial diseases which are transmitted by infected seeds (Narayan and Ayodhya, 2013). Seed transmitted fungal pathogens, often reduce the germination ability or kill the infected plants lowering the productive capacity. Many farmers in the small holder farming systems including western Kenya do not use certified seeds, they instead use their harvested seeds from previous seasons (Maredia *et al*., 1999; Scott *et al*., 2003). The use of their own seeds from season to season encourages build up of the pathogen inoculum source resulting in high crop losses due to the diseases (Buruchara, 1990). Inaccessibility of the seeds to farmers is also a big problem. Most seed companies are only willing to manufacture those varieties that are profitable to them and not the local varieties that play a major role to the resource poor farmer's food security (Tripp, 2003).

2.5 Strategies for managing legume diseases

There are several methods that small holder farming systems use to manage the legume diseases. Cultural methods like deep ploughing of debris, crop rotation, weed control and minimizing of movement when the foliage is wet, are commonly used to control the diseases (Allen *et al*., 1998; Schwartz and Otto, 2000). These cultural methods are commonly used by the smallholder

farmers instead of the expensive pesticides which are unaffordable to most of them (Allen *et al*., 1998). These methods play a big role in disease and pest management by breaking the disease cycle and limiting spread.

Use of fungicides are also employed by farmers to protect their crop from various pathogens that cause loss or reduced yields. Fungicides, one of the primary methods to manage fungal diseases, contain one or more active ingredients that affect the pathogen. Fungicides are therefore necessary to the farmers in growing crops economically by avoiding crop loss in the field (Abawi and Widmer, 2000; Naab *et al*., 2009). Chemicals however, have a limitation as they are expensive and most small scale farmers are not able to afford (Allen *et al.,* 1998).

Use of certified seeds is another method employed in ensuring minimal crop losses. These however, are expensive and inaccessible to small holder farmers. Majority of the farmers mainly get their seeds from informal channels which contribute about 90-100% of seed supply depending on crop type (Maredia *et al*., 1999). Efforts to make certified and disease resistant varieties are hindered by seed companies' main focus on the crops that benefit them in terms of profit rather than a range of crops that make up the backbone of resource poor farmer's food security (Tripp, 2003; Rubyogo *et al*., 2007).

2.6 Use of geographical information system in the study of plant diseases

Geographic information systems (GIS) provide valuable tools in monitoring, predicting, managing and fighting the spread of pests and diseases (Bouwmeester *et al*., 2010). The tools ensure cost-effective and timely control interventions. Geographical information systems information can also be used in site specific management by identifying spots in the field where the pathogen thrives and applying control measure like pesticides on that spot (Azahar *et al*., 2011). It can also be used in generating weather and disease weather forecasts which can help in

eliminating surprise factor of disease outbreaks (Thomas *et al*., 2002). Disease forecast models can be used in estimating global severity of diseases, which can help in identifying zones where the disease is more susceptible and this can be helpful in allocation of resources and priotization in research (Hijmans *et al*., 2000). Current applications of geographical information systems in agriculture have included not only in the study of diseases but also in the study of insect pests (Huang *et al*., 2008) and also in spatial analysis of weeds (Jarnevich *et al*., 2010). Geographical information system can therefore, be used to predict the projected spread of diseases, to provide input for risk assessment models and in quantifying changing thresholds of pests and diseases due to climate change (Bouwmeester *et al.*, 2010). Color coded spatial maps generated are usually easily understood and less likely to be misused by farmers and makes forecasting easier to understand and interpret and results in reduced pesticide use and an economical and environmental friendly crop protection strategy (Kleinhenz and Zeuner, 2010).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Determination of the occurrence of fungal and bacterial diseases in western Kenya

3.1.1 Study areas

The study was carried out during the short rains season of 2013 in the months of October, November and december in seven Counties with their corresponding agro-ecological zone: Busia (LM2), Bungoma (LM2), Homabay (LM1, LM2), Migori (LM1), Nandi (LH1, UM1), Siaya (LM4) and Vihiga (UM1) (Figure 1; Table 1). The study areas were selected based on the intensity of legume production.

3.1.2 Sampling

A total of 635 households were covered in the study where the number of households sampled in each area and agro-ecological zone was based on the human population size (Table 2). Sample size for each agro ecological zone was determined by (Table 2):

$$\frac{\text{Percentage of the specific zone}}{\text{Total percentage of the study population}} \text{ X Target (635farmers)}$$

Cluster sampling approach was used to select legume farmers. Farmers participating in the legume up-scaling projects (Legume up-scaling projects were started in western Kenya by non governmental organizations together with ministry of agriculture and Kenya agricultural and livestock research organization (KARLO) with the purpose of coming up with improved legume varieties, introduction of alternative legumes and consequently improving food security) in the six agro ecological zones as well as non participating farmers were sampled.

Figure 1: Map of western Kenya showing the various regions covered in the legume disease survey carried out during the short rains season of 2013.

Source: Google map, 2015

Table 1: Characteristics of the agro-ecological zones covered in the legume disease survey

Region	AEZ	Altitude(m)	Annual Rainfall(mm)	Average temp.(°C)	Description of characteristics
Rongo, Butula	LM1	1350-1500	160 0-1800	21.1-22.0	sugarcane zone
Rangwe, Busia, Bungoma	LM2	1350-1550	1350-1650	20.9-22.0	Marginal sugarcane zone
Siaya, Teso north	LM3	1200-1400	1200-1450	21.6-22.4	Cotton zone
Bondo	LM4	1135-1200	600-1100	22.3-22.7	Maize, cotton, sisal,
Nandi south, Sabatia	UM1	1500-2000	1540-1800	18.0-21.0	Coffee-tea zone tea, maize
Nandi south	LH1	1950-2400	1600-2000	15.2-18.0	Tea dairy zone

LM1- low midland zone 1; LM2- low midland zone 2; LM3- low midland zone 3; LM4- low midland zone 4; LH1- low highlands zone 1; UM1- upper midlands zone 1. Source: Jaetzold *et al*., 2006

Table 2: Distribution of sample size in different agro-ecological zones in various regions in western Kenya

AEZ	Regions	% of study area	% of study population	Target N = 635
LM3	Siaya, Teso north	18	16	122
LM2	Busia, Bungoma, Rangwe	17	15	115
LM1	Rongo, Butula	15	18	138
UM1	Vihiga, Nandi south	12	21	161
LM4	Bondo	8	5	38
LH1	Nandi south	6	8	61
Total			83	635

LM1- low midland zone 1; LM2- low midland zone 2; LM3- low midland zone 3; LM4- low midland zone 4; LH1- low highlands zone 1; UM1- upper midlands zone 1

3.1.3 Survey of the occurrence of legume diseases

A semi-structured questionnaire (Appendix 1) together with visual observations were used to gather information on farmer practices. Information on the types of legumes grown by the farmer, variety grown, incidence and severity of each legume disease was gathered. Sampling points within a farm were randomly selected. At each point, disease distribution, incidence and severity were determined in an area measuring $1m^2$. Diseases affecting the legumes were identified based on symptoms. Disease distribution was determined on a scale of 0-2, 0 = no disease, where 1 = spots and 2 = whole field. Disease incidence was determined as the number of infected plants over the total number of plants within $1m^2$. Disease severity was assessed on a 0 – 3 scale where 0 = No disease; 1 = Mild; 2 = Moderate and 3 = Severe. Disease indices were calculated by summing up the scores of distribution, incidence and severity. The same procedure was repeated for three more randomly selected sampling points on the same farm, a minimum of five meters apart. Distribution, incidence and severity of all diseases affecting each legume in the farms were determined.

3.1.4 Sample collection

Diseased plant tissues (leaves, stems, roots and pods) were sampled from each farm using the zig-zag sampling approach. Scissors used during sampling was surface sterilized using 70% ethanol to avoid cross contamination from one farm to the other. The samples were put in Kraft bags, labeled, stored in a cool box and transported to the laboratory where they were stored at 4° C until isolation and identification of the pathogen causing the disease

3.1.5 Mapping the distribution of legume diseases in western Kenya

Global Positioning System (GPS) coordinates – latitude, longitude and elevation - of the sampled farms were taken at the middle of the farm and were obtained with the aid of a GPS tool (Garmin

version 6.13.7, Garmin limited, USA). The coordinates were used to map the distribution of major diseases of major legumes in the study region. Google earth software (version 7.1.3.22.3), a mapping software, was used to generate the maps.

3.1.6 Isolation of bacterial pathogens

The diseased tissues were rinsed under running tap water for 30 seconds, surface sterilized for 2 minutes in 1.3% sodium hypochlorite and then rinsed twice in sterile water for 1 min each. The tissues were then macerated in a droplet of sterile water and the macerate streaked onto nutrient agar. Streaking was done by picking a loopful of bacteria using sterile wire loop and making three parallel streaks on one side of the nutrient agar medium surface. This was followed by another set of streaks perpendicular to the first after flaming the wire loop. The wire loop was flamed again and the third set of streaks perpendicular to the second were made. Plates were then incubated at 25°C for 72 hours. Well separated single colonies were sub cultured on fresh nutrient agar media plates and the pathogen was identified based on cultural characteristics (including color of colonies) and pathogenicity test (Section 3.2.4.1) .

3.1.7 Isolation of fungal pathogens

Isolation of fungal pathogens involved cutting the diseased tissues into small pieces (approximately 1cm long) and then surface sterilizing them for a period of 30s, using sodium hypochlorite (3.5%). The sterilized tissues were then rinsed in three changes of sterile distilled water to remove the sodium hypochlorite. Soiled samples like roots were first rinsed with sterile distilled water before undergoing the same procedure. The sterilized pieces were aseptically transferred to Petri plates containing potato dextrose agar (PDA) (39g PDA per 1000g distilled water) supplemented with 50 ppm streptomycin sulfate. Five pieces (≈ 1cm long) of plant tissues were aseptically plated per Petri dish and incubated at room

temperatures (23 ± 2°C). The fungal isolates were then sub cultured in PDA to obtain pure colonies for identification. The type of pathogen was identified based on morphological and cultural characteristics of the fungal pathogens such as type, shape and color of sexual or asexual spore formed, by microscopic examination and as well as by conducting a pathogenicity test (Section 3.2.5.1).

3.2 Determination of the contribution of seed quality to legume diseases

3.2.1 Sample collection

Approximately 0.5 kg of common bean seed samples were collected from each farmer involved in the survey. Ten seed samples, five from farmers participating in legume up scaling projects in each area and another five from non participating farmers were collected from each agro-ecological zone in each study region (Table 3). The samples were packaged in Kraft bags, labeled with the farmer's name, name of bean variety, agro-ecological zone, County and village, and whether the farmer was participating or non-participating in the legume up-scaling projects in the area. The samples were transported to the Plant Pathology laboratory at the Department of Plant Science and Crop Protection, University of Nairobi where they were kept in a dry environment, at ambient temperature (23 ± 2°C) until laboratory analysis.

Table 3: Distribution of common bean seed samples in different regions and agro-ecological zones covered during the field survey in western Kenya

Agro-ecological zone	Region	Number of samples		
		Participating[a]	Non-participating[b]	Total
LM3	Teso north	5	5	10
LM2	Busia	5	5	10
	Rangwe	5	5	10
LM1	Rongo	5	5	10
	Butula	5	5	10
LM4	Bondo	10	10	20
LH1	Nandi south	10	10	20
UM1	Vihiga	10	10	20
Total number of samples				110

[a] Farmers participating in legume up-scaling projects. [b] Farmers not participating in legume up-scaling projects.

3.2.2 Determination of physical and varietal quality of seeds

The common bean seeds were physically examined to determine the composition and quality of the seed sample following the procedure described by International seed testing association (ISTA, 2010). The seed samples were subjected to physical purity analysis to determine varietal purity, discoloration, presence of inert materials and weed seeds. Three replicates of 100g each of the seed samples were separated using a knife blade on a purity board under good lighting, into pure seeds, other crop seeds, other bean variety seeds, insect damaged seeds, weed seeds, discolored and shriveled seeds and inert material (soil particles, stones, and chaff). The different fractions were individually weighed and the percentage of each proportion calculated as follows:

$$\text{Component (\%)} = \frac{\text{Weight of component fraction}}{\text{Total test sample}} \quad \text{X } 100$$

3.2.3 Determination of germination and infection of common bean seeds

Germination test was determined following the procedure described by ISTA (2010). Three layers of sterile paper towels were wet with sterile water and five rows, each of ten seeds taken at random from a seed sample were placed evenly on the wet paper towels. Two layers of wet sterile paper towels were placed above the seeds and carefully rolled up. Three replicates of each seed sample were analyzed. The rolled up sterile wet paper towels were placed in sterile polythene and were placed near the window with sufficient diffused light for 5-7 days to allow for germination. Data on the number of germinated seeds, normal seeds, abnormal seeds, mouldy seeds, dead seeds and seedlings showing infection were collected (ISTA, 2010).

3.2.4 Determination of bacterial infection of the seed samples

Bacterial infection was determined by the dilution and plating technique (ISTA, 2007). Sterile saline solution for extracting the bacteria from the seeds was prepared by dissolving 8.5g sodium chloride (NaCl) in 1000 ml distilled water plus 0.2 ml Tween 20. The solution was autoclaved for 15 minutes at 121˚C and pressure of 15psi. Each seed sample was thoroughly mixed to obtain a composite sample. The number of seeds in 50g of each sample were counted and the thousand seed weight (TSW) calculated as follows:

$$TSW = \frac{\text{Weight of seed (50g)}}{\text{Number of seeds in 50g}} \text{ X } 1000$$

Fifty grams of each seed sample was suspended overnight for 16-18 h at 5^{o}C in sterile saline plus Tween 20 (0.02%) in sterile conical flasks. The volume of saline used was equivalent to 1.0 x TSW (g). The containers were shaken to obtain a homogenous extract and the extract was subjected to a 10-fold dilution series up to 10^{2} by pipetting 1 ml of the extract into 9 ml of sterile

saline. Each dilution was plated on nutrient agar by pipetting 100 µl onto sterile Petri dishes and then adding about 20ml of sterile molten nutrient agar. Once solidified, the plates were sealed with cling film and then incubated at 28° C in an inverted position for 2 days. The number typical of each of *Xanthomonas campestris* pv *phaseoli* and *Pseudomonas savastanoi* pv *phaseolicola* were counted for each dilution. The numbers of colony forming units (CFU) for each pathogen were calculated by multiplying the number of colonies by the dilution factor. The numbers of propagules (CFU) per seed were calculated as follows:

$$\text{CFU per seed} = \frac{\text{Calculated CFU}}{\text{Number of seeds in 50g}}$$

Pure cultures of the resulting bacteria were prepared by sub culturing single colonies on nutrient agar and identification was based on cultural characteristics (yellow mucoid convex colonies surrounded by a zone of hydrolysis and cream colored (Remeeus and Sheppard, 2006) and pathogenicity on susceptible bean seedlings.

3.2.4.1 Determination of pathogenicity of bacteria isolates: *Xanthomonas campestris* pv *phaseoli* and *Pseudomonas savastanoi* pv *phaseolicola*

Pathogenicity of *Xanthomonas campestris* pv *phaseoli* and *Pseudomonas savastanoi* pv *phaseolicola* bacteria was done using GLP 2 bean seeds. The bean seeds were surface sterilized in 1% sodium hypochlorite solution. Using a sterile needle, the seeds were injured by making holes in the hilum; 20 seeds in 5 replicates. The seeds were then soaked in *Xanthomonas campestris* pv *phaseoli* and *Pseudomonas savastanoi* pv *phaseolicola* bacterial suspensions (prepared by adding 10 ml of sterile distilled water to each nutrient agar petri dish containing the cultured bacterial isolates, scraping the bacterial off using a sterile slide and adjusting the concentration to 1 to 3 x10^8 colony forming units per ml using serial dilution method) for an

hour. The seeds were then planted in moist sterile sand in trays, 20 seeds per tray (Hsieh et al., 2003). For the control, the seeds were soaked for an hour in sterile water. Symptoms were observed in 8-14 days which included greasy water soaked lesions on the underside of leaves for *Xanthomonas campestris* pv *phaseoli* isolate and small water soaked pin pricks on the underside of leaves surrounded by a yellow halo for *Pseudomonas savastanoi* pv *phaseolicola* isolates (Fourier, 2002; Buruchara, 2010).

3.2.5 Determination of fungal infection of the seed samples

Fungal infection of bean seeds was determined by agar plate method (ISTA, 2010). Seeds were surface sterilized in 1% sodium hypochlorite for 2 minutes, rinsed in three changes of sterile distilled water and then blot dried on sterile paper towel. Five seeds were plated on potato dextrose agar plates amended with 50ppm streptomycin sulphate (made by dissolving 0.05g per liter of sterile potato dextrose agar) and 13.45g per liter of sodium chloride (Falleiro *et al*., 2010). Fifteen seeds were plated for each sample and the plates incubated for 5-14 days at 22^{o}C. The plates were examined for characteristic fungal colonies and the number of seeds infected with each pathogen type counted. The infected seeds were examined under a microscope to view the fungal structures and spores, the results were expressed as a percentage of total seeds infected. Each fungal type isolated was sub cultured on potato dextrose agar. The fungus was then identified using morphological and cultural characteristics and by using a pictorial atlas of soil and seed fungi and finally by conducting a pathogenicity test (Bhale *et al*., 2001).

3.2.5.1 Determination of pathogenicity of *Colletotrichum lindemuthianum*

Pathogenicity of the isolated *Colletotrichum lindemuthianum* was carried out using GLP 2 variety of bean seeds. The bean seeds were first pre- germinated according to (ISTA, 2010). The bean seeds were surface sterilized in 1% sodium hypochlorite and placed evenly in three layers

of wet sterile paper towels each of 20 seeds taken at random from the seed sample. Two layers of sterile paper towels were placed above the seeds and carefully rolled up. Five replicates of 20 seeds from the seed sample were analyzed. The rolled up sterile wet paper towels were placed in humid chamber with sufficient diffused light for 3 days to allow for emergence of radical. Fungal isolates were grown in potato dextrose agar (PDA). When they had sporulated, in 10 days, the plates were flooded with 10 ml of sterile water and the spores were scraped off from the plates using a sterile slide and the suspension was filtered using a 0.2mm by 0.2mm sterile nylon mesh. The number of spores was estimated and adjusted using a haemocytometer to 10^5 spores/ml. After emergence of the radical, inoculation of the pre germinated seeds was done by soaking them for 5 minutes in 200 ml of inoculum containing 10^5 spores/ml. The pre germinated seeds were then planted in moist sterile sand contained in trays and covered by 1 cm layer of the sand followed by incubation at 15-18 °C for about 3 days (Kruger *et al*., 1977; Bigiramana and Hofte, 2001). Symptoms were observed after seedling emergence which included dark brown or black lesions on hypocotyls and primary leaves (Buruchara, 2010) for *Colletotrichum lindemuthianum*.

3.4 Data analysis

Survey data was reported in percentage form as was seed health parameters data except bacterial isolation data which was reported as CFU/ seed. Total disease indices were obtained by summing disease distribution (0-2), severity (0-3) and incidence (0-1). The data was subjected to Analysis of variance (ANOVA) using the PROC ANOVA procedure of Genstat version 15. Percentage data that was not normally distributed was transformed using arcsin transformation while other data not normally distributed was transformed using square root before analysis. Data from bacterial isolation (colony forming units) was transformed to $\log_{10}$ (X+1) before analysis. The differences among the treatments were compared using Duncan's multiple range test at 5%

probability level. Google earth software (version 7.1.3.22.3) was used to generate disease distribution maps from the GPS coordinates of the sampled farms.

CHAPTER FOUR: RESULTS

4.1 Occurrence of fungal and bacterial diseases in legumes grown in western Kenya

4.1.1 Land sizes under legume production

Common bean was the major legume in all the regions surveyed taking up the most farming area, an average of 0.07 Ha per farmer; not taking into account Bungoma and Teso north regions where harvesting had already been done. Butula (LM1) region recorded the highest average acreage under common bean production of 0.12 Ha per farmer while cowpea was allotted the least farm area of 0.01 Ha in almost all areas surveyed. Lablab was not common and took up an insignificant farming area. Soybean and green grams took up the same farming area, an average of 0.05 Ha per farmer. This was followed by groundnut and cowpeas, with an average farming area of 0.04 and 0.02 Ha, respectively (Table 4).

Table 4: Average area (Ha) under legume production in various agro-ecological zones and regions in western Kenya during the short rain season (September, October, November) of 2013

AEZ	Region	Common bean	Soybean	Green gram	Groundnut	Cow pea
LM1	Rongo	0.1	*	0.03	0.04	0.01
	Butula	0.12	0.03	0.01	0.04	0.01
LM2	Rangwe	0.08	*	0.06	0.05	0
	Bungoma	-	0.06	0.04	0.02	0.01
	Busia	0.06	0.06	0.06	0.07	0.01
LM3	Siaya	0.05	*	0.02	0.04	0.03
	Teso North	-	0.1	0.07	0.05	0.02
LM4	Bondo	0.08	*	0.07	0.04	0.05
UM1	Sabatia	0.03	0.02	0.05	0.01	0.01
	Nandi South	0.02	0.02	*	0.04	0.01
LH1	Nandi South	0.11	*	*	*	*
Mean		0.07	0.05	0.05	0.04	0.02

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; (-) legume had been harvested; (*) legume not cultivated in the sampled farms.

4.1.2 Diseases affecting legumes grown in the survey areas

There were eight legumes that were grown in various regions in different agro ecological zones in the study areas in western Kenya. The legumes from the most to least common were: common bean, cowpeas, groundnuts, soybean, green grams, climbing bean, Bambara nuts and lablab. The major legumes were the common bean, cowpeas and groundnuts, which were grown in all the regions surveyed in the six agro ecological zones while the minor ones included Bambara nuts which was only cultivated in Butula and Busia regions, Lablab in Sabatia district and the climbing bean which was cultivated only in three regions - Teso north (LM3), Sabatia (LM3) and Nandi south (UM1) regions. The major diseases in all areas included common bacterial blight and root rots while the minor ones were damping off, downy mildew and halo blight. The most common diseases included angular leaf spot, common bacterial blight and root rots for common bean; Cercospora leaf spot, common bacterial blight and leaf rust for cowpeas; and Ascochyta leaf spot, early and late leaf spots for groundnuts (Table 5A, Table 5B, Table 5C, Figure 2A, Figure 2B).

Table 5A: Legumes grown and common diseases associated with the crops in various agro-ecological zones in western Kenya during the short rain season of 2013

AEZ	Region	Type of legumes	Common diseases
LM1	Rongo	Common bean	ALS, Anthra, Asco, CBB, DM, Rust, RR, Web
		Cowpeas	Anthra, Asco, Cerco, CBB, Rust, RR
		Green grams	Anthra, Asco, Cerco, CBB, PM, RR, Septo
		Groundnuts	Altern, Asco, EB, LB, RR
	Butula	Bambara nuts	Cerco, RR
		Common bean	ALS, Rust, CBB, RR, web
		Cowpeas	Anthra, CBB, Rust, PM, RR
		Groundnuts	Altern, Asco, EB, LB, Rust, RR
		Lablab	Anthra, Asco, CBB, RR, CBB, Rust, RR, Septo
		Soybean	Web
LM3	Siaya	Common bean	ALS, Asco, CBB, Rust, RR
		Cowpeas	Asco, CBB, RR
		Green grams	Cerco, CBB, RR, Septo
		Groundnuts	Asco, EB, LB
		Climbing bean	ALS, CBB
	Teso north	Common bean	- - -
		Cowpeas	Altern, Anthra, Asco, cerco, CBB, Septo, Rust, RR, web
		Green grams	Ascho, PM, RR, Septo, CBB,
		Groundnuts	Altern, Anthra, Asco, Cerco, CBB, EB, LB, Rust, RR
		Soybean	Asco, CBB, Rust, RR, Septo, web

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM3 – lower midland zone 3; ALS – angular leaf spot; Altern- Alternaria leaf spot; Anthra – anthracnose; Ascho – Ascochyta leaf spot; CBB – common bacterial blight; Cerco- Cercospora leaf spot; Downy – Downy mildew; Halo-Halo blight; PM – powdery mildew; RR – root rot; Septo-Septoria leaf spot; Web – Web blight; LB- Late leaf blight; EB-Early leaf blight; (-) legumes had been harvested.

Table 5B: Legumes grown and common diseases associated with the crops in various agro-ecological zones in western Kenya during the short rain season of 2013

AEZ	Region	Legumes grown	Common diseases
LM2	Rangwe	Common bean	ALS, Anthra, Asco, CBB, Rust, RR
		Cowpeas	Cerco, CBB, Rust
		Green grams	Asco, CBB, PM, RR
		Groundnuts	Altern, Asco, EB , LB, RR
	Bungoma	Common bean	- - - - -
		Cowpeas	Anthra, Cerco, CBB, Damp, Rust, PM, RR, Sept, Web
		Green grams	Asco, CBB, Cerco,PM, Halo, Rust, RR
		Groundnuts	Altern, Anthra, Asco, EB, LB, Rust, RR
		Soybean	CBB, Rust, RR, Septo, Web
	Busia	Bambara nuts	Cerco, RR
		Common bean	ALS, CBB, Rust, RR
		Cowpeas	Altern, Asco, Anthra, Cerco, CBB, Rust, PM, RR, Septo, Web
		Green grams	CBB, PM, Rust
		Groundnuts	Altern, Asco, EB, LB, Rust, RR
		Soybean	Rust, Web, Cerco, CBB, Septo, RR,
LH1	Nandi south	Common bean	ALS, Anthra, Ascho, CBB, PM, Rust, RR, Web
		Cowpeas	Ascho, Cerco, Rust, RR
		Groundnuts	Altern, Asco, EB, LB, RR
		Soybean	Rust, Septo

AEZ – agro-ecological zone; LM2 – lower midland zone 2; LH1 – lower highland zone 1; ALS – angular leaf spot; Altern- Alternaria leaf spot; Anthra – anthracnose; Ascho – Ascochyta leaf spot; CBB – common bacterial blight; Cerco- Cercospora leaf spot; Downy – downy mildew; Halo-Halo blight; PM – powdery mildew; RR – root rot; Septo-Septoria leaf spot; Web – web blight; LB- Late leaf blight; EB-Early leaf blight; (-) legumes had been harvested.

Table 5C: Legumes grown and common diseases associated with the crops in various agro-ecological zones in western Kenya during the short rain season of 2013

AEZ	Region	Legumes grown	Corresponding diseases
LM4	Bondo	Common bean	ALS, CBB, Rust, RR, Anthra
		Cowpeas	Cerco, RR
		Green grams	CBB, Septo
		Groundnuts	Altern, Asco, EB, LB
UM1	Sabatia	Climbing bean	Altern, ALS, CBB, Asco, Anthra, Rust, PM,Web, RR
		Common bean	ALS, Anthra, Asco, CBB, Rust, PM,RR
		Cowpeas	ALS, Asco, CBB, Cerco, Damp, Rust, RR, Web
		Green grams	Asco, Cerco, CBB, Rust, PM, RR, Septo, Web
		Groundnuts	Asco, EB, LB
		Soybean	Ascho, Cerco, CBB, Rust, RR, Septo, Web
	Nandi south	Climbing bean	ALS, Asco, CBB, Cerco, Damp,Rust, RR, Web
		Common bean	ALS, CBB, Rust, PM, RR, Web
		Cowpeas	Anthra, Asco, Cerco, CBB, Damp, Rust,RR
		Green grams	Asco, CBB, PM
		Groundnuts	Altern, Asco, EB, LB
		Soybean	Asco, Cerco, CBB, RR, Rust, Web, Septo

AEZ – agro-ecological zone; LM4 – lower midland zone 4;UM1 upper midland zone 1; ALS – angular leaf spot; Altern- Alternaria leaf spot; Anthra – anthracnose; Asco – Ascochyta leaf spot; CBB – common bacterial blight; Cerco- Cercospora leaf spot; Downy – Downy mildew; Halo-Halo blight; PM – powdery mildew; RR – root rot; Septo- Septoria leaf spot; Web – web blight; LB- Late leaf blight; EB-Early leaf blight

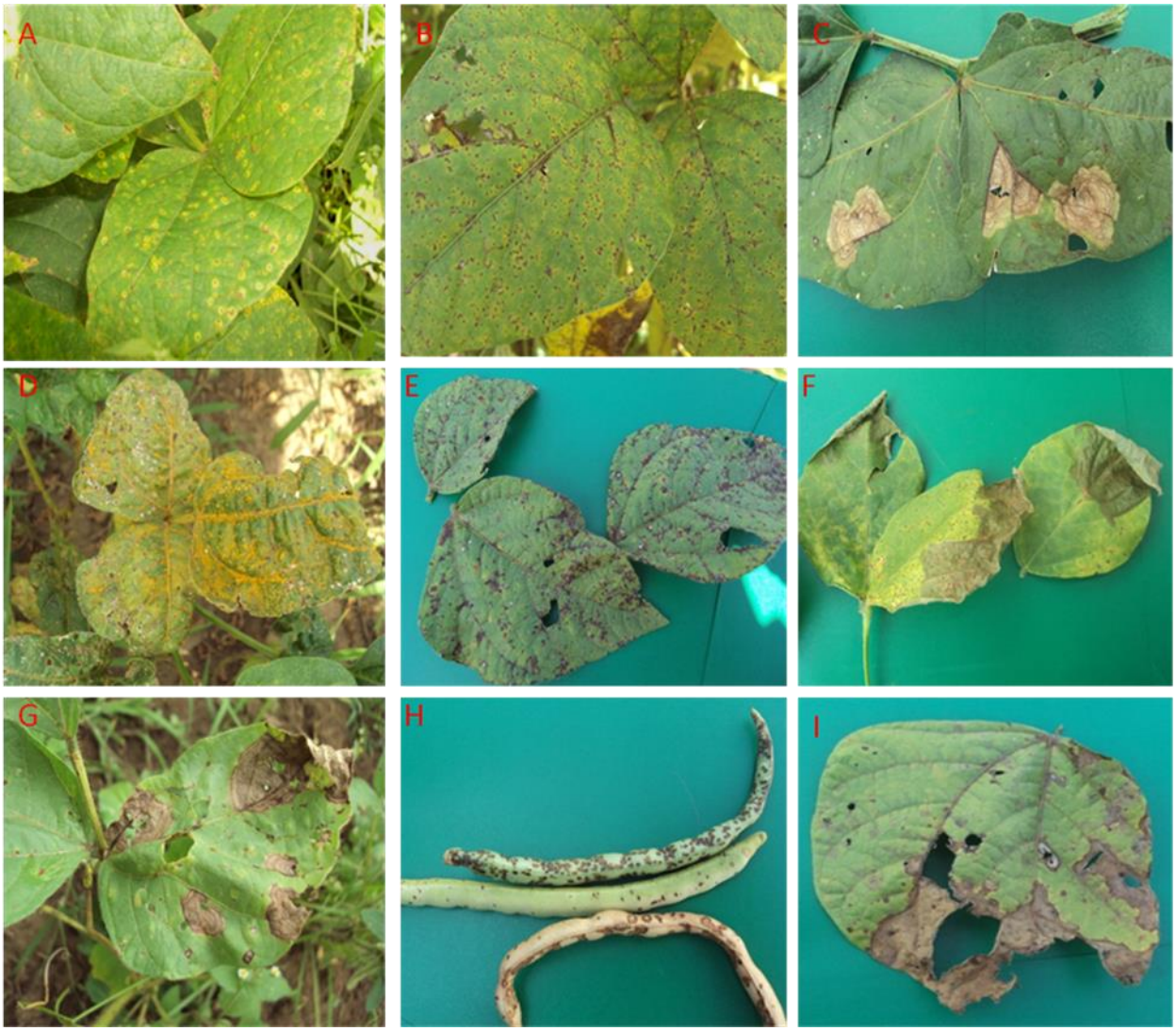

Figure 2A: Common diseases of different legumes grown in western Kenya during short rain season of 2013. A: Powdery mildew on cowpea; B: Root trot on common bean; C: Early leaf blight on groundnuts; D: Alternaria leaf spot on groundnuts; E: Septoria leaf spot on cowpea; F: Leaf rust on common bean; G: Ascochyta leaf spot on common bean; H: Late leaf blight on groundnuts; I: Anthracnose on cowpea.

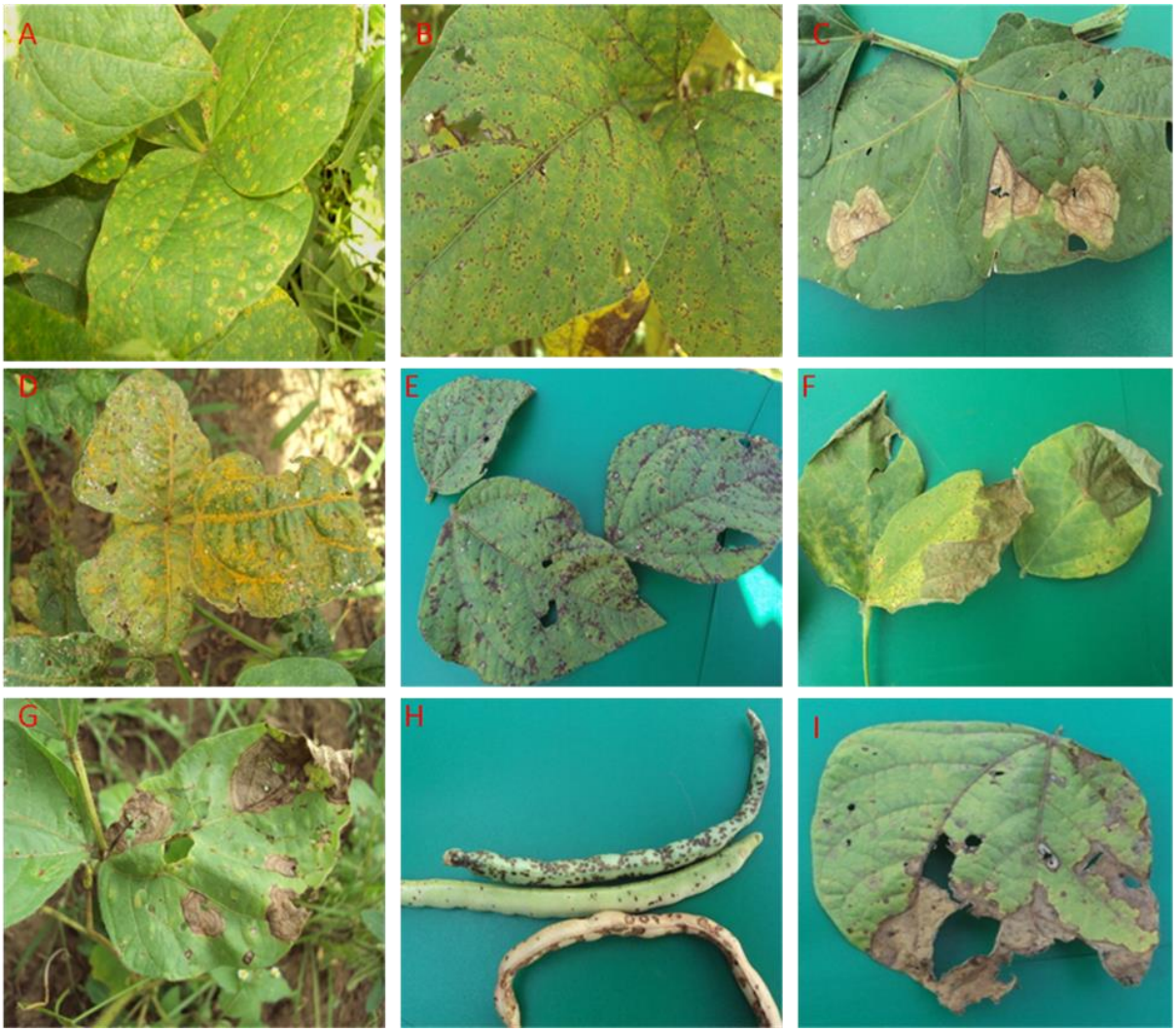

Figure 2B: Common diseases of different legumes grown in western Kenya during short rain season of 2013. A: Leaf rust on common bean; B: Angular leaf spot on common bean; C: Ascochyta leaf spot on cowpea; D: Leaf rust on cowpea; E: Septoria leaf spot on soy bean; F: Web blight on soy bean; G: Ascochyta leaf spot on green grams; H: Septoria leaf spot on cowpea pods; I: Common bacterial blight on common bean.

4.1.3 Varieties of legumes grown in the survey regions

KK8 and GLP 2 were the major varieties of common bean grown in the survey regions. Punda (Jessica) and Zaire varieties were also common in Bondo (LM4) and Siaya (LM3) while the small yellow variety was common in Nandi south (LH1). Red Valencia, CG7, Uganda red and Homabay were the major groundnut varieties cultivated while local varieties (landraces) were the majority for cowpea (Table 6, Table 7, Table 8, Table 9, Table 10).

Table 6: Percentage of farmers who grew different varieties of common bean in different agro- ecological zones of western Kenya during the short rains season of 2013

Variety	Rongo LM1	Butula LM1	Rangwe LM2	Busia LM2	Bungoma LM2	Siaya LM3	Teso North LM3	Bondo LM4	Sabatia UM1	Nandi South UM1	Nandi South LH1
GLP2	29.6	50.0	40.0	42.9		35.0		61.5	10.0	25.0	63.5
KATX56	22.2		15.0								
Wairimu	11.1		10.0	14.3				7.7	40.0		3.2
KATB1	3.7							7.7			
Punda	7.4		25.0								
Zaire	22.2		5.0			25.0		7.7			
Canadian wonder	3.7	37.5				10.0					
GLP585				14.3							1.6
Mwezi moja		12.5									
Local KK8			5.0	28.6		25.0		7.7		25.0	
KK8						5.0			20.0		25.4
KAT41								7.7			
KK071										50.0	
KK15									30.0		
Small yellow											6.3

Table 7: Percentage of farmers who grew different varieties of cowpea in different agro-ecological zones of western Kenya during the short rains season of 2013

AEZ	Region	Varieties	% Farmers growing variety
LM1	Rongo	Local	75.0
		M66	25.0
	Butula	Local	80.0
		Uganda strip	20.0
LM2	Rangwe	Local	100.0
	Busia	Local	100.0
	Bungoma	Local	100.0
LM3	Siaya	Local	100.0
	Teso North	Local	80.0
		M66	20.0
LM4	Bondo	Local	100.0
UM1	Sabatia	Local	97.4
		K80	2.6
	Nandi south	Local	100.0
LH1	Nandi south	Local	100.0

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; (*) - legume not cultivated in the sampled farms in the region.

Table 8: Percentage of farmers who grew different varieties of groundnut in different agro-ecological zones of western Kenya during the short rains season of 2013

AEZ	Region	Varieties	% farmers growing variety
LM1	Rongo	Nyaela	7.7
		Kabonge	23.1
		Red Valencia	61.5
		Uganda red	7.7
	Butula	Red valencia	80.0
		CG7	10.0
		Local	10.0
LM2	Rangwe	Red valencia	18.2
		CG7	36.4
		Homabay	45.5
	Busia	Homabay	4.8
		Red valencia	52.4
		Uganda red	42.9
	Bungoma	Uganda red	40.0
		Homabay	10.0
		Red valencia	50.0
LM3	Siaya	Red valencia	50.0
		Homabay	50.0
	Teso north	Homabay	10.5
		Local purple	2.6
		Red valencia	68.4
		Uganda red	18.4
LM4	Bondo	*	*
UM1	Sabatia	CG7	20.0
		Red valencia	60.0
		Homabay	20.0
	Nandi south	Uganda red	25.0
		CG7	75.0
LH1	Nandi south	CG7	83.3
		Red valencia	16.7

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; (*) - legume not cultivated in the sampled farms in the region.

Table 9: Percentage of farmers who grew different varieties of green gram in different agro-ecological zones of western Kenya during the short rains season of 2013.

AEZ	Region	Varieties	% farmers growing variety
LM1	Rongo	N26	100.0
	Butula	*	*
LM2	Rangwe	N26	100.0
	Busia	N26	33.3
		Local	66.7
	Bungoma	N26	33.3
		Local	66.7
LM3	Siaya	Local	100
	Teso north	Local	63.6
		N26	36.4
LM4	Bondo	Local	100.0
UM1	Sabatia	N26	10.0
		Local	90.0
	Nandi south	Local	100.0
LH1	Nandi south	*	*

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; (*) - legume not cultivated in the sampled farms in the region.

Table 10: Varieties of soybean grown in different regions and agro ecological zones in western Kenya and the percentage of farmers growing the variety during the short rains season of 2013

AEZ	Region	Varieties	% of farmers growing variety
LM1	Butula	SB19	83.3
		Squire	16.7
LM2	Busia	SB19	73.3
		SB25	6.7
		SB3	13.3
		Local	6.7
LM3	Teso north	SB19	78.9
		SB23	5.3
		SB24	5.3
		SB13	5.3
		Squire	5.3
UM1	Sabatia	SB19	57.6
		Squire	30.3
		SB24	3.0
		Local	9.1

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; UM1 – upper midland zone 1

4.1.4 Distribution of legume diseases in fields in different regions and agro-ecological zones

Angular leaf spot, common bacterial blight and root rots were the most widely distributed diseases of common bean covering the entire fields (100%) for angular leaf spot in Busia (LM2), and common bacterial blight and root rots in Nandi south (UM1). Powdery mildew in Nandi south (LH1), downy mildew and web blight in Rongo (LM1) covered 1% of the fields (Table 11). Diseases of cowpeas which were most widely distributed were Ascochyta leaf blight, leaf rust and common bacteria blight covering 100% of the fields while Alternaria leaf spot, web blight and damping off occurred in small (2%) portions of the fields (Table 12).

Diseases of green grams which were most widely distributed were common bacterial blight, root rots and Ascochyta leaf spot covering 100% of the field while anthracnose, halo blight and web blight occurred in small (1%) portions of the field (Table 13). Ascochyta leaf spot, early leaf spot, late leaf spot and Alternaria leaf spot were the most widely distributed diseases of groundnut covering 91.5% of the fields while anthracnose, Cercospora leaf spot and common bacterial blight occurred in spots in less than 3% of the fields (Table 14). Diseases of soybean which were most widely distributed were leaf rust, Septoria leaf spot and common bacterial blight covering up to 90% of the fields for Septoria leaf spot in Bungoma (LM2) while Cercospora leaf spot and web blight occurred in small portions (1%) for Cercospora leaf spot in Sabatia (UM1). Majority of the soybean diseases were distributed in small portions of the fields except Septoria leaf spot that covered the entire field in Nandi south (Table 15).

Table 11: Mean percentage of the field crop covered with diseases of common bean in various agro-ecological zones and regions in western Kenya during the short rain season of 2013

AEZ	Region	CBB	ALS	RR	Rust	Asco	Anthra	Web
LM1	Rongo	59.5	85.0	48.0	44.5	33.5	18.5	3.5
	Butula	69.0	94.0	37.5	12.5	0.0	0.0	6.5
LM2	Bungoma	-	-	-	-	-	-	-
	Rangwe	85.5	75.0	78.5	25.0	53.5	21.5	0.0
	Busia	50.0	100.0	43.0	28.5	0.0	0.0	0.0
LM3	Siaya	95.0	70.0	85.0	15.0	2.5	0.0	0.0
	Teso north	-	-	-	-	-	-	-
LM4	Bondo	82.0	10.5	50.0	10.5	0.0	7.0	0.0
UM1	Sabatia	59.0	91.0	41.0	27.5	22.5	9.0	0.0
	Nandi south	100.0	75.0	100.0	25.0	0.0	0.0	25
LH1	Nandi south	70.0	46.0	30.0	50.0	63.5	12.0	10.5
Mean		74.5	72.0	57.0	26.5	19.5	7.5	5.0

Key to disease distribution: 0 = No disease, 1 = occur in spots, 2 = distributed over whole field; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; ALS – angular leaf spot; Anthra – Anthracnose; Ascho – Ascochyta leaf spot; CBB – common bacterial blight; RR – root rot; Web – Web blight; (-) - Legume had been harvested at the time of survey

Table 12: Mean percentage of the field crop covered with the diseases of cow pea in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	Cerco	Rust	CBB	RR	Anthra	Asco	Septo
LM1	Rongo	56.5	56.5	12.5	6.5	37.5	12.5	0.0
	Butula	60.0	25.0	25.0	15.0	5.0	0.0	0.0
LM2	Rangwe	50.0	100.0	100.0	0.0	0.0	0.0	0.0
	Bungoma	33.5	50.0	25.0	25.0	25.0	0.0	8.5
	Busia	30.5	30.5	19.5	28.5	30.5	7.0	21.5
LM3	Siaya	0.0	5.5	72.0	16.5	0.0	11.0	0.0
	Teso North	54.0	35.0	11.0	28.5	23.0	5.5	11.0
LM4	Bondo	76.5	0.0	0.0	9.0	0.0	0.0	0.0
UM1	Sabatia	27.0	9.5	11.0	36.5	0.0	40.5	0.0
	Nandi South	18.0	22.5	41.0	50.0	9.0	13.5	0.0
LH1	Nandi South	83.5	16.5	0.0	8.5	0.0	41.5	0.0
Mean		44.5	32.0	29.0	20.5	12.0	12.0	3.5

Key to disease distribution: 0 = No disease, 1 = occur in spots, 2 = distributed over whole field; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; Anthra – anthracnose; Asco – Ascochyta leaf spot; CBB – common bacterial blight; RR – root rot; Rust- leaf rust; Septo- Septoria leaf spot.

Table 13: Mean percentage of the field crop covered with the diseases of green grams in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	CBB	RR	Asco	PM	Sept	Cerco	Rust
LM1	Rongo	41.0	32.0	27.5	32.0	50.0	9.0	0.0
	Butula	50.0	0.0	0.0	0.0	50.0	0.0	0.0
LM2	Rangwe	83.5	66.5	66.5	33.5	0.0	0.0	0.0
	Bungoma	100.0	33.5	33.5	66.5	0.0	33.5	16.5
	Busia	75.0	25.0	0.0	12.5	0.0	0.0	12.5
LM3	Siaya	33.5	0.0	0.0	0.0	16.5	16.5	0.0
	Teso north	86.5	54.5	18.0	22.5	36.5	9.0	0.0
LM4	Bondo	50.0	50.0	0.0	0.0	0.0	0.0	0.0
UM1	Sabatia	32.0	18.0	68.0	18.0	9.0	9.0	9.0
	Nandi south	13.0	7.0	62.0	22.0	1.0	1.0	1.0
LH1	Nandi south	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean		56.5	28.5	27.5	20.5	16.5	8.0	4.0

Key to disease distribution: 0 = No disease, 1 = occur in spots, 2 = distributed over whole field; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; Asco – Aschochyta leaf spot; Cerco- Cercospora leaf spot; CBB – common bacterial blight; Rust- leaf rust; PM – powdery mildew; RR – root rot; Septo- Septoria leaf spot

Table 14: Mean percentage of the field crop covered with the diseases of groundnuts in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	EB	LB	Asco	Altern	RR	Rust
LM1	Rongo	38.5	34.5	46.0	46.0	4.0	0.0
	Butula	40.0	40.0	20.0	5.0	5.0	5.0
LM2	Rangwe	54.5	18.0	41.0	72.5	32.0	0.0
	Bungoma	40.0	50.0	10.0	5.0	20.0	20.0
	Busia	48.0	61.0	30.5	6.5	17.5	35.0
LM3	Siaya	91.5	25.0	83.5	0.0	0.0	0.0
	Teso north	31.5	22.0	4.5	33.5	20.0	15.0
LM4	Bondo	0.0	0.0	0.0	50.0	0.0	0.0
UM1	Sabatia	30.0	60.0	20.0	10.0	0.0	0.0
	Nandi south	15.0	30.0	30.0	35.0	5.0	0.0
Mean		39.0	34.0	28.5	26.5	10.5	7.5

Key to disease distribution: 0 = No disease, 1 = occur in spots, 2 = distributed over whole field; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; Altern – Alternaria leaf spot; Asco – Ascochyta leaf spot; EB- early leaf blight; LB- late leaf blight; RR – root rot; Rust- leaf rust

Table 15: Mean percentage of the field crop covered with the diseases of soybean in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	Rust	Septo	CBB	RR
LM1	Rongo	*	*	*	*
	Butula	75.0	16.5	41.5	25.0
LM2	Rangwe	*	*	*	*
	Bungoma	45.0	90.0	30.0	15.0
	Busia	46.5	80.0	26.5	16.5
LM3	Siaya	*	*	*	*
	Teso North	55.5	58.0	66.0	39.5
UM1	Sabatia	59.5	5.0	48.0	29.0
	Nandi South	68.0	9.0	32.0	9.0
LH1	Nandi South	50.0	100.0	0.0	0.0
Mean		57.1	51.2	34.9	19.1

Key to disease distribution: 0 = No disease, 1 = occur in spots, 2 = distributed over whole field; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; CBB – common bacterial blight;RR – root rot; Septo-Septoria leaf spot; (*) – legume not cultivated in the sampled farms in the region.

4.1.5 Incidence of legume diseases in different agro-ecological zones and regions

Diseases of common bean with the highest incidence were angular leaf spot, common bacterial blight and root rots while web blight, downy mildew and powdery mildew had low incidence (Table 16). Overall, common bacterial blight had the highest incidence (95%) in Nandi south (UM1). Diseases of cowpea with the highest incidence were Cercospora leaf spot, leaf rust and common bacteria blight while Alternaria leaf spot, web blight and damping off had low incidences (Table 17). Overall, leaf rust had the highest disease incidence (80%) in Rangwe.

Diseases of green grams with the highest incidence were common bacterial blight, root rots, powdery mildew and Ascochyta leaf spot while anthracnose, halo blight and web blight had low incidences (Table 18). Overall, common bacterial had the highest disease incidence (73.3%) in Rangwe (LM2). Early and late leaf spots were the diseases with high incidence for groundnuts while Cercospora leaf spot and anthracnose had low incidences (Table 19). Overall, Early leaf

blight had the highest disease incidence (80.3%) in Siaya (LM3). The diseases for soy bean with the highest incidence were leaf rust and Septoria leaf spot (Table 20) while Ascochyta leaf spot, Cercospora leaf spot and web blight had low incidences. Overall, Septoria leaf spot had the highest incidence (82.5%) in Nandi south (LH1).

Table 16: Mean incidence (%) of the major diseases of common bean in various agro-ecological zones and regions in western Kenya during the short rains season 2013

AEZ	Region	ALS	CBB	Root rot	Rust	Ascochyta	Anthracnose
LM1	Rongo	69.5	32.0	46.7	25.1	11.6	9.6
	Butula	89.0	58.8	32.3	6.3	0.0	0.0
LM2	Rangwe	48.9	64.5	67.1	11.1	23.6	14.6
	Bungoma	-	-	-	-	-	-
	Busia	99.3	42.4	32.3	17.9	0.0	0.0
LM3	Siaya	41.8	66.9	68.2	3.0	0.0	3.0
	Teso North	-	-	-	-	-	-
LM4	Bondo	14.0	72.6	53.2	9.3	0.4	0.0
UM1	Sabatia	82.3	40.0	39.8	13.1	6.8	4.6
	Nandi South	67.5	95.0	82.5	5.0	0.0	0.0
LH1	Nandi South	29.6	39.5	13.0	28.8	32.1	7.0
Mean		60.2	56.9	48.3	13.3	8.3	4.3

Key to disease distribution: 0 = No disease, 1 = occur in spots, 2 = distributed over whole field; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; ALS – angular leaf spot; CBB – common bacterial blight (-)- harvesting had been done at the time of survey

Table 17: Mean incidence (%) of diseases of cowpea in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	Cercospora	Rust	CBB	Anthracnose	Root rot	Ascochyta
LM1	Rongo	36.9	49.4	45.0	37.5	2.0	5.1
	Butula	51.6	11.3	6.1	0.6	6.3	0.0
LM2	Rangwe	40.0	80.0	70.0	0.0	0.0	0.0
	Bungoma	26.7	40.8	5.0	20.0	4.2	0.0
	Busia	24.5	19.2	9.6	19.1	10.5	3.2
LM3	Siaya	0.0	1.1	25.2	0.0	7.8	6.1
	Teso North	40.1	24.7	3.3	13.2	11.6	2.0
LM4	Bondo	64.3	0.0	0.0	0.0	0.3	0.0
UM1	Sabatia	17.8	8.0	4.9	0.0	24.3	25.3
	Nandi South	7.7	11.2	21.4	6.4	16.6	1.8
LH1	Nandi South	63.3	11.7	0.0	0.0	5.0	27.5
Mean		33.9	23.4	17.3	8.8	8.1	6.5

EZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1;Anthra – anthracnose; CBB – common bacterial blight

Table 18: Mean incidence (%) of diseases of green grams in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	CBB	Root rot	PM	Ascochyta	Septoria	Cercospora
LM1	Rongo	21.5	20.5	20.5	16.8	33.9	2.7
	Butula	25.0	0.0	0.0	0.0	30.0	0.0
LM2	Rangwe	73.3	43.3	20.0	43.3	0.0	0.0
	Bungoma	61.0	26.7	64.3	10.0	0.0	26.7
	Busia	56.3	12.5	7.5	0.0	0.0	0.0
LM3	Siaya	6.5	15.0	0.0	0.0	0.3	0.0
	Teso north	45.1	31.3	20.2	7.1	21.1	9.1
LM4	Bondo	25.0	0.0	0.0	0.0	15.0	30.0
UM1	Sabatia	19.6	12.7	5.5	48.8	6.4	5.5
	Nandi south	12.5	0.0	17.5	26.3	0.0	0.0
Mean		34.6	16.2	15.6	15.2	10.7	7.4

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; CBB –common bacterial blight; PM-powdery mildew

Table 19: Mean incidence (%) of diseases of groundnuts in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	Early blight	Late blight	Ascochyta	Alternaria	Root rot	Rust
LM1	Rongo	36.4	18.9	23.1	23.6	1.5	0.0
	Butula	39.3	34.9	6.5	3.0	4.0	0.5
LM2	Rangwe	37.0	11.6	37.7	37.4	19.1	0.0
	Bungoma	22.5	49.5	1.5	4.0	14.0	12.0
	Busia	27.0	59.1	17.4	4.4	12.2	26.4
LM3	Siaya	80.3	12.5	44.3	0.0	0.0	0.0
	Teso north	27.4	10.7	1.6	21.3	10.6	10.4
LM4	Bondo	0.0	0.0	0.0	25.0	0.0	0.0
UM1	Sabatia	20.0	57.0	3.0	4.0	0.0	0.0
	Nandi south	18.8	13.8	46.8	5.0	0.0	0.0
LH1	Nandi south	0.0	16.7	3.3	35.0	6.7	0.0
Mean		28.1	25.9	16.8	14.8	6.2	4.5

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1

Table 20: Mean incidence (%) of diseases of soybean in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	Rust	Septoria	CBB	Root rot
LM1	Butula	65.5	13.3	29.0	26.7
LM2	Bungoma	39.5	72.2	14.2	11.0
	Busia	43.9	58.8	20.9	11.0
LM3	Teso north	42.8	38.6	28.7	25.1
UM1	Sabatia	47.4	2.6	24.6	17.1
	Nandi south	56.4	8.2	18.6	8.2
LH1	Nandi south	30.0	82.5	0.0	0.0
Mean		46.5	39.5	19.4	14.1

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; CBB- Common bacterial blight

4.1.6 Severity of legume diseases in different agro-ecological zones and regions

Angular leaf spot, common bacterial blight and root rots were the most severe diseases of common bean with a score of up to 100% for angular leaf spot in Busia (Table 21). The less severe diseases of common bean were powdery mildew in Nandi south (LH1), downy mildew and web blight in Rongo (LM1) with a severity score of less than1%. Cercospora leaf spot, leaf rust and common bacterial blight were the most severe diseases of cowpea with a score of up to 100% for leaf rust and common bacterial blight in Rangwe (Table 22). The less severe diseases of cowpea were alternaria leaf spot, angular leaf spot, Septoria leaf spot and web blight with severity score of less than 1%.

Common bacterial blight was the most severe disease of green grams with a score of up to 89% in Rangwe (Table 23) while the less severe diseases were anthracnose, halo blight, and web blight with a severity score of ≤3% for web blight in Sabatia (UM1). Early leaf blight, late leaf blight and Ascochyta leaf spot were the most severe disease of groundnuts with a severity score of up to 100 % for both early and late leaf blight in Butula (Table 24). The less severe disease for groundnuts was Cercospora leaf spot with a severity score of ≤1% in Teso north (LM3). Common bacterial blight, Septoria leaf spot and leaf rust were the most severe disease of soybean with a severity score of up to 100% for leaf rust in Butula (Table 25). The less severe diseases for soybean were Cercospora leaf spot, web blight and Ascochyta leaf spot with a severity score of 1% or less for Cercospora leaf spot in Nandi south (UM1) and Sabatia (UM1).

Table 21: Mean severity (%) of common bean diseases in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	CBB	ALS	Rootrot	Rust	Ascochyta	Anthracnose
LM1	Rongo	47.0	68.0	43.3	33.3	14.7	14.7
	Butula	60.0	93.3	40.0	13.3	0.0	0.0
LM2	Rangwe	81.0	47.7	66.7	16.7	40.3	14.3
	Bungoma	-	-	-	-	-	-
	Busia	62.0	100.0	43.0	28.7	0.0	0.0
LM3	Teso north -	-		-	-	-	-
	Siaya	88.3	65.0	85.0	11.7	1.7	0.0
LM4	Bondo	85.7	9.7	47.7	7.0	0.0	7.0
UM1	Sabatia	60.7	91.0	39.3	27.3	18.3	9.0
	Nandi south	50.0	58.3	66.7	16.7	0.0	0.0
LH1	Nandi south	43.7	38.7	22.3	37.0	45.3	12.7
Mean		64.3	63.5	50.4	21.3	13.4	6.4

Disease severity scoring scale: 0 = no disease; 1 = mild; 2 = moderate; 3 = severe; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; ALS – angular leaf spot; CBB – common bacterial blight; (-)- legume had been harvested at the time of survey.

Table 22: Mean disease severity scores (%) of cowpea in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	Cerco	Rust	CBB	RR	Anthra	Asco	PM
LM1	Rongo	37.7	50.0	8.3	4.3	37.7	16.7	0.0
	Butula	0.0	33.3	33.3	33.3	16.7	0.0	16.7
LM2	Rangwe	66.7	100.0	100.0	0.0	0.0	0.0	0.0
	Bungoma	27.7	44.3	16.7	16.7	27.7	0.0	5.7
	Busia	38.0	30.3	15.3	21.0	22.0	4.7	11.3
	Siaya	0.0	0.0	66.7	13.3	0.0	6.7	0.0
LM3	Teso north	46.0	32.3	7.3	21.7	16.3	5.3	0.0
LM4	Bondo	78.3	0.0	0.0	9.7	0.0	0.0	0.0
UM1	Sabatia	24.3	10.7	9.0	35.0	0.0	37.0	0.0
	Nandi south	15.0	12.0	15.0	27.3	6.0	6.0	0.0
LH1	Nandi south	72.3	27.7	0.0	16.7	0.0	50.0	0.0
Mean		36.9	31.0	24.7	18.1	11.5	11.5	3.1

Disease severity scoring scale: 0 = no disease; 1 = mild; 2 = moderate; 3 = severe; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; Anthra – anthracnose; Asco – Ascochyta leaf spot; Cerco- Cercospora leaf spot; CBB – common bacterial blight; PM – powdery mildew; RR – root rot

Table 23: Mean disease severity (%) of green grams in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	CBB	Asco	RR	PM	Septo	Cerco	Rust
LM1	Rongo	54.7	27.3	30.3	33.3	39.3	6.0	0.0
LM2	Rangwe	89.0	66.7	66.7	33.3	0.0	0.0	0.0
	Bungoma	66.7	33.3	33.3	55.7	0.0	22.3	22.3
	Busia	66.7	0.0	16.7	8.3	0.0	0.0	8.3
LM3	Siaya	33.3	0.0	8.3	0.0	8.3	16.7	0.0
	Teso north	54.7	15.0	36.3	18.3	27.3	9.0	0.0
LM4	Bondo	66.7	0.0	0.0	0.0	66.7	0.0	0.0
UM1	Sabatia	27.3	69.7	18.3	12.0	9.0	9.0	12.0
	Nandi south	16.7	41.7	0.0	33.3	0.0	0.0	0.0
Mean		52.9	28.2	23.3	21.6	16.7	7.0	4.7

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; Asco – Ascochyta lef spot; CBB – common bacterial blight; Rust- leaf rust; PM – powdery mildew; RR – root rot; Septo- Septoria leaf spot

Table 24: Mean disease severity scores (%) of groundnuts in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	EB	LB	Asco	Altern	RR	Rust
LM1	Rongo	28.3	18.0	33.3	59.0	2.7	0.0
	Butula	100.0	100.0	33.3	16.7	16.7	8.3
LM2	Rangwe	39.3	12.0	36.3	54.7	21.3	0.0
	Bungoma	20.0	43.3	6.7	6.7	16.7	6.7
	Busia	31.0	48.3	24.0	5.7	15.0	26.3
LM3	Siaya	77.7	11.0	77.7	0.0	0.0	0.0
	Teso north	24.0	15.7	4.0	31.7	16.3	11.7
LM4	Bondo	60.0	20.0	46.7	20.0	0.0	0.0
UM1	Sabatia	26.7	60.0	13.3	0.0	0.0	0.0
	Nandi south	16.7	16.7	41.7	8.3	0.0	0.0
LH1	Nandi south	0.0	16.7	5.7	77.7	11.0	0.0
Mean		38.5	32.9	29.3	25.5	9.1	4.8

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; Altern- alternaria leaf spot; Asco – Ascochyta leaf spot; LB- late leaf blight; EB- early leaf blight; Rust- leaf rust; RR – root rot

Table 25: Mean disease severity scores (%) of soybean in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	Leaf rust	Septoria	CBB	Root rot
LM1	Butula	100.0	0.0	66.7	25.0
LM2	Bungoma	40.0	70.0	10.0	10.0
	Busia	45.0	76.3	27.3	17.7
LM3	Teso North	40.3	49.0	44.0	33.3
UM1	Sabatia	54.3	4.3	40.3	27.7
	Nandi South	54.7	4.7	37.3	25.0
LH1	Nandi South	50.0	83.3	0.0	0.0
Mean		54.9	41.1	32.2	19.8

Disease severity scoring scale: 0 = no disease; 1 = mild; 2 = moderate; 3 = severe; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3;UM1 – upper midland zone 1; LH1 – lowerhighland zone 1; CBB- Common bacteria blight

4.1.7 Overall disease indices for the three common diseases of major legumes

There was variation in total disease indices of the three major diseases of common bean among participating and nonparticipating farmers (Table 26). In some regions, farmers who were participating in legume up scaling projects recorded higher disease indices, mostly for common bacterial blight and root rots, than those who were not participating. There was variation in total disease indices of the three major diseases of cowpea among participating and nonparticipating farmers (Table 27). In some regions, farmers who were participating in legume up scaling projects recorded higher total disease indices for the three major diseases of cowpea. There was variation in total disease indices of the three major diseases of groundnuts among participating and nonparticipating farmers (Table 28). Participating farmers recorded lower disease indices as compared to nonparticipating farmers who had higher disease indices**.**

Table 26: Disease indices for major common bean diseases among participating and non-participating farmers in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	Participation	ALS	CBB	Root rot	Total
LM1	Rongo	Participating	53.3	48.3	46.7	49.4
		Non-participating	41.7	43.3	40.0	41.7
	Butula	Participating	50.0	31.7	13.3	31.7
		Non-participating	43.3	53.3	46.7	47.8
LM2	Rangwe	Participating	41.7	41.7	50.0	44.4
		Non-participating	63.3	61.7	46.7	56.7
	Bungoma	Participating	50.0	50.0	23.3	41.1
		Non-participating	=	=	=	=
	Busia	Participating	50.0	23.3	26.7	33.3
		Non-participating	50.0	18.3	18.3	28.9
LM3	Siaya	Participating	33.3	50.0	66.7	50.6
		Non-participating	46.7	46.7	35.0	42.2
	Teso north	Participating	*	*	*	*
		Non-participating	*	*	*	*
LM4	Bondo	Participating	15.0	61.7	48.3	41.1
		Non-participating	25.0	46.7	26.7	32.8
UM1	Sabatia	Participating	56.7	46.7	30.0	44.4
		Non-participating	56.7	68.3	46.7	56.7
	Nandi south	Participating	=	=	=	=
		Non-participating	48.3	66.7	80.0	65.0
LH1	Nandi south	Participating	48.3	86.7	45.0	60.0
		Non-participating	23.3	53.3	28.3	35.0

Disease index (0-6) is a total of distribution (0-2), incidence (0-1) and severity (0-3); (*) Harvesting had been done at the time of survey; (=)- participating /non-participating farmers not sampled; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; ALS-angular leaf spot; CBB-common bacterial blight.

Table 27: Disease indices for major cow pea diseases among participating and non-participating farmers in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	Participation	Cercospora	CBB	Root rot	Total
LM1	Rongo	Participating	28.3	13.3	38.3	26.7
		Non-participating	18.3	3.3	50.0	23.9
	Butula	Participating	28.3	16.7	23.3	22.2
		Non-participating	8.3	41.7	23.3	24.4
LM2	Rangwe	Participating	=	=	=	=
		Non-participating	66.7	45.0	46.7	52.8
	Bungoma	Participating	16.7	51.7	58.3	42.2
		Non-participating	8.3	13.3	31.7	17.8
	Busia	Participating	8.3	20.0	30.0	19.4
		Non-participating	11.7	41.7	36.7	29.4
LM3	Siaya	Participating	5.0	48.3	13.3	22.2
		Non-participating	1.7	41.7	16.7	20.0
	Teso north	Participating	25.0	28.3	25.0	26.1
		Non-participating	26.7	23.3	20.0	23.3
LM4	Bondo	Participating	5.0	8.3	3.3	5.6
		Non-participating	45.0	1.7	15.0	20.6
UM1	Sabatia	Participating	11.7	20.0	23.3	18.3
		Non-participating	16.7	13.3	18.3	16.1
	Nandi south	Participating	11.7	30.0	20.0	20.6
		Non-participating	5.0	13.3	11.7	9.4
LH1	Nandi south	Participating	46.7	8.3	50.0	35.0
		Non-participating	33.3	16.7	5.0	18.9

Disease index (0-6) is a total of distribution (0-2), incidence (0-1) and severity (0-3; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; Cercospora- Cercospora leaf spot; CBB- common bacterial blight; (=)-participating /non-participating farmers not sampled;

Table 28: Disease indices for major groundnuts diseases among participating and non-participating farmers in various agro-ecological zones and regions in western Kenya during the short rains season of 2013

AEZ	Region	Participation	Asco	EB	LB	Total
LM1	Rongo	Participating	6.7	0.0	16.7	7.8
		Non-participating	23.3	25.0	15.0	20.6
	Butula	Participating	13.3	33.3	31.7	26.1
		Non-participating	0.0	0.0	0.0	0.0
LM2	Rangwe	Participating	16.7	28.3	0.0	15.0
		Non-participating	21.7	23.3	11.7	18.3
	Bungoma	Participating	0.0	13.3	20.0	11.1
		Non-participating	6.7	26.7	40.0	25.0
	Busia	Participating	16.7	18.3	25.0	19.4
		Non-participating	23.3	25.0	41.7	30.0
LM3	Siaya	Participating	48.3	60.0	21.7	43.3
		Non-participating	56.7	81.7	53.3	63.3
	Teso north	Participating	3.3	8.3	11.7	7.8
		Non-participating	3.3	13.3	18.3	12.2
LM4	Bondo	Participating	25.0	8.3	35.0	22.8
		Non-participating	=	=	=	=
UM1	Sabatia	Participating	0.0	0.0	0.0	0.0
		Non-participating	11.7	35.0	61.7	36.1
	Nandi south	Participating	33.3	28.3	31.7	31.1
		Non-participating	=	=	=	=
LH1	Nandi south	Participating	23.3	21.7	50.0	31.7
		Non-participating	33.3	16.7	5.0	18.9

Disease index (0-6) is a total of distribution (0-2), incidence (0-1) and severity (0-3); AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; Asco- Ascochyta leaf spot; LB- late leaf blight; EB- early leaf blight; (=)- Non-participating farmers not surveyed

4.1.8 Overall disease intensity of major legumes grown in western Kenya

The diseases affecting common bean in all the regions were: angular leaf spot, anthracnose, Ascochyta leaf spot, common bacterial blight, downy mildew, leaf rust, powdery mildew, root rots and web blight. Common bacterial blight, angular leaf spot and root rot were the diseases with the highest overall disease intensity while downy mildew and web blight had the lowest disease intensity (Table 29, Appendi 3, Appendix 4, Appendix 5, Appendix 6). The highest total disease indice (13.2) on common bean was recorded in Rangwe (LM2) while the lowest (7.4) was recorded in Butula (LM1) and Busia (LM2) regions.

The diseases affecting cowpea in all the surveyed regions were: Alternaria leaf spot, anthracnose, Ascochyta leaf spot, damping off, powdery mildew, root rots, Septoria leaf spot, web blight, Cercospora leaf spot, leaf rust and common bacteria blight. The three common cowpea diseases were Cercospora leaf spot, leaf rust and common bacterial blight having the highest overall disease indice. The highest overall total disease indice of 11.4 and 14.9 were recorded in Busia (LM2) and Rangwe (LM2), respectively while the lowest (5.1) was recorded in Siaya and Bondo (Table 30, Appendix 7, Appendix 8, Appendix 9, Appendix 10).

The diseases affecting groundnuts in all the regions and agro ecological zones were: Alternaria leaf spot, leaf rust, early blight, late blight and Ascochyta leaf spot. The three common groundnut diseases were early blight, late blight and Ascochyta leaf spot. The highest overall total disease indice of 11.1 and 11.0 respectively for the diseases affecting groundnuts was recorded in Busia (LM2) and Siaya (LM3) while Bondo (LM4) recorded the lowest total disease indice of 2.8 (Table 31, Appendix 11, Appendix 12, Appendix 13, Appendix 14).

Table 29: Total disease indices for the diseases affecting common bean in different regions and agro ecological zones in western

AEZ	Region	CBB	ALS	RR	Rust	Asco	Anthra	Web	Total
LM1	Rongo	48.3	68.3	45.0	35.0	20.0	15.0	3.3	33.6
	Butula	70.0	90.0	38.3	11.7	0.0	0.0	5.0	30.7
LM2	Rangwe	78.3	55.0	66.7	20.0	40.0	15.0	0.0	39.3
	Busia	55.0	90.0	41.7	26.7	0.0	0.0	0.0	30.5
	Bungoma	*	*	*	*	*	*	*	*
LM3	Siaya	83.3	63.3	76.7	8.3	1.7	3.3	0.0	33.8
	Teso north	*	*	*	*	*	*	*	*
LM4	Bondo	86.7	26.7	58.3	11.7	1.7	1.7	0.0	26.7
UM1	Sabatia	70.0	90.0	53.3	20.0	10.0	6.7	1.7	36.0
	Nandi south	80.0	70.0	63.3	13.3	3.3	3.3	0.0	33.3
LH1	Nandi south	51.7	41.7	23.3	40.0	48.3	11.7	8.3	32.1
Mean		69.3	66.1	51.9	20.7	13.9	6.3	2.0	

Disease index (0-6) is a total of distribution (0-2), incidence (0-1) and severity (0-3) per disease; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; ALS – angular leaf spot; Anthra – anthracnose; Asco – Ascochyta leaf spot; CBB – common bacterial blight; RR – root rot; Web – web blight; Rust-Leaf rust; (*) Harvesting of the legume had been done at the time of survey.

Table 30: Total disease indice (%) for the diseases affecting cowpea in different regions and agro ecological zones in western Kenya

AEZ	Region	Cerco	Rust	CBB	PM	Anthra	Asco	Total
LM1	Rongo	43.3	51.7	8.3	5.0	38.3	13.3	26.7
	Butula	55.0	25.0	18.3	26.7	3.3	0.0	21.4
LM2	Rangwe	56.7	96.7	95.0	0.0	0.0	0.0	41.4
	Busia	28.3	28.3	16.7	50.0	26.7	6.7	26.1
	Bungoma	30.0	45.0	18.3	30.0	25.0	0.0	24.7
LM3	Siaya	63.3	3.3	3.3	11.7	0.0	0.0	13.6
	Teso north	48.3	31.7	8.3	20.0	18.3	5.0	21.9
LM4	Bondo	41.7	0.0	28.3	8.3	0.0	5.0	13.9
UM1	Sabatia	23.3	10.0	8.3	30.0	0.0	36.7	18.1
	Nandi south	15.0	15.0	25.0	30.0	6.7	8.3	16.7
LH1	Nandi south	75.0	21.7	0.0	11.7	0.0	43.3	25.3
Mean		43.6	29.8	20.9	20.3	10.8	10.8	

Disease index (0-6) is a total of distribution (0-2), incidence (0-1) and severity (0-3) per disease; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1;; Anthra – anthracnose; Ascho – Aschochyta; CBB – common bacterial blight; PM – powdery mildew; RR – root rot; Rust-Leaf rust; Cerco- Cercospora leaf spot.

Table 31: Total disease indice (%) for all the diseases affecting groundnuts in different regions and agro ecological zones in western Kenya

AEZ	Region	EB	LB	Altern	Asco	RR	Total
LM1	Rongo	33.3	23.3	48.3	36.7	3.3	29.0
	Butula	40.0	38.3	5.0	15.0	5.0	20.7
LM2	Rangwe	43.3	13.3	58.3	38.3	25.0	35.7
	Busia	40.0	60.0	6.7	28.3	16.7	30.3
	Bungoma	26.7	46.7	5.0	6.7	16.7	20.3
LM3	Siaya	88.3	21.7	0.0	73.3	0.0	36.7
	Teso north	26.7	16.7	30.0	3.3	16.7	18.7
LM4	Bondo	0.0	0.0	46.7	0.0	0.0	9.3
UM1	Sabatia	26.7	60.0	6.7	13.3	0.0	21.3
	Nandi south	23.3	26.7	10.0	50.0	0.0	22.0
LH1	Nandi south	0.0	16.7	61.7	6.7	10.0	19.0
Mean		31.7	29.4	25.3	24.7	8.5	

Disease index (0-6) is a total of distribution (0-2), incidence (0-1) and severity (0-3) per disease; AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1;Alt – Alternaria leaf spot; RR – root rot; EB- Early blight; LB- late blight; Asco- Ascochyta leaf spot

4.2 Contribution of seed quality to the occurrence of fungal and bacterial diseases

4.2.1 Percentage purity and germination of common bean seed samples

The mean purity of common bean samples from participating and non participating farmers was 74.1% (Table 32, Figure 14). Busia (LM2) and Bondo (LM4) regions had the highest percentage of pure seed while Nandi south (LH1) had the lowest with a high (15.8%) proportion of discolored and shriveled seeds. Mean germination percentage was generally high up to 96.5% in samples from Rongo. There was a significant ($P \leq 0.05$) variation in proportion of discolored/shriveled seeds among participating and non participating farmers in Busia (LM2), Rangwe (LM2), Butula (LM1) and Nandi south (LH1).

Figure 3: Quality of common bean seed samples collected from different regions in western Kenya. A: Discolored/ shriveled seeds, pure seeds, other bean seed varieties, other crop seeds; B: Discolored/ shriveled seeds, other bean seed varieties, inert matter, pure seed.

Table 32: Percentage purity and germination of common bean seed samples collected from participating and non-participating farmers in legume up scaling projects in various agro-ecological zones in western Kenya

AEZ	Region	Pure seed	Shriveled seed	Germination
Participating				
LH1	Nandi south	62.9 $_{fg}$	16.5 $_{ab}$	92.5 $_{b}$
LM1	Butula	71.4 $_{cde}$	13.2 $_{bc}$	95.7 $_{ab}$
LM1	Rongo	81.3 $_{ab}$	8.7 ef	96.3 $_{a}$
LM2	Busia	82.2 $_{ab}$	6.8 $_{ef}$	94.0 $_{a}$
LM2	Rangwe	82.8 $_{ab}$	12.3 cd	96.5 $_{ab}$
LM3	Teso North	69.5 $_{def}$	19.9 $_{a}$	97.1 $_{a}$
LM4	Bondo	86.9 a	7.7 $_{ef}$	95.1 $_{ab}$
UM1	Sabatia	66.8 $_{efg}$	12.7 $_{bc}$	95.1 $_{ab}$
Mean		75.5	12.2	95.3
LSD Part ($P \leq 0.05$)		0.2	0.1	0.1
LSD Region ($P \leq 0.05$)		0.3	0.1	0.1
LSD Part and Region ($P \leq 0.05$)		0.5	0.2	0.2
CV (%)		5.5	3.8	1.7
Non-Participating				
LH1	Nandi South	58.2 $_{g}$	15.1 $_{abc}$	96.9 $_{a}$
LM1	Butula	78.3 $_{abc}$	8.5 $_{ef}$	95.2 $_{ab}$
LM1	Rongo	73.2 $_{bcd}$	15.0 $_{abc}$	96.7 $_{a}$
LM2	Busia	84.6 $_{a}$	5.0 $_{f}$	97.7 a
LM2	Rangwe	74.5 $_{bcd}$	15.9 $_{abc}$	94.0 $_{ab}$
LM3	Teso north	66.0 $_{efg}$	16.6 $_{ab}$	93.9 $_{ab}$
LM4	Bondo	85.2 $_{a}$	8.4 $_{de}$	94.7 $_{ab}$
UM1	Sabatia	61.3 $_{g}$	12.1 $_{bc}$	96.4 $_{a}$
Mean		72.7	12.1	95.7
LSD Part ($P \leq 0.05$)		0.2	0.1	0.1
LSD Region($P \leq 0.05$)		0.3	0.1	0.1
LSD Part and Region ($P \leq 0.05$)		0.5	0.2	0.2
CV (%)		5.5	3.8	1.7

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; CV- Coefficient of variation; LSD-Least significant difference. Means followed by the same letter(s) within columns for each category of farmers are not significantly different (Duncan's multiple range test LSD at $p \leq 0.05$); LSD Part- Least significant difference among participating and nonparticipating farmers in legume up scaling projects; LSD Region- Least significant difference among the regions.

4.2.2 Infection of moist blotter incubated bean seed samples

More than 80% of germinated seedlings (84.2%) sampled from all the regions were healthy (Table 33). The highest percentage of infected seedlings among farmers participating in legume up scaling projects were recorded in samples from Bondo (LM4) and Busia (LM2) regions while the highest mean percentage of infected seedlings for non-participating farmers were in Rangwe (LM2) and Nandi south (LH1) (Table 33, Figure 7). There was no significant ($P \leq 0.05$) variation in the overall percentage of germinated seedlings, dead seeds and mouldy seeds in seed samples collected from participating and non-participating farmers from all the regions and agro ecological zones. However, there was a significant ($P \leq 0.05$) variation in the percentage of infected seedlings between participating and non-participating farmers in Nandi south (LH1), Rangwe (LM2), Bondo (LM4) and Busia (LM2) regions.

Figure 4: Seed health parameters of common bean seed samples collected from different regions in western Kenya. A: seedlings germinated on moist blotter paper, B: Seedlings showing infection, C: Dead and mouldy seeds, D: mouldy seed (a); ungerminated seed (b); seedling showing infection (c); germinated abnormal seedling (d); germinated normal seedling(e); seedling showing infection (f).

Table 33: Percentage infection of moist blotter incubated bean seed samples collected from participating and non-participating farmers in various agro-ecological zones in Western Kenya

AEZ	Region	Healthy seedlings	Mouldy seeds	Dead seed	Infected seedlings
Participating					
LH1	Nandi south	78.9 $_{d}$	7.5 $_{a}$	7.7 $_{ab}$	8.6 $_{ab}$
LM1	Butula	87.0 $_{abc}$	4.0 $_{abc}$	4.3 $_{abc}$	10.6 $_{a}$
LM1	Rongo	82.9 $_{abcd}$	3.6 $_{bcdef}$	3.7 $_{c}$	9.5 $_{ab}$
LM2	Busia	84.0 $_{abcd}$	1.8 $_{ef}$	3.2 $_{c}$	4.3 $_{def}$
LM2	Rangwe	86.4 $_{abc}$	3.5 $_{abcde}$	5.9 $_{ab}$	2.7 $_{f}$
LM3	Teso North	89.1 $_{a}$	2.2 $_{cdef}$	2.6 $_{c}$	3.6 $_{def}$
LM4	Bondo	80.5 $_{cd}$	4.4 $_{abcde}$	5.1 $_{abc}$	11.2 $_{ab}$
UM1	Sabatia	84.2 $_{abcd}$	3.5 $_{bcdef}$	4.7 $_{abc}$	5.8 $_{cdef}$
Mean		84.1	3.8	4.6	7.0
LSD Part ($P \leq 0.05$)		0.1	0.8	0.2	0.2
LSD Region($P \leq 0.05$)		0.2	1.5	0.4	0.4
LSD P and R ($P \leq 0.05$)		0.3	0.5	0.6	0.6
CV (%)		3.7	78.6	55.8	52.9
Non-Participating					
LH1	Nandi south	85.5 $_{abc}$	2.9 $_{bcdef}$	3.2 $_{bc}$	5.7 $_{bcde}$
LM1	Butula	82.7 $_{abcd}$	2.8 $_{cdef}$	4.4 $_{bc}$	10.3 $_{abc}$
LM1	Rongo	81.5 $_{cd}$	2.8 $_{abcdef}$	3.2 $_{abc}$	7.0 $_{abcde}$
LM2	Busia	88.0 $_{ab}$	1.3 $_{f}$	2.0 $_{c}$	3.1 $_{ef}$
LM2	Rangwe	84.5 $_{bcd}$	4.7 $_{ab}$	5.0 $_{a}$	2.4 $_{f}$
LM3	Teso North	81.7 $_{bcd}$	4.8 $_{abcd}$	6.3 $_{abc}$	10.6 $_{ab}$
LM4	Bondo	83.2 $_{abcd}$	4.3 $_{cdef}$	5.2 $_{c}$	8.1 $_{abcd}$
UM1	Sabatia	87.3 $_{abc}$	2.0 $_{def}$	3.3 $_{bc}$	2.6 $_{f}$
Mean		84.3	3.2	4.1	6.2
LSD Part ($P \leq 0.05$)		0.1	0.2	0.2	0.2
LSD Region ($P \leq 0.05$)		0.2	0.4	0.4	0.4
LSD P and R ($P \leq 0.05$)		0.3	0.5	0.6	0.6
CV (%)		3.7	78.6	55.8	52.9

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; CV- Coefficient of variation; LSD-Least significant difference. Means followed by the same letter(s) within columns for each category of farmers are not significantly different (Duncan's multiple range test LSD at $p \leq 0.05$); LSD Part- Least significant difference among participating and nonparticipating farmers in legume up scaling projects; LSD Region- Least significant difference among the regions

4.2.3 Mean quality parameters for different varieties of common bean seed samples

There were a total of 13 different trade names of common bean varieties of samples collected from different regions in all the agro ecological zones in western Kenya (Table 34, Figure 8). Rose coco and KK8 were the major varieties accounting for 23% and 22%, respectively. GLP2, Canadian wonder, KK071, KATX56 and small yellow were the least common varieties among the farmers in all the regions. GLP2, KK8 and Jessica were the least pure samples while KK8 and KATX56 had the highest percentage of shriveled/discolored seeds of up to 16.8% and 17.2%, respectively. KK8 variety also had the highest inoculum level (1,480 CFU/seed) of *Pseudomonas savastanoi* pv *phaseolicola* pathogen and also had the highest percentage of seeds infected with anthracnose. GLP2 was the variety that was not infected with the *Pseudomonas savastanoi* pv *phaseolicola* pathogen. For the *Xanthomonas campestris* pv p*haseoli* KATB1 variety had the highest inoculum level of 789 CFU/seed of *Xanthomonas campestris* pv p*haseoli* while GLP2 and KK071 had none.

Figure 5: Different common bean seed varieties grown in western Kenya. A: Small yellow; B: Jessica (Punda); C: KATB1; D: Rose coco; E: Red kidney beans; F: KK8; G: Zaire; H: KK16; I: GLP2; J: Wairimu K: Rose coco.

Table 34: Mean quality parameters for the varieties of common bean seed samples collected from farmers in western Kenya

Local name	Trade name	% of samples	Purity (%)	Discolored/ shrivelled (%)	Germination (%)	Halo blight (CFU/seed	CBB (CFU/seed)	Anthra infected seeds (%)
Punda	Jessica	5	69.6	13.6	97.0	396	329	0.0
Rosecoco	Rosecoco	23	70.0	12.0	94.0	1196	229	0.0
GLP2	GLP2	1	65.8	13.5	99.0	0	0	0.0
Zaire	Zaire	11	88.2	8.0	97.0	437	30	1.2
Yellow green	KATB1	3	85.2	5.2	95.0	1148	789	0.0
KATX56	KATX56	2	76.8	17.2	94.0	900	203	0.0
KK071	KK071	2	84.4	13.4	98.0	1028	0	0.0
KK15	KK15	5	58.0	8.3	96.0	398	489	0.0
Wairimu	Wairimu	8	79.0	12.9	93.0	175	111	0.8
Local varieties	Landrace	15	75.0	12.2	96.0	1447	199	1.9
KK8	KK8	22	62.7	16.8	95.0	1480	213	2.4
Yellow beans	SY	2	74.9	12.4	99.0	54	52	1.7
Pocho	CW	2	85.5	7.2	96.0	544	15	0.0

CBB- Common bacterial blight; Anthra-Anthracnose; SY- Small yellow; CW –Canadian wonder; Local varieties- Mlingoti, Ukimwi, Hayaki, Raura

4.2.4 Bacterial infection of bean seed samples

Xanthomonas campestris pv p*haseoli* and *Pseudomonas savastanoi* pv *phaseolicola* were the main bacterial pathogens isolated from the bean seed samples (Figure 9). The mean population of 1,775 CFU/seed for *Pseudomonas savastanoi* pv *phaseolicola* and 555 CFU/seed for *Xanthomonas campestris* pv *phaseoli* for farmers participating in legume up scaling projects was isolated (Table 35). Population levels of up to 3,603 CFU/seed for *Pseudomonas savastanoi* pv *phaseolicola* and 317 CFU/seed for *Xanthomonas campestris* pv *phaseoli* were also isolated from samples from non participating farmers (Table 35). There was a significant ($P \leq 0.05$) variation in *Pseudomonas savastanoi* pv *phaseolicola* inoculum in Rangwe (LM2) and Teso north (LM3) and *Xanthomonas campestris* pv *phaseoli* in Sabatia (UM1), Rongo (LM1) and Teso north (LM3) among participating and non-participating farmers. Generally, inoculum level for *Xanthomonas campestris* pv *phaseoli* was low with a mean frequency of 283 CFU/seed for participating farmers and 151 CFU/seed for non participating farmers as compared to *Pseudomonas savastanoi* pv *phaseolicola* with a mean frequency of 747 CFU/seed for participating farmers and 1241 CFU/seed for nonparticipating farmers.

All the seed samples from Bondo (LM4) were infected with *Pseudomonas savastanoi* pv *phaseolicola*.Teso north (LM3) had the highest percentage of samples infected with the bacterium. Samples from Rangwe had the highest (≥3000 CFU/seed) inoculum levels of the bacterium. For *Xanthomonas campestris* pv *phaseoli*, Butula (LM1) recorded the lowest percentage of infected seed samples while Bondo recorded the highest. Only seeds from Sabatia had samples with inoculum levels of 2000-3000 CFU/seed (Table 36).

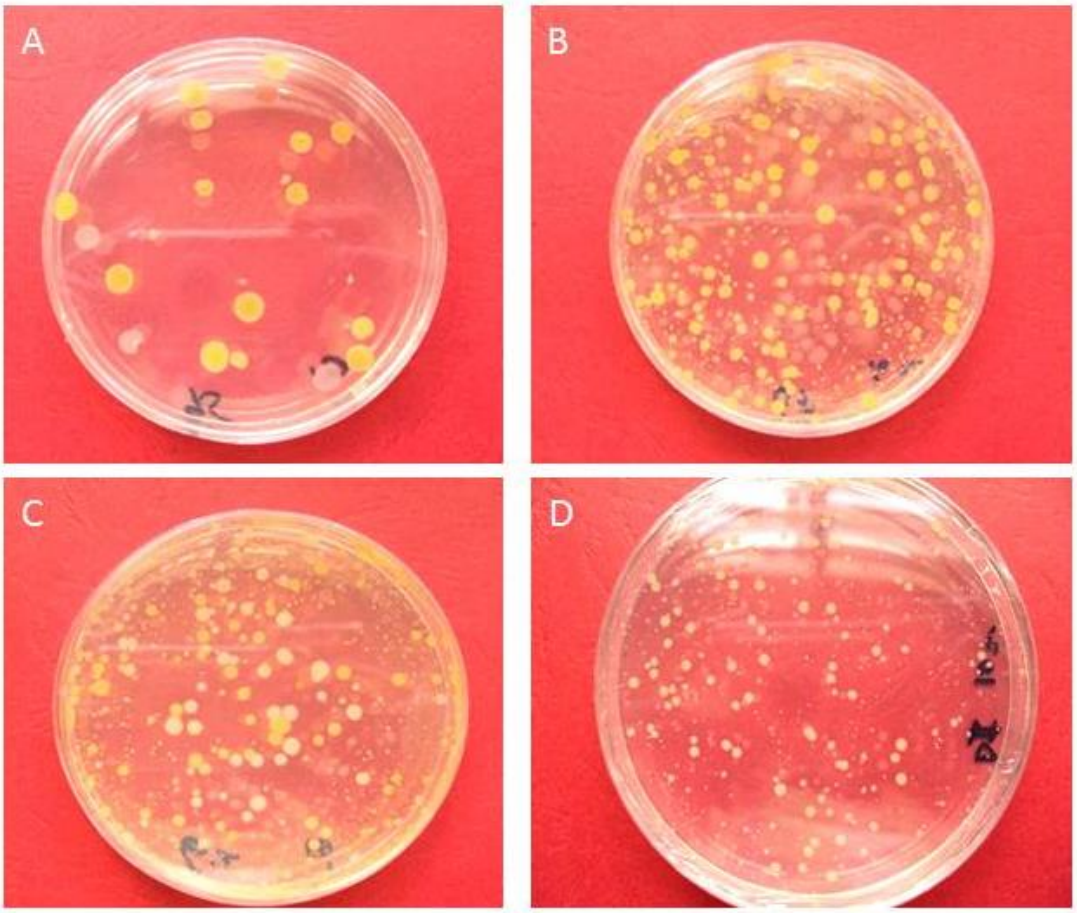

Figure 6: Cultural characteristics of the two bacterial blight pathogens isolated from bean seed samples growing on nutrient agar. A: *Xanthomonas campestris* pv *phaseoli* (yellow colonies) from a sample with less population of the pathogen; B: *Xanthomonas campestris* pv *phaseoli* (yellow colonies) from a sample with high population of the pathogen; C: Sample with both yellow and cream colonies (*Xanthomonas campestris* pv *phaseoli* and *Pseudomonas savastanoi* pv *phaseolicola*). D: *Pseudomonas savastanoi* pv *phaseolicola* (cream colonies).

Table 35: Population (CFU/ seed) of *Xanthomonas campestris* pv *phaseoli* and *Pseudomonas savastanoi* pv *phaseolicola* in bean seeds sampled from different regions and agro ecological zones in western Kenya

		Participating		**Nonparticipating**	
AEZ	Region	*Psp*	*Xap*	*Psp*	*Xap*
LH1	Nandi South	215 $_{ef}$	242 $_{ab}$	608 $_{def}$	43 $_{de}$
LM1	Butula	486 $_{def}$	4 $_{e}$	655 $_{cde}$	51 $_{de}$
LM1	Rongo	1203 $_{bc}$	555 $_{a}$	567 $_{cdef}$	306 $_{bc}$
LM2	Busia	130 $_{f}$	249 $_{ab}$	500 $_{cdef}$	317 $_{bc}$
LM2	Rangwe	917 $_{bcde}$	305 $_{ab}$	1882 $_{b}$	281 $_{bcd}$
LM3	Teso North	708 $_{def}$	355 $_{bc}$	3603 $_{a}$	17 $_{e}$
LM4	Bondo	542 $_{cdef}$	127 $_{bcd}$	478 $_{cdef}$	121 $_{bcd}$
UM1	Sabatia	1775 $_{bcd}$	428 $_{bc}$	1634 $_{b}$	69 $_{cde}$
Mean		747	283	1241	151
LSD Part ($P \leq 0.05$)		15	4	15	4
LSD Region ($P \leq 0.05$)		57	16	57	16
LSD Part and Region ($P \leq 0.05$)		114	31	114	31
CV (%)		62.7	96.4	62.7	96.4

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; CV- Coefficient of variation; LSD-Least significant difference. Means followed by the same letter(s) within columns for each category of farmers are not significantly different (Duncan's multiple range test LSD at $p \leq 0.05$); LSD Part- Least significant difference among participating and nonparticipating farmers in legume up scaling projects; LSD Region- Least significant difference among the regions; *Psp- Pseudomonas savastanoi* pv *phaseolicola; Xap- Xanthomonas campestris* pv *phaseoli*

Table 36: Proportion (%) of samples contaminated with different population levels (CFU/seed) of *Pseudomonas savastanoi pv phaseolicola* and *Xanthomonas axonopodis pv phaseolicola* from various regions and agro-ecological zones in western Kenya

AEZ	Region	Not infected	0-100	100-500	500-1000	1000-2000	2000-3000	>3000
Pseudomonas savastanoi pv phaseolicola								
LM1	Rongo	10.0	20.0	10.0	20.0	30.0	0.0	10.0
LM1	Butula	42.9	0.0	0.0	42.9	14.2	0.0	0.0
LM2	Rangwe	22.2	11.1	22.2	0.0	11.1	0.0	33.3
LM2	Busia	40.0	0.0	60.0	0.0	0.0	0.0	0.0
LM3	Teso North	18.2	16.7	0.0	0.0	9.1	18.2	16.7
LM4	Bondo	0.0	20.0	45.0	15.0	10.0	10.0	0.0
LH1	Nandi south	40.0	15.0	35.0	0.0	5.0	0.0	5.0
UM1	Sabatia	31.6	10.5	15.8	0.0	10.5	15.8	15.8
Mean		25.6	11.7	23.5	9.7	11.2	5.5	10.1
Xanthomonas axonopodis pv phaseolicola								
LM1	Rongo	40.0	10.0	20.0	10.0	20.0	0.0	0.0
LM1	Butula	85.7	0.0	14.3	0.0	0.0	0.0	0.0
LM2	Rangwe	44.4	22.2	11.1	22.2	0.0	0.0	0.0
LM2	Busia	20.0	20.0	40.0	20.0	0.0	0.0	0.0
LM3	Teso North	63.6	18.2	9.1	0.0	9.1	0.0	0.0
LM4	Bondo	20.0	35.0	40.0	5.0	0.0	0.0	0.0
LH1	Nandi south	50.0	5.0	35.0	10.0	0.0	0.0	0.0
UM1	Sabatia	57.9	21.1	10.5	0.0	5.3	5.3	0.0
Mean		47.7	16.4	22.5	8.4	4.3	0.7	0.0

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; CFU-colony forming units

4.2.5 Incidence of fungal pathogens in common bean seeds

Different fungal species were isolated from the common bean seed samples in all the regions in different agro ecological zones (Table 37, Figure 10). The fungi included *Fusarium solani*, *Rhizoctonia solani*, *Colletotrichum lindemuthianum*, *Macrophomina* spp. and *Phythium* spp. *Fusarium solani* was the most common fungi isolated in high incidence in almost all the seed samples from different regions and agro ecological zones. There was no significant ($P \geq 0.05$) variation in the percentage of seed samples infected by a particular fungi in regions with farmers

in the participating legume up scaling projects as well as the non participating farmers except in Rongo (LM1) and Butula for *Colletotrichum lindemuthianum*, Teso north and Busia for *macrophomina* and Rangwe for *Rhizoctonia.* There was a significant ($P \leq 0.05$) variation among participating farmers in Busia (LM2) and Butula (LM1). The mean total percentage of infected seeds by the different fungi was similar for both participating (mean = 27.6%) and non participating (mean = 28.1%) farmers (Table 37).

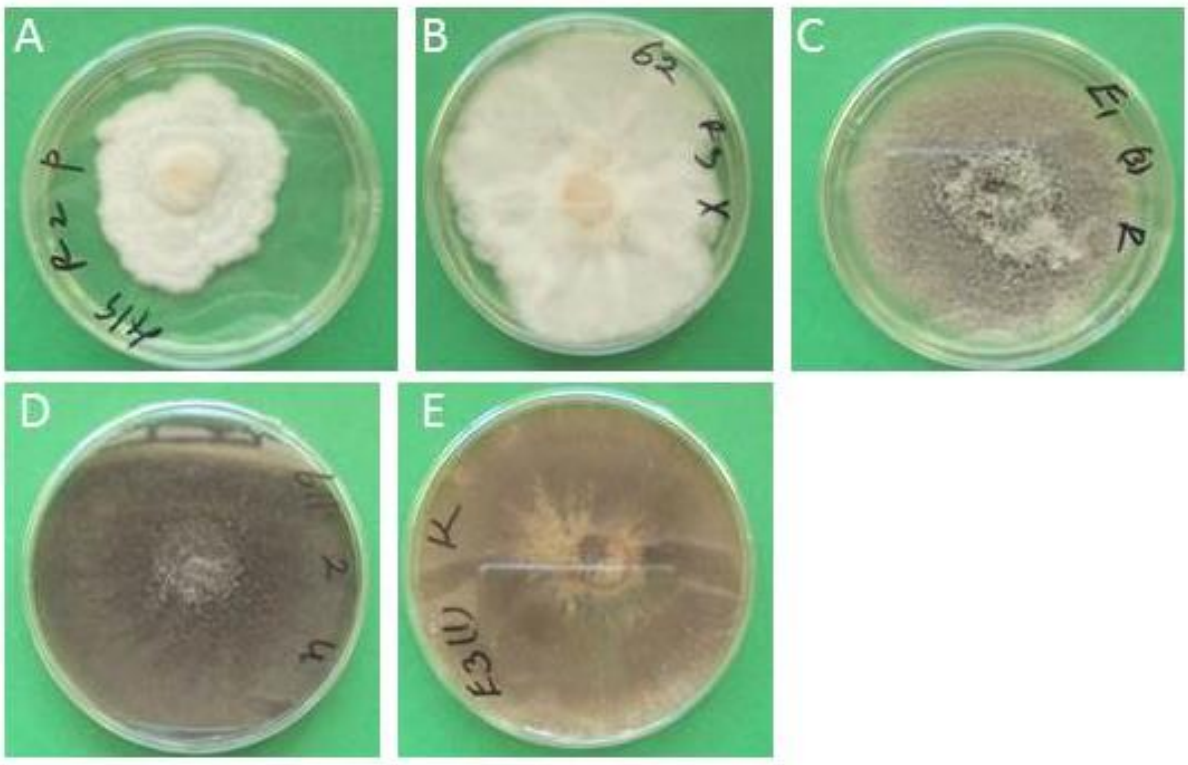

Figure 7: Cultural characteristics of the fungal species isolated from bean seed samples growing on potato dextrose agar. A: *Fusarium solani*. B: *Pythium* spp. C: *Colletotrichum lindemuthianum* D: *Macrophomina spp.* E: *Rhizoctonia* spp.

Table 37: Percentage of fungal infection of common bean seed samples collected from participating and non-participating farmers in different regions in western Kenya

AEZ	Region	Total ıfected seeds (%)	Fus	Cole	Rhi	Mac	pty
Participating							
LH1	Nandi South	28.0 $_{bcde}$	17.3 $_{bcde}$	2.7 $_{bc}$	4.7 $_{ab}$	0.0 $_{b}$	2.7 $_{b}$
LM1	Butula	29.3 $_{ab}$	26.5 $_{ab}$	9.9 $_{a}$	0.1 $_{b}$	0.0 $_{b}$	0.0 $_{b}$
	Rongo	29.3 $_{bcdef}$	24.0 $_{ab}$	9.9 $_{a}$	2.7 $_{ab}$	0.0 $_{b}$	0.1 $_{b}$
LM2	Busia	13.3 $_{h}$	13.3 $_{bcde}$	0.0 $_{c}$	0.0 $_{b}$	0.0 $_{b}$	0.0 $_{b}$
	Rangwe	34.7 $_{abcd}$	16.0 $_{bcde}$	0.0 $_{c}$	13.3 $_{a}$	6.7 $_{b}$	0.0 $_{b}$
LM3	Teso North	33.3 $_{bcde}$	25.6 $_{abc}$	2.2 $_{bc}$	0.0 $_{b}$	0.0 $_{b}$	0.0 $_{b}$
LM4	Bondo	27.3 $_{bcd}$	22.0 $_{bcde}$	0.0 $_{c}$	2.7 $_{b}$	3.3 $_{b}$	2.0 $_{b}$
UM1	Sabatia	18.0 $_{efgh}$	8.7 $_{de}$	0.0 $_{c}$	0.7 $_{b}$	3.3 $_{b}$	3.3 $_{ab}$
Mean		27.6	19.2	1.8	3.0	1.7	1.0
Non-participating							
LH1	Nandi South	30.0 $_{bcde}$	20.7 $_{bcde}$	2.0 $_{bc}$	2.7 $_{b}$	0.0 $_{b}$	2.0 $_{b}$
LM1	Butula	14.7 $_{gh}$	10.7 $_{cde}$	1.3 $_{bc}$	2.7 $_{bc}$	0.0 $_{b}$	0.0 $_{b}$
	Rongo	38.7 $_{ab}$	26.7 $_{abcd}$	4.0 $_{b}$	2.7 $_{b}$	0.0 $_{b}$	5.3 $_{a}$
LM2	Busia	32.2 $_{abc}$	16.7 $_{ab}$	0.2 $_{c}$	0.0 $_{b}$	31.6 $_{a}$	0.0 $_{b}$
	Rangwe	18.3 $_{defgh}$	16.7 $_{bcde}$	0.0 $_{c}$	0.5 $_{b}$	0.0 $_{b}$	0.4 $_{b}$
LM3	Teso North	53.3 $_{a}$	37.3 $_{a}$	4.0 $_{c}$	1.3 $_{b}$	46.7 $_{a}$	0.0 $_{b}$
LM4	Bondo	22.7 $_{cdefgh}$	21.3 $_{abcde}$	0.0 $_{c}$	0.7 $_{b}$	0.0 $_{b}$	0.0 $_{b}$
UM1	Sabatia	14.8 $_{fgh}$	8.9 $_{e}$	1.5 $_{c}$	3.0 $_{ab}$	0.0 $_{b}$	0.0 $_{b}$
Mean		28.1	20.9	1.6	1.7	9.8	1.0
LSD Part ($P \leq 0.05$)		0.5	0.5	0.2	0.2	0.3	0.2
LSD Region ($P \leq 0.05$)		1.0	1.0	0.3	0.5	0.6	0.4
LSD Part and Region ($P \leq 0.05$)		1.4	1.5	0.5	0.7	0.9	0.5
CV (%)		62.4	82.3	95.7	132.2	155.0	119.5

AEZ – agro-ecological zone; LM1 – lower midland zone 1; LM2 – lower midland zone 2; LM3 – lower midland zone 3; LM4 – lower midland zone 4; UM1 – upper midland zone 1; LH1 – lower highland zone 1; CV-Coefficient of variation; LSD-Least significant difference. Means followed by the same letter(s) within columns for each category of farmers are not significantly different (Duncan's multiple range test LSD at $p \leq 0.05$); LSD Part- Least significant difference among participating and nonparticipating farmers in legume up scaling projects; LSD Region- Least significant difference among the regions; Fus- *Fusarium solani;* Cole- *Coletotrichum lindemuthianum;* Rhi- *Rhizoctona solani;* Mac- *Macrophomina spp.;* Pty- *Pythium* spp.

CHAPTER 5: DISCUSSION

5.1 Role of farming practices on occurrence of legume diseases in western Kenya

Legume farmers in the seven counties of Busia (LM2), Bungoma (LM2), Homabay (LM1, LM2), Migori (LM1), Nandi (LH1, UM1), Siaya (LM4) and Vihiga (UM1) were small scale farmers who allocated small land sizes to legume production of less than 0.1ha. This is because of the decreasing land sizes due to increasing population density which increases land fragmentation. This concurs with Marenya and Barett (2007) who found out that average farm size was 0.6ha with seven people per household in western Kenya, as a result, most legume farmers are subsistence farmers with majority of them producing legumes on small land portions and consequently low production output. In addition, legumes are considered as minority crops as compared to cereals (Tsubo *et al*., 2005) which are the majority and therefore allotted larger tracts of land as compared to legumes. In the current study, common bean was allocated the most farming area followed by green grams, soybean, groundnuts and cowpea. This is in agreement with findings by Anon (2010), who concluded that common bean took up most farming area followed by green grams and cowpea. A study by Akibode and Maredi (2011) also concluded that the challenge of pests and diseases determined the frequency of inclusion of the legumes in the cropping system.

In the current study, nearly all the sampled legume farmers intercropped their legumes with cereals like maize, cassava, millet and some cash crops like tea, an old common cropping practice in the tropics (Tsubo *et al*., 2005; Hauggard-Nielsen *et al*., 2007). Only a small proportion of farmers in Nandi south (LH1) planted their

legumes in pure stands. These finding agrees with earlier research findings by Katungi *et al*., (2009) who reported that, majority of the small scale legume farmers produced legumes under multiple inter-cropping systems with cereals, bananas and coffee among other crops. This can be attributed by the small scale famers need to maximize on the limited farming land as well as reap other benefits of intercropping which includes reduction in use of farm inputs, reduced labor cost, and reduced risk of crop failure (Hauggard-Nielsen *et al*., 2007). In addition, use of legumes as intercrops has been shown to have numerous benefits to the soil including controlling erosion, weed control, reducing water and nutrient loss and increasing nutrient access from deep soil horizons (Shapiro and Sanders, 2002; Adu-Gyamfi *et al*., 2007; Takim, 2012).

In the current study, the legumes cultivated from the most to the least common were: common bean, cowpeas, groundnuts, soybean, green grams, climbing bean, Bambara nuts and lablab. The major legumes were the common bean, cowpeas and groundnuts which were grown in all the regions and agro-ecological zones surveyed. According to Ojiem, (2006), in western Kenya, these legumes were adopted due to their role as sources of food and market availability. In a previous study by Maobe *et al*. (1998), the type of grain legume that was cultivated by a farmer was determined by yield levels, palatability and how much income the legume generated. In addition, pests and diseases have a major influence on the choice of legumes cultivated (Akibode and Maredi, 2011).

GLP 2 and KK8 were the major legume varieties in all the sampled farms. The preferred use of these varieties could be due to farmers recycling the seed that were

issued to them by the government during global legume programs (GLP) in the early 80s (Buruchara *et al*., 2011). Local legume varieties were still popular across western Kenya, with each region growing a unique local variety. For instance, farmers cultivated local varieties (local cream, black and white varieties) of cowpea throughout western Kenya. M66, an improved variety of cowpea was not commonly cultivated. This was due to the fact that farmers tend to have their own unique variety preferences which are usually not valued by seed companies due to their desire for profitable varieties with already an established market (Tripp, 2003). In addition, this could have been due to the fact that most farmers grew cowpea in small plots for subsistence purposes and there is a lack of market to push for commercial production. New varieties should be acceptable by the farmers in terms of performance and market before release to enable adoptability and to avoid financial waste (Buruchara *et al*., 2011). Gichangi *et al*. (2012) also reported that the level of adoption of new varieties was dictated by yield levels of the variety and that most farmers had difficulty accessing clean seeds due to limited resources and lack of knowledge of the improved varieties. Inaccessibility of improved seeds to farmers could also be attributed to the fact that seed companies target varieties that are profitable to them with no commercial motivation for varieties that play a role to the resource poor farmer's food security (Tripp, 2003). But with careful selection, these varieties could be used to come up with new improved varieties (Buruchara *et al*., 2011).

5.2 Occurrence of fungal and bacterial diseases in legumes grown in western Kenya

There was high prevalence of fungal and bacterial diseases of legumes in all the regions covered in the study in western Kenya. This might have been due to favourable weather conditions and poor agronomic practices by the farmers (Hirano *et al*., 1995; Appendix 2). Most foliar disease pathogens can cause considerable damage when there are favorable weather conditions, this explains why there were high disease incidences. Disease incidence, distribution and severity differed among the various agro-ecological zones because of the differences in weather conditions in the different agro ecological zones (Jaetzold *et al*., 2006; Appendix 2). Similar studies have also reported that environmental factors such as elevation, humidity and precipitation affect the occurrence of pests and diseases (Bernardi, 2001; Fininsa and Tefera, 2006). These diseases affect legume production and yields (Muthomi *et al*., 2007) leading to declining agricultural productivity, poor rural livelihood and poverty rates that are among the highest in Kenya (Giller *et al*., 2011). Common bacterial blight of common bean, cowpea, green grams, and soybean was the most prevalent foliar bacterial disease in all the regions. This concurs with findings by Saettler, (1989), who concluded that common bacterial blight was the most important foliar diseases in East Africa especially in hot and humid areas. Root rots, on the other hand, were the most common fungal disease. The high prevalence of root rot diseases could be due to small land sizes which results to overcultivation without period breaks between cropping seasons or a lack of crop rotation, to break the pathogen cycle. This results in decreased soil fertility and build-up of pathogen inocula and

consequently severity of the diseases (Gichangi *et al*., 2012). Farmers also do not use clean certified legume seeds, instead, majority use farm saved seed from previous seasons which could be disease causing pathogen carriers (Maredia *et al*., 1999). Similarly, research conducted by Makelo (2010) and Gichangi *et al*. (2012) indicated that, most small scale farmers in Kenya planted uncertified seeds saved from previous harvest, borrowed from the neighbours or purchased from the local markets. Use of farm saved seed allows the pathogen to constantly thrive in the seeds and soil (Buruchara, 1990). A similar study in Malawi, found that majority of the farmers kept seeds from previous seasons for replanting (Scott *et al*., 2003). In another study by Abawi *et al*. (2006), overuse of land resulted in decreased soil fertility leading to build up of pathogen inocula. Common bacterial blight and root rots can cause yield losses of up to 40% and 70%, respectively (Opio *et al*., 1996; Nzungize *et al*., 2012).

There was variation in total disease indices for the major legumes among farmers participating in legume up-scaling projects and the non participating farmers. In some instances, higher total disease indices were recorded in fields where farmers were participating in legume up-scaling projects than non participating farmers. This could be attributed to lack of adherence to proper agronomic practices such as failure by the farmers to observe sanitary conditions. For instance, mixing of clean seeds by farmers with their own farm saved seeds to cover a large area or using the inputs like fertilizers meant for other crops other than legumes (Maredia *et al*., 1999). Despite lack of differences in disease indices between the two categories, farmer participation is important in adoption and diffusion of new varieties and/or new technologies (Odendo *et al*., 2004).

In the current study, geographical information system was used to map the distribution and intensity of major diseases on the major legumes (common bean, cowpea and groundnuts) grown in western Kenya. Different colors were used to represent the level of disease intensities in the region. Disease maps and weather forecast maps generated by geographical information system can be useful in identifying disease hot spots and in the application of site/ region specific management. For instance, development of varieties suitable for that region or chemical control in that specific site (Kleinhenz and Zeuner, 2010; Azahar *et al*., 2011). Geographical information system can also be used to predict the projected spread of legume diseases, provide input control and also in quantifying changing patterns of diseases due to climatic changes (Bouwmeester *et al.*, 2010).

5.3 Contribution of seed quality to the occurrence of fungal and bacterial diseases

The quality of planting seeds is a critical component to high grain yield in legume production (Rubyogo *et al*., 2007). Good quality seeds leads to good crop establishment and increases the potential of legume crop yield resulting in high productivity. Planting of quality and pathogen free seed is therefore very crucial for any significant yield improvement for the resource poor farmers (Icishahayo *et al*., 2009). Common bean seed samples from different regions and agro ecological zones did not significantly differ in the number of germinated seeds when subjected to germination test. There was however a significant variation in the number of germinated seedlings showing infection, discolored/shrivelled and pure seeds from different regions and agro ecological zones. Percentage pure seed was way below

(74%) ISTA`s minimum pure seed standard (95%) and varied significantly among different regions and agro ecological zones. This is consistent with Oshone *et al*., (2013) who reported variation in proportion of pure seed from samples obtained from small scale farmers from different agro-ecological zones in Ethiopia. This could also be attributed to poor pre and post harvest handling practices like threshing and storage (Greven *et al*., 2004). The variation in seed discoloration is due to a higher prevalence of bean diseases in some agro-ecological zones as compared to others probably due to favourable weather conditions for disease development in a particular zone (Makelo, 2010). Seed discoloration/shrivelling is an indicator of disease caused by the presence of seed borne pathogen inoculum present in the seeds (ISTA, 1999; Icishahayo *et al*., 2009). Mouldy and dead seeds together with diseased seedlings showing infections can also be directly associated with the level of pathogen inoculum on the surface of the seed (Icishahayo *et al*., 2009). There was significant variation in percentage of mouldy, dead seeds and germinated seedlings showing infection among the various agro-ecological zones. Mouldy and dead seeds together with diseased seedlings showing infections can be directly associated with the level of pathogen inoculum on the surface of the seed (Icishahayo *et al*., 2009). Infected seeds are usually the source of infections. For instance, for bacterial diseases, infected seed is the main source of infection (Allen *et al*., 1998). A study by Narayan and Ayodhya (2013), reported that legume seed production was affected by both fungal and bacterial diseases which are seed borne. Healthy seed is therefore the most important agricultural input affecting yield levels of the crop (Diaz *et al*., 1998).

There were 13 different trade name varieties including landraces of the common bean samples collected from farmers in different regions and agro-ecological zones in western Kenya. KK8 and Rosecoco were the major varieties which are popular with farmers and consumers in Kenya because of their size and color (Korir *et al*., 2005). There were other common bean varieties which were only grown in specific regions. For instance, Punda (Jessica) was only grown in Siaya and Bondo regions while the Small yellow variety was only grown in Nandi south. This could have been due to regional preferences of food source and also market value of the legumes in that region (Ojiem, 2006). Local varieties were also common among the farmers accounting for 15% of the bean seed samples collected. This also concurs with Broughton *et al*. (2002), who reported that local and market preferences as well as the variability in climatic and agronomic conditions dictated the varieties that were most popular in a region. A previous study by Spilsbury *et al*. (2004) also reported that adoption of new varieties was low due to low market demands and lack of variety attributes demanded by the consumers. According to Wagara and Kimani (2007), these local varieties, should be embraced by seed companies and their resistance traits ought to be used as a source of resistance to improve the preferred but susceptible varieties.

Seed borne bacterial and fungal pathogens were isolated from the bean seeds collected from farmers in different regions and agro-ecological zones. This concurs with findings by Oshone *et al*. (2014) who also isolated bacteria and fungal pathogens from bean seed samples obtained from small holder farmers in eastern Ethiopia. In the current study, there were two main bacteria isolated from the common bean seed

samples from all the regions and agro-ecological zones: *Xanthomonas campestris* pv *phaseoli* and *Pseudomonas savastanoi* pv *phaseolicola. Pseudomonas savastanoi pv phaseolicola* was isolated in high frequency from KK8 and landrace varieties while *Xanthomonas campestris* pv *phaseoli* was isolated in high frequency from KATB1 variety. This high frequencies are due to pathogen inocula build up in the seeds due to farmers recycling their own farm saved seed throughout the seasons for planting. *Xanthomonas campestris* pv *phaseoli*, the causative agent of common bacterial blight is a major constraint in bean production in many countries and causes severe disease in high rainfall, humidity and temperature (25-35˚C) with maximum development occurring at 28˚C (Saettler 1989; Gilbertson and Maxwell, 1992). The bean seeds were therefore, the main source of inocula for these pathogens which explained why common bacterial blight was prevalent in all the regions and agro ecological zones. There was a significant variation in the population of bacterial pathogens isolated from seed samples from different regions and agro ecological zones. This was because pathogen survival in the soil or plant debris is influenced by geographical area, climate, cultural practices and host genotypes and strains (Karavina *et al*., 2008). A study by Karavina *et al*. (2008), in Zimbabwe showed that certified seeds had less inocula of *Xanthomonas campestris pv phaseoli* than farm saved seed. The current study was also in agreement with previous studies by Allen *et al*. (1998) who reported that seeds are the primary source of inocula for bacterial diseases. Additionally, plant pathogens are seed-borne and cause huge crop losses, reduction in plant growth and productivity of crops (Dawson and Bateman, 2001; Islam *et al*., 2009).

Different fungal species were also isolated from the common bean seed samples. The fungi included *Fusarium solani, Rhizoctonia solani, Colletotrichum lindemuthianum, Macrophomina* and *Phythium spp.* *Fusarium solani* was the most common fungi isolated in high incidence in almost all the seed samples from different regions and agro ecological zones. This observation agrees with research findings by Icishahayo *et al*. (2009), who reported high incidence of the pathogens in beans obtained from different agro-ecological zones in Zimbabwe. Bean seeds were therefore a source of not only bacterial pathogens but also fungal pathogens. This concurs with previous studies by Narayan and Ayodhya (2013), who concluded that legume seed production was affected by fungal and bacterial diseases which were seed borne. There was no significant variation in the percentage of seed samples infected by a particular fungus in different regions and between participating and non-participating farmers in the legume up-scaling projects. The mean total percentage of infected seeds by the different fungi was similar for both participating and non participating farmers, indicating that farmers participating in the legume up-scaling projects were not applying the knowledge gained as recommended.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Poor cropping practices resulted to high prevalence of fungal and bacterial diseases of legumes. Most of the farmers allocated small land sizes for legume production due to diminishing land sizes and therefore did not practice crop rotation hence continuous cropping which led to reduced soil fertility and pathogen build up. Farmers also heavily relied on local legume varieties a factor which could have been due to inaccessibility of clean certified seeds and lack of awareness on improved varieties.

Farmer participation in legume up-scaling projects did not translate to reduced occurrence of legume diseases in the fields compared to farmers who were not participating in legume up-scaling projects. This could be attributed to the fact that farmers participating in the legume up-scaling projects were not strictly following the recommended agronomic practices.

There was a high prevalence of fungal and bacterial diseases of legumes in western Kenya. Disease incidence, distribution and severity differed among the different agro-ecological zones. Higher disease indices were therefore recorded for the various legume in different regions. This could be due to favorable weather conditions and poor agronomic practices by the farmers which results in huge yield losses.

Both fungal and bacterial pathogens were isolated from the bean seed samples collected from the farmers from different regions, indicating that most of the farm-saved seeds used by the farmers were unhealthy and were the primary source of inocula for diseases. The samples differed in level of contamination across the six

agroecological zones. Geographical information systems could be a useful tool in studying distribution of legume diseases and prediction of possible outbreaks thereby contributing to their effective management.

6.2 Recommendations

Based on the findings of this study, the following is recommended:

i. Legume farmers in western Kenya should be trained on good agronomic practices like use of clean, certified legume seeds; avoid recycling farm-saved seeds over many years to avoid accumulation of disease inocula.

ii. Farmers should be discouraged from using their own farm saved seed, those obtained through local exchanges or even from local markets.

iii. Adoption of legume disease management measures such seed treatments and field sanitation in managing the seed borne diseases.

iv. Farmers should be trained on the importance of adopting and using improved legume varieties.

v. Further research is recomended to determine suitability of legume species and varieties to specific agro-ecological zones.

vi. Promotion of farmer-based clean seed production practices.

vii. Further studies should be conducted to determine the role of seed borne disease inocula in other legume species

viii. Use of geographical information system should be promoted to generate weather models and disease distribution maps to enable predict potential outbreak and spread of legume diseases in the region and to provide input for risk assessment models.

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APPENDICES

Appendix 1: Survey questionnaire: Effect of cropping systems on the occurrence of fungal and bacterial diseases in western Kenya

Section I: Background information

Farmer ID: ---------- Name of the farmer: ---------- Date: ----/----/2013

Age: -------- Gender: (M) (F) Village: ---------- Agro-Ecological Zone: ---------- Latitude: ---------- Longitude: ---------- Elevation (m): ----------

Section II: Information on farming practices

1. Total land size (Acres) ---------- Area under legume production (Acres): ----------
2. How many years have you practiced legume production? ----------
3. Types of legumes grown: a) ---------- b) ----------c) ---------- ---------- d) ---------- e)----------
4. Sources of seeds: a) Own b) Neighbor c) Local Market d) Agro-shop e) Other (specify) ---
5. Other crops grown on the farm a) ---------- b) ----------c) ---------- ---------- d) ---------- e) ----------
6. Do you mix legume crops with other crops? (Yes) (No)
7. If yes, with what crops? a) ---------- b) ----------c) ---------- ---------- d) ---------- e) ----------
8. Do you practice crop rotation in legume production? (Yes) (No)
9. If yes, with what crops? a) ---------- b) ----------c) ---------- ---------- d) ---------- e) ----------
10. What crop(s) did you plant the previous season on the area currently under legumes? a) - ---------- b) ----------c) ----------d) ---------- ---------- e) ---------- f) ----------
11. What do you do with the legume debris after harvesting? a) ---------- b) ---------- ---------- c) ---------- d) ----------
12. Do you use any soil amendments in legume production? (Yes) (No)
13. If yes, which amendments and at what growth stage? a) ---------- b) ---------- ---------- c) ----------

14. What are the most common legume diseases in your farm? a) ----------b) -------- ---------- c) ---------- d) ----------e) ---------- ---------- f) ---------- g) ----------

15. Do you employ any methods of pest and disease control? (Yes) (No)

16. If yes, which ones? a) ---------- b) ---------- c) ---------- ---------- d) ----------

17. Why do you produce legumes? a) Subsistence b) Commercial c) Others (specify) ----------

18. If commercial production, where do you market your legumes? a) ----------b) -------- ---------- c) ---------- d) ----------

19. What challenges do you face as a farmer in your legume production process?
    a) ---------- b) ---------- c) ----------d) -------- ---------- e) ---------- f) ----------

20. Are you participating in any legume up scaling projects?(Yes) (No)

21. If not, would you be interested in participating? (Yes) (No)

22. Legume disease score sheet

Disease Name:_____

No. plants affected/Total No. of plants per 1M^2	part affected (root, stem, leaves, pods)	Distribution (whole field, spots)	Severity* 0,1, 2, 3

Disease Name:_____

No. plants affected per 1 M^2	part affected (root, stem, leaves, pods)	Distribution (whole field, spots)	Severity* 0, 1, 2, 3

Disease Name:_____

No. plants affected per 1 M^2	part affected (root, stem, leaves, pods)	Distribution (whole field, spots)	Severity* 0, 1, 2,3

Disease Name:_____

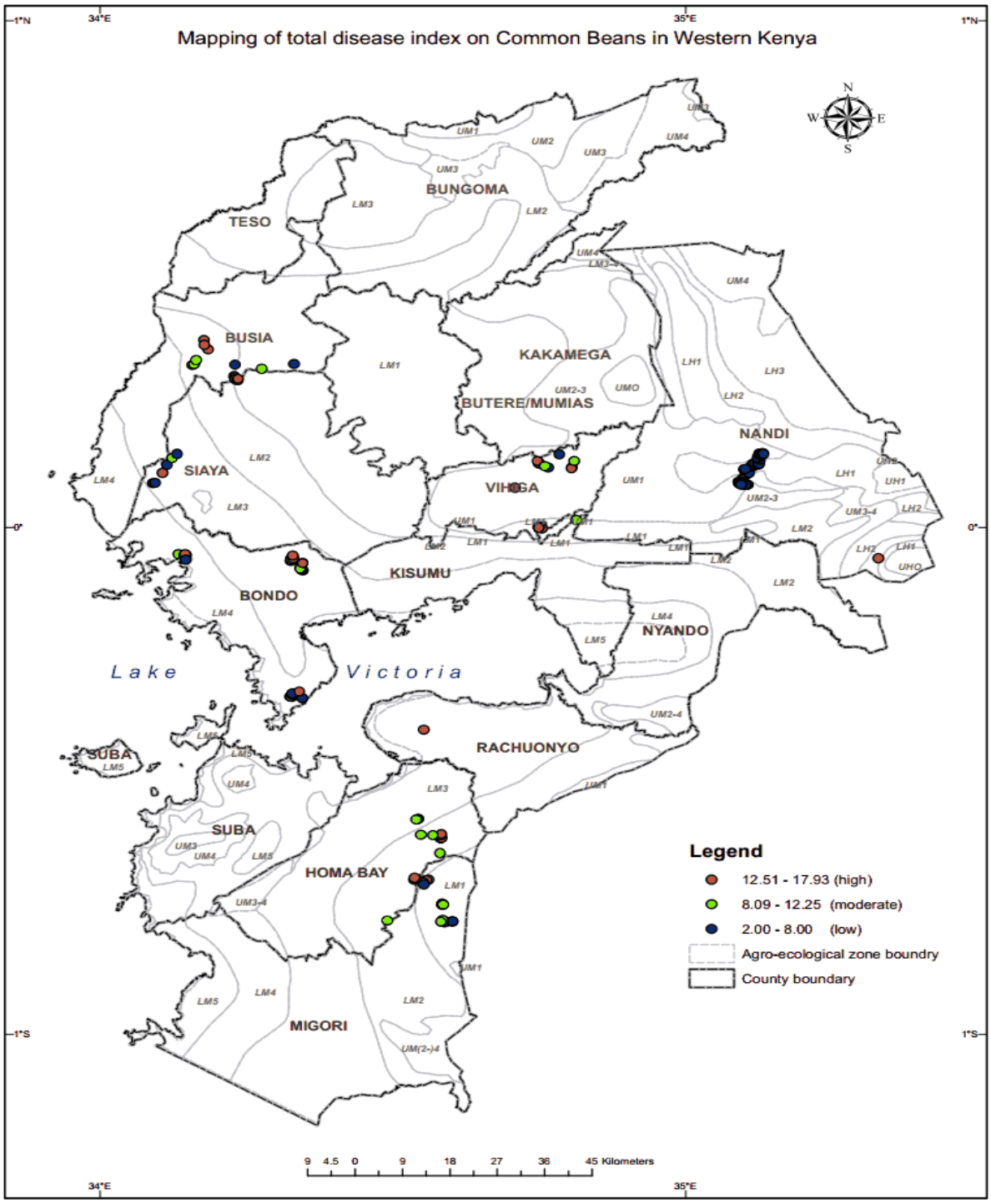
No. plants affected per 1 M^2	part affected (root, stem, leaves, pods)	Distribution (whole field, spots)	Severity 0, 1, 2,3

Severity: 0 = No disease; 1 = Mild 2 = Moderate 3 = Severe

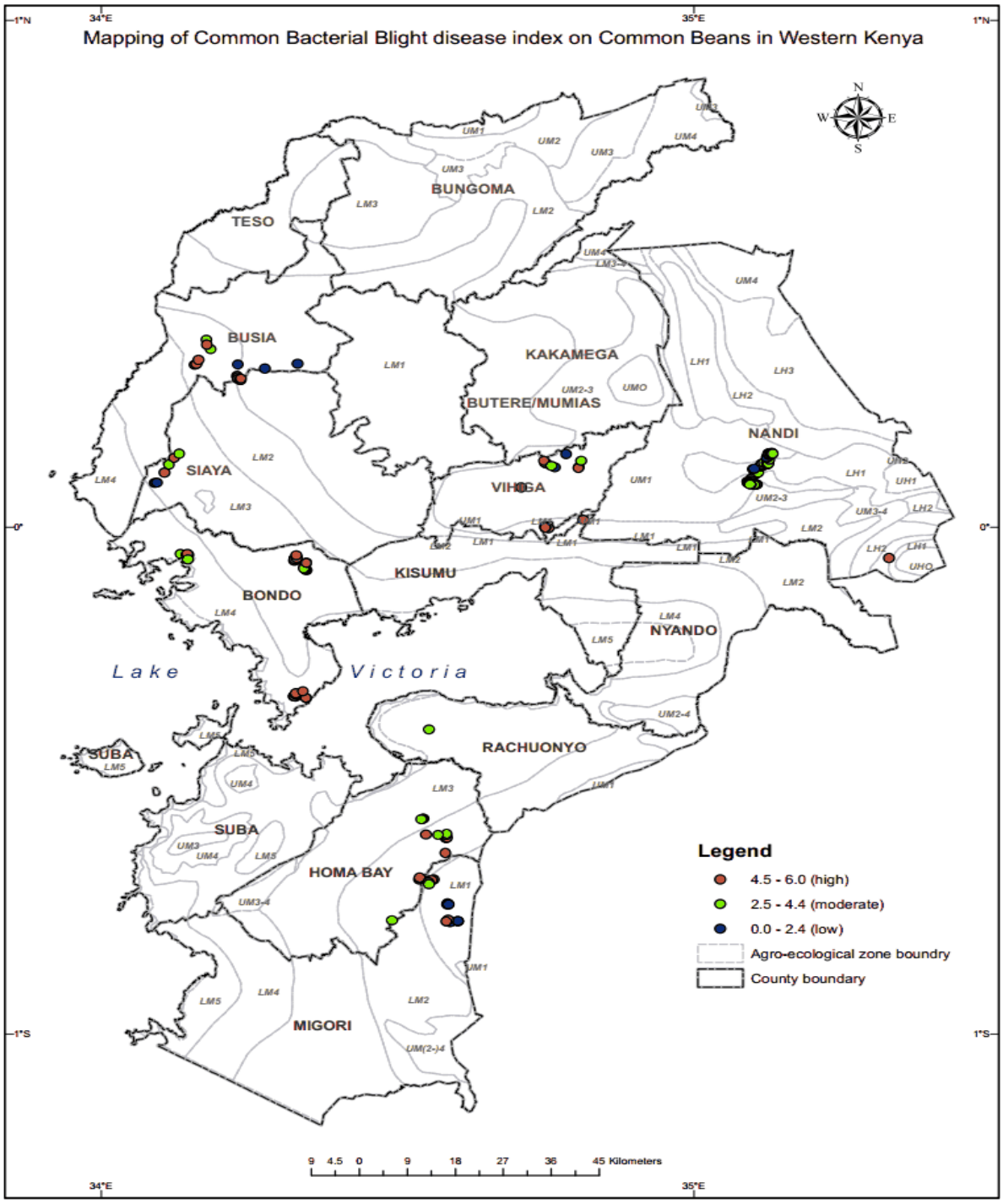
Thanks for your time and cooperation.

Appendix 2: Western Kenya region weather information during the short rains season of 2013.

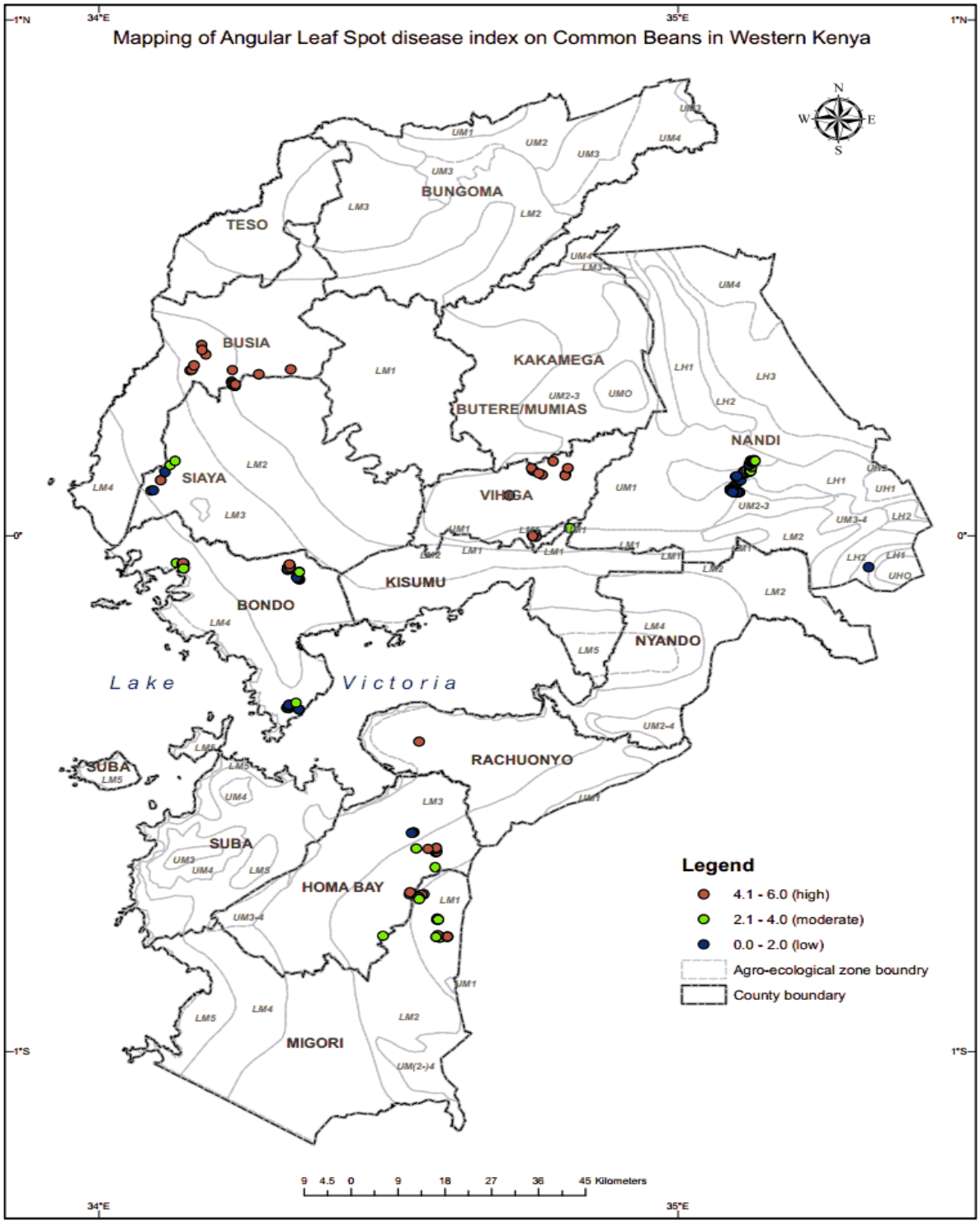
Region	Element	October	November	December
Busia	Precipitation total(mm)	192.1	157.6	90.8
Sabatia	Precipitation total(mm)	86.9	141.9	145.9
Homabay	Precipitation total(mm)	47.2	103.2	92.6
Bungoma	Precipitation total(mm)	173.6	186.5	21.5
Kakamega	Precipitation total(mm)	173.6	118.8	223.9
Kisumu	Precipitation total(mm)	110.4	102.1	143.4
Kakamega	Average max temp. (°C)	27.5	27.3	27.5
Kakamega	Average min temp. (°C)	14.7	14.8	14.5
Kisumu	Average max temp. (°C)	29.9	29.8	29.1
Kisumu	Average min temp. (°C)	18.1	18	18.1



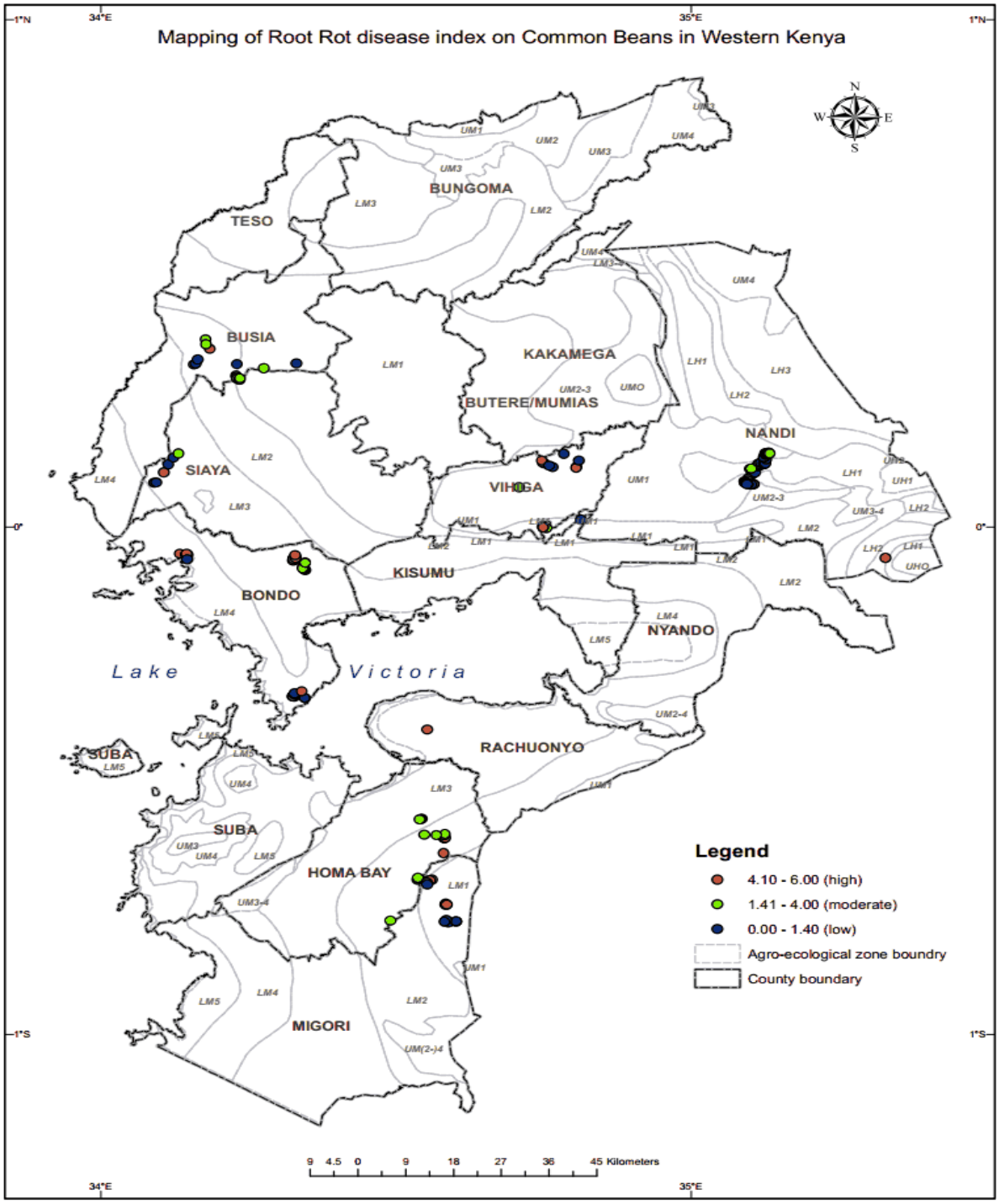
Appendix 3: Total disease intensity of the three major diseases (angular leaf spot, common bacterial blight and root rots) affecting common bean in different agro-ecological zones and regions in western Kenya during the short rain season of 2013.



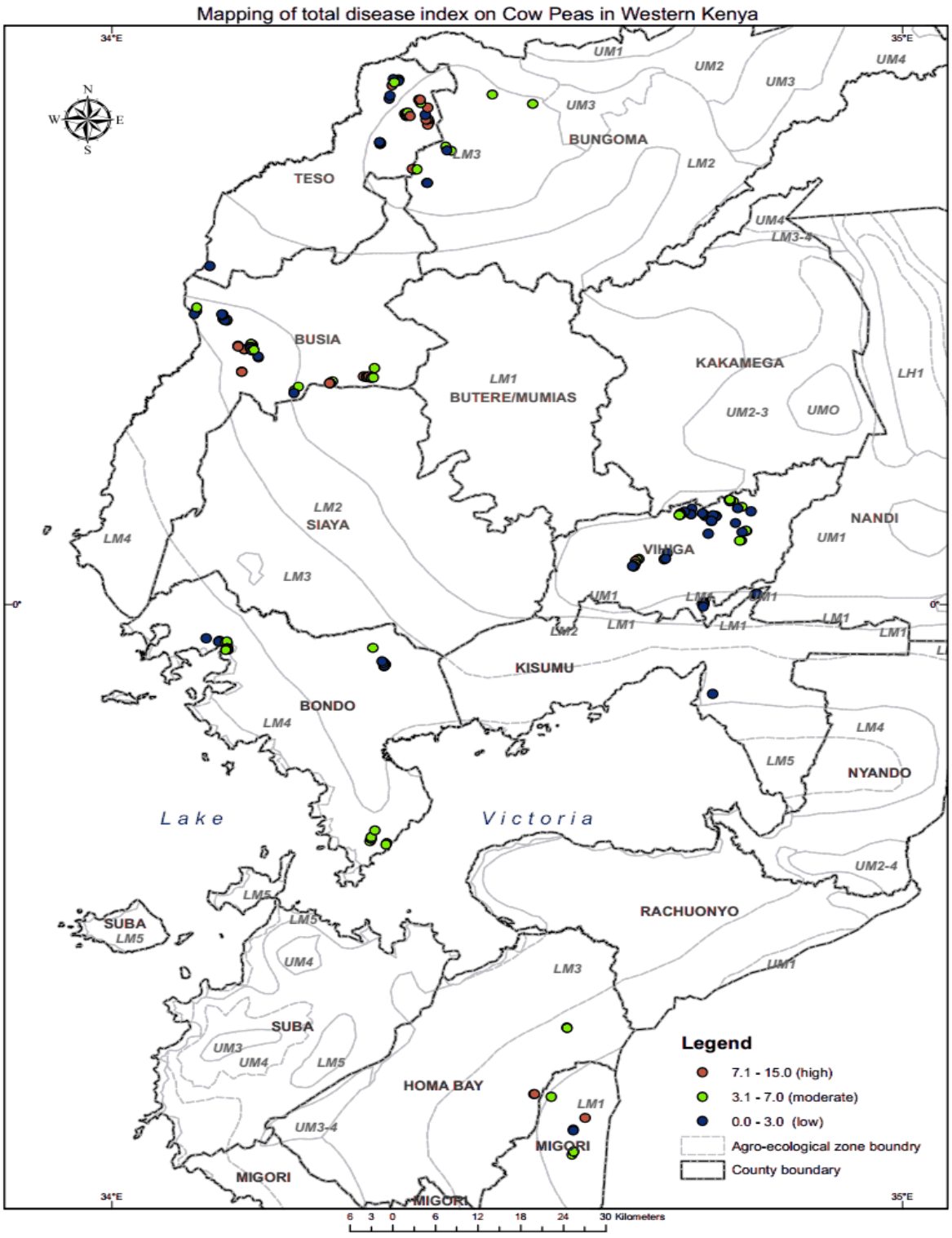
Appendix 4: Intensity of common bacterial blight of common bean in different agro-ecological zones and regions in western Kenya during the short rain season of 2013.



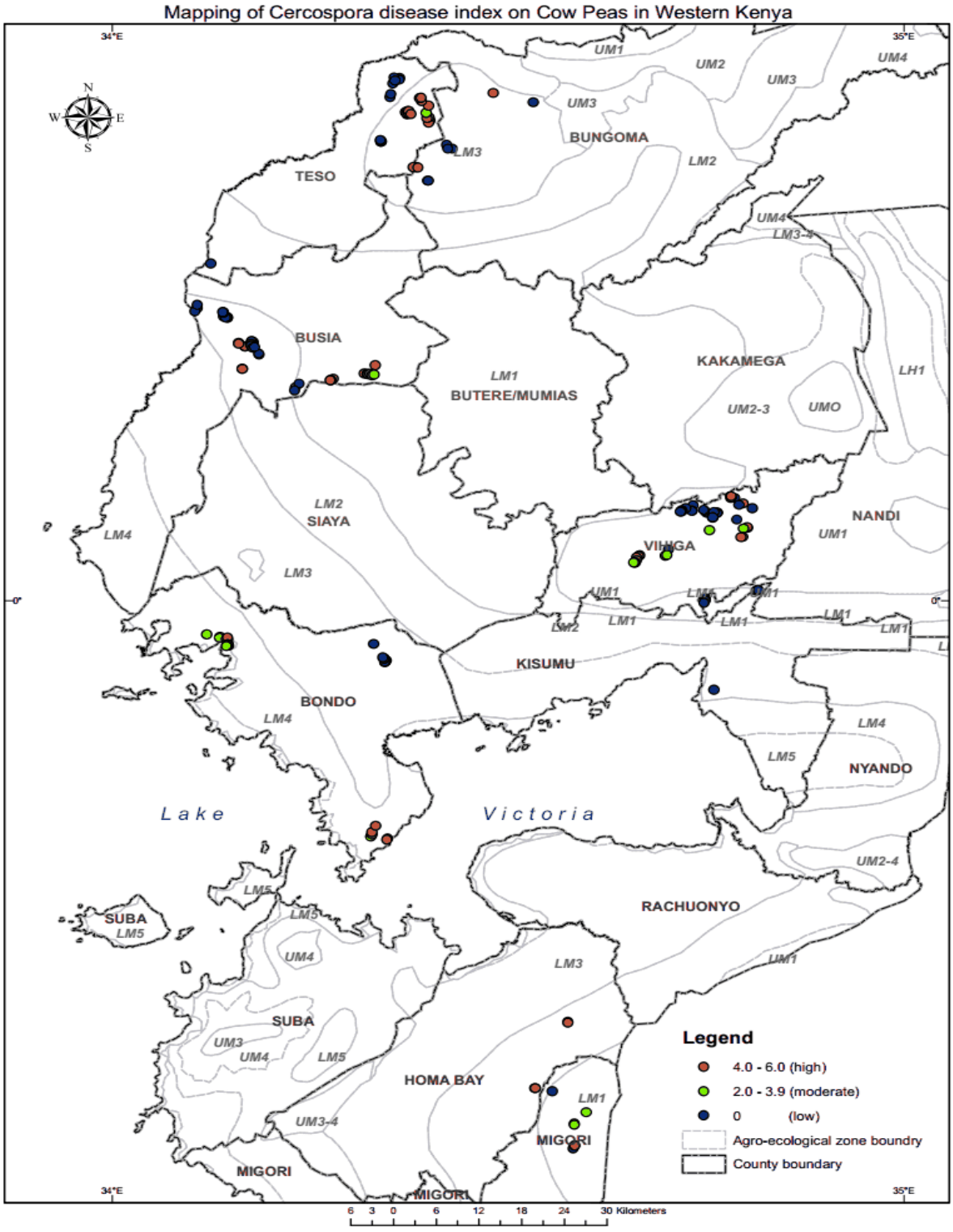
Appendix 5: Angular leaf spot disease intensity affecting common bean in different agro-ecological zones and regions in western Kenya during the short rain season of 2013.



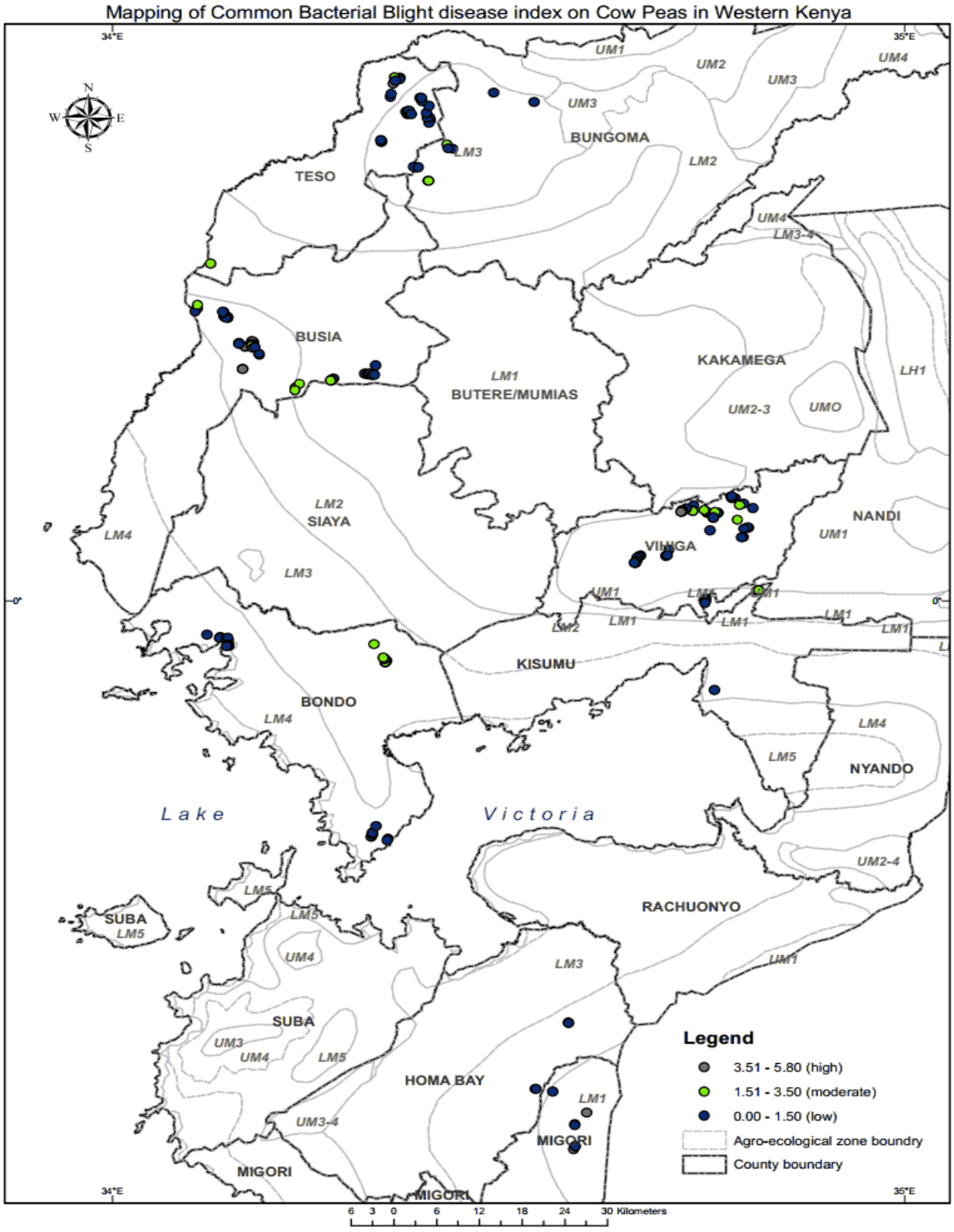
Appendix 6: Root rot disease intensity affecting common bean in different agro-ecological zones and regions in western Kenya during the short rain season of 2013.



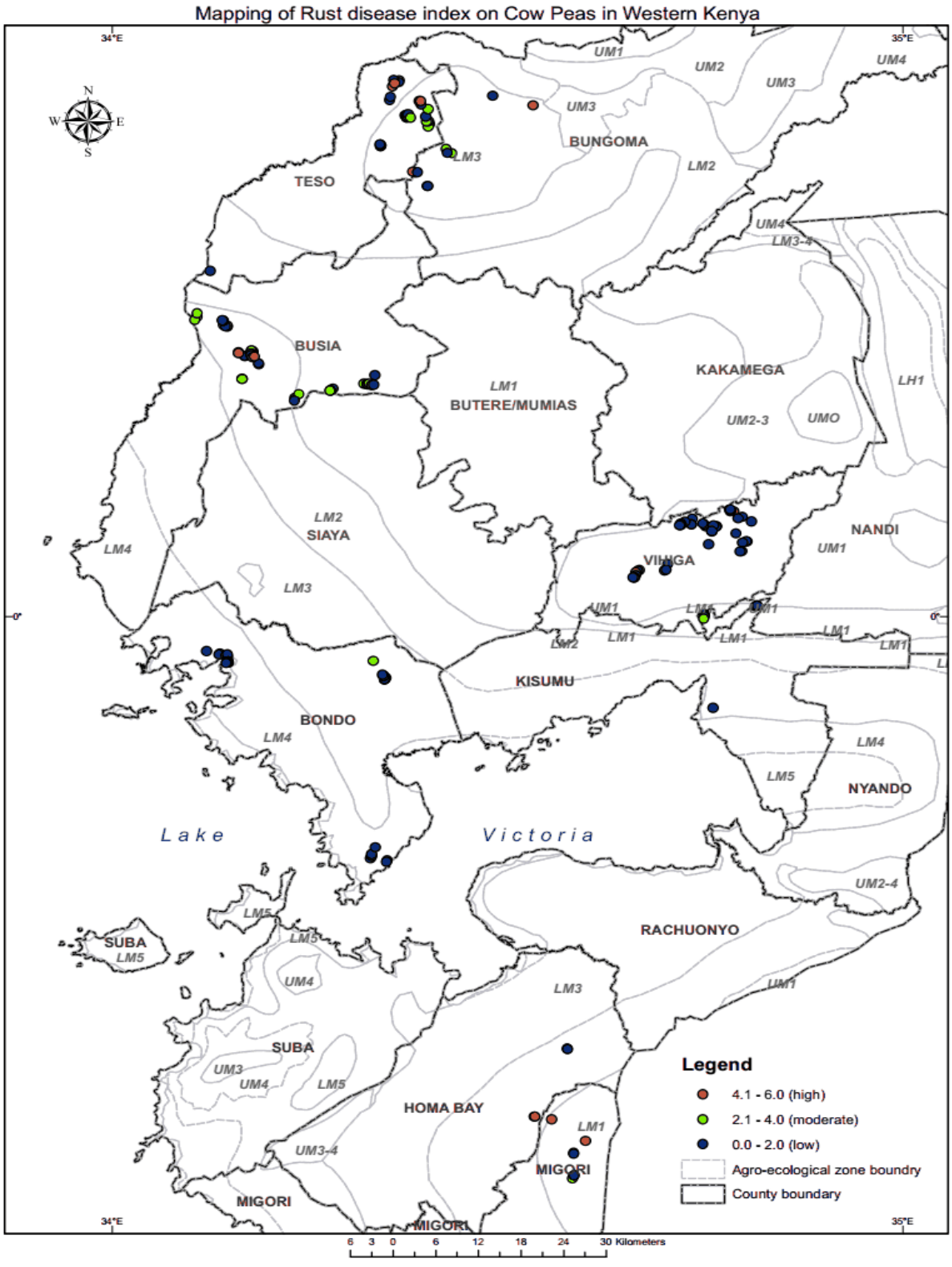
Appendix 7: Total disease intensity of the three major diseases (Cercospora leaf spot, common bacterial blight and leaf rust) affecting cow pea in different agro-ecological zones and regions in western Kenya during the short rain season of 2013



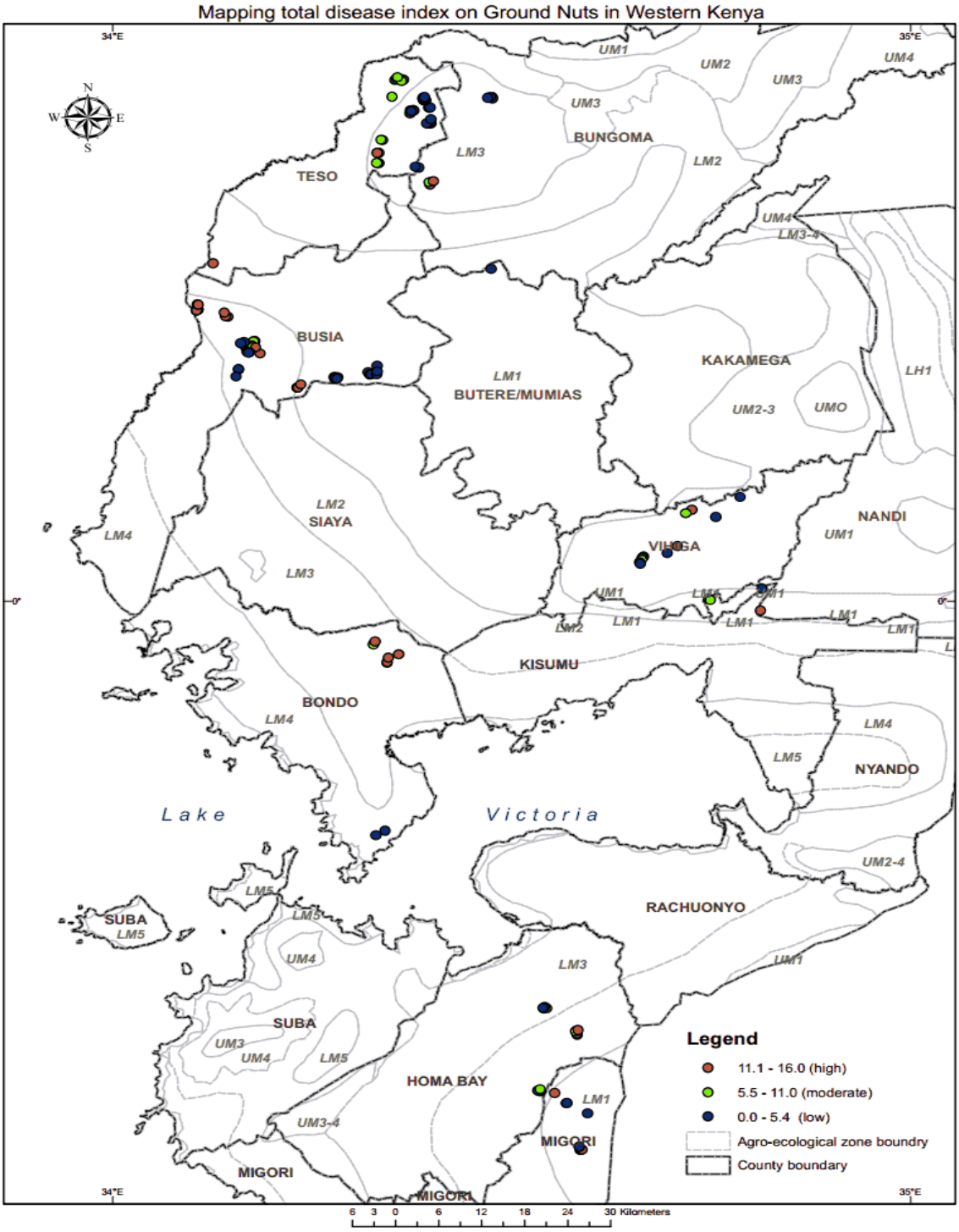
Appendix 8: Cercospora leaf spot disease intensity of cowpea in different agro-ecological zones and regions in western Kenya during the short rain season of 2013



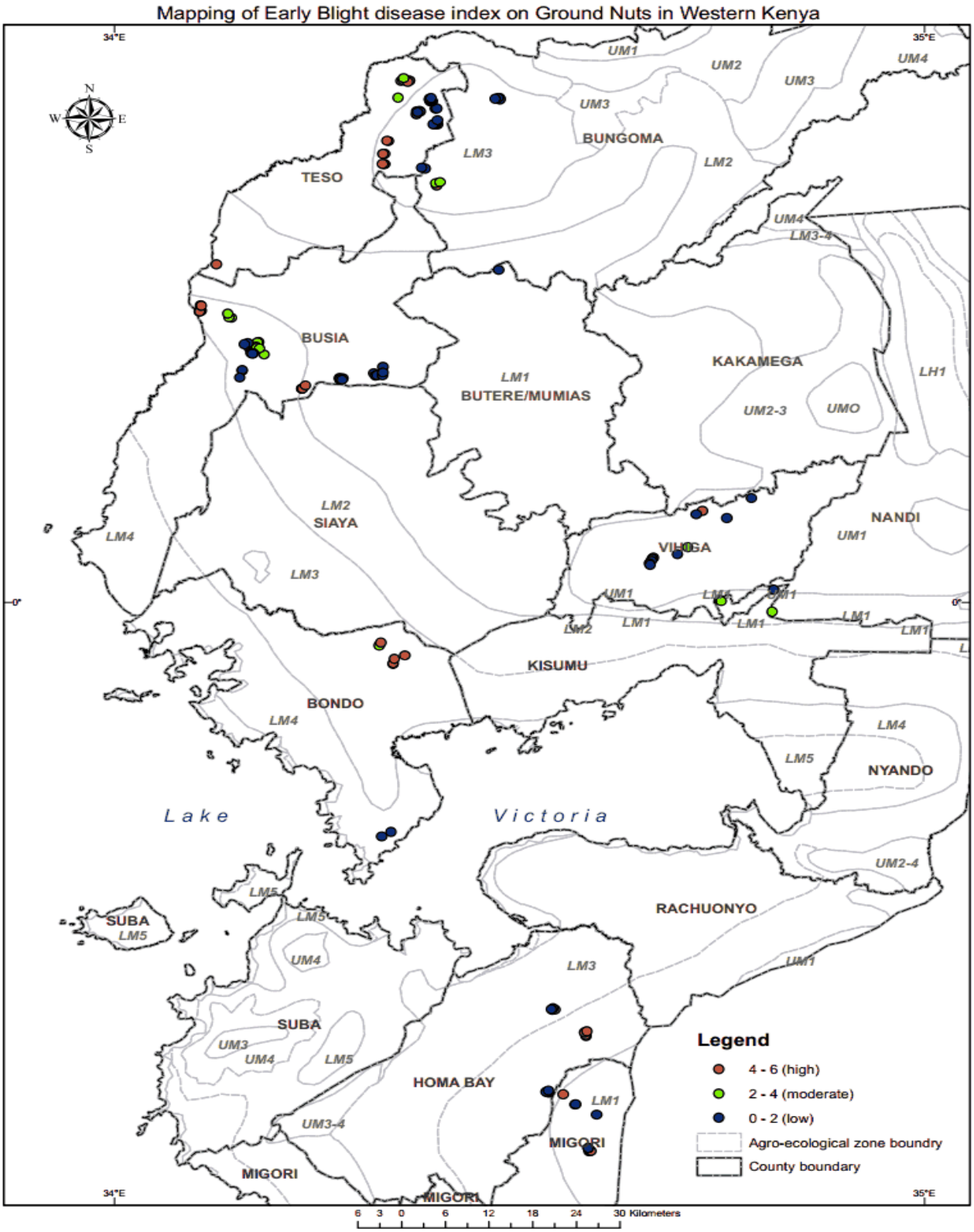
Appendix 9: Common bacterial blight disease intensity of cowpea in different agro-ecological zones and regions in western Kenya during the short rain season of 2013



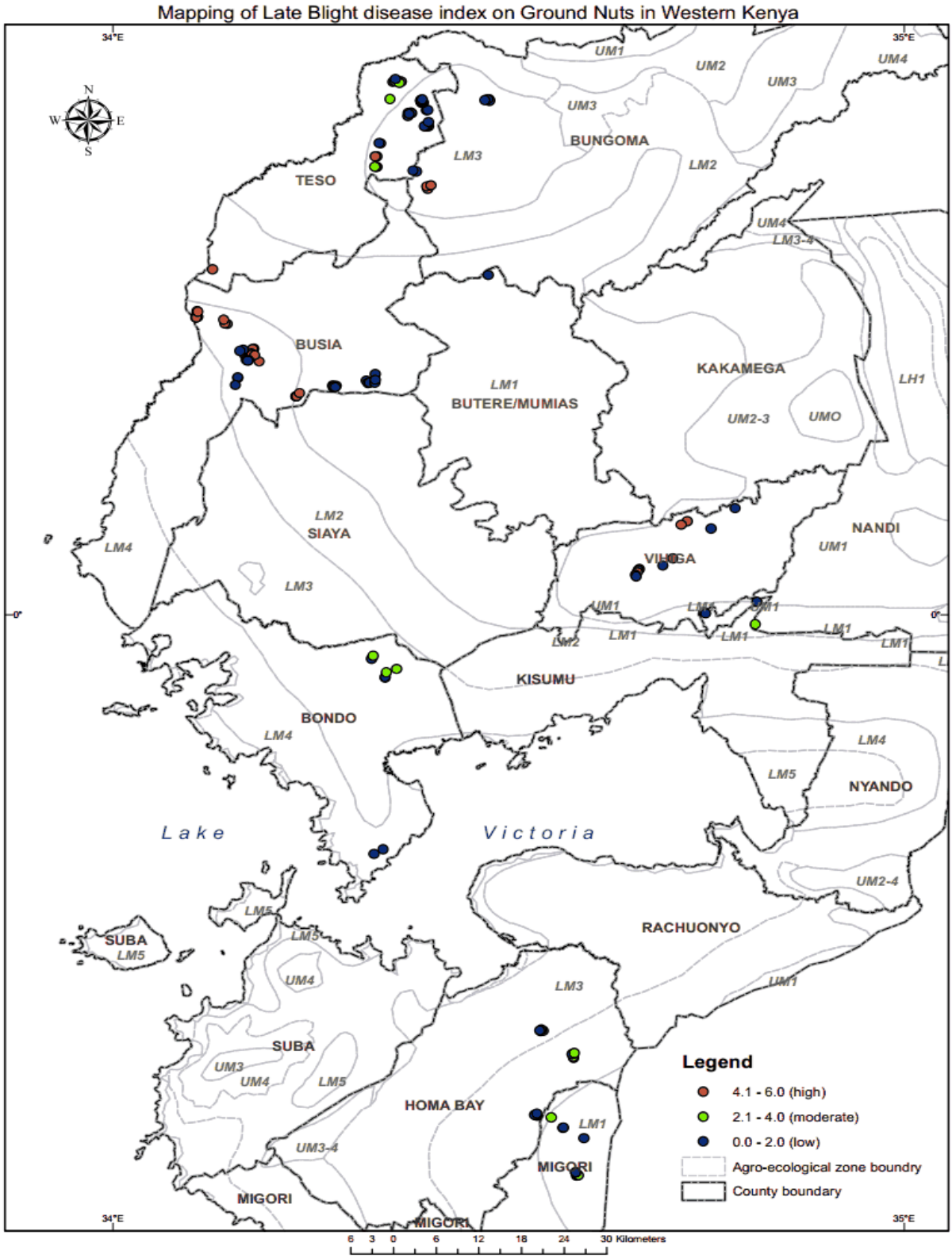
Appendix 10: Leaf rust disease intensity of cowpea in different agro-ecological zones and regions in western Kenya during the short rain season of 2013



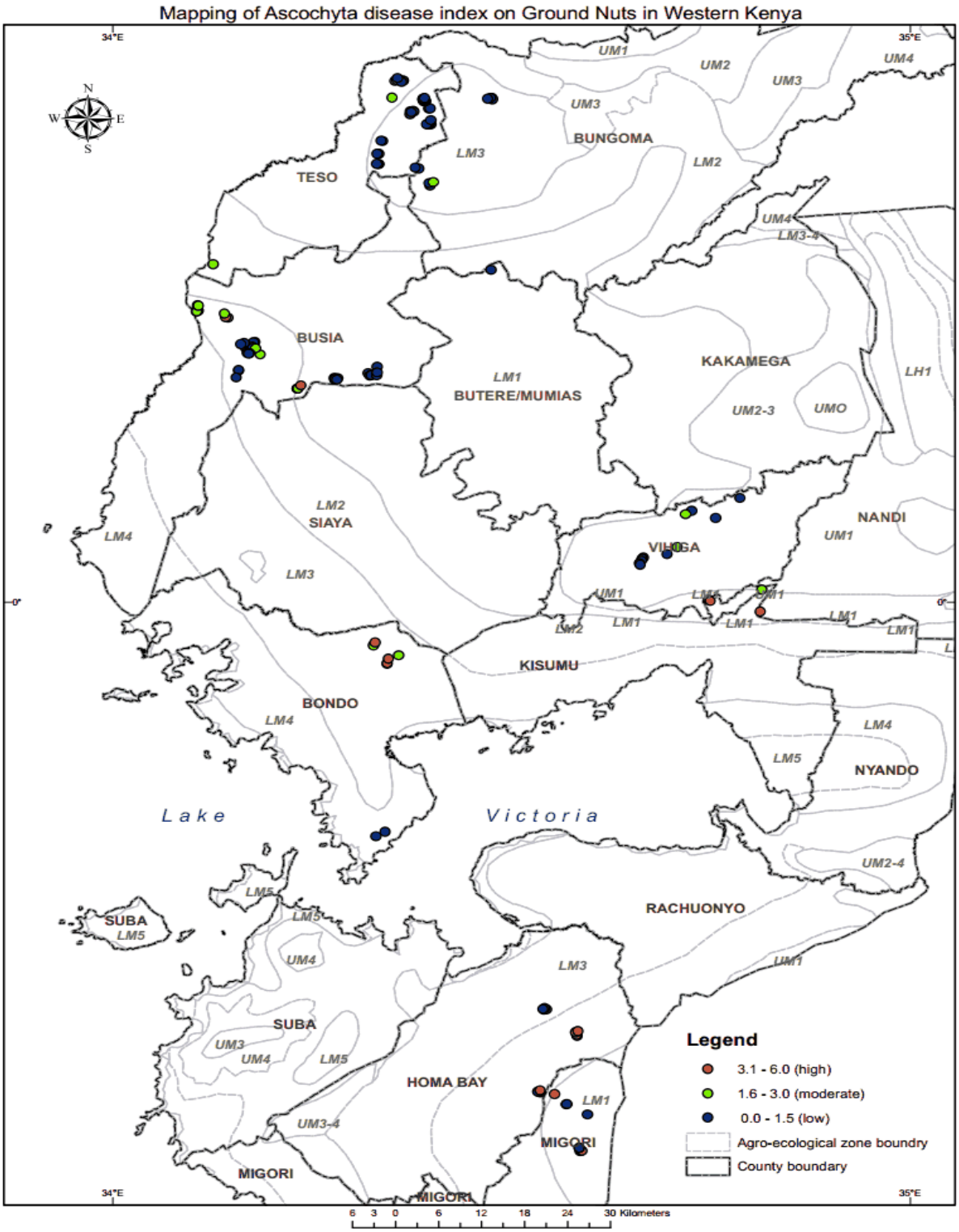
Appendix 11: Total disease intensity of the three major diseases (early leaf blight, late leaf blight and Ascochyta leaf spot) affecting groundnuts in different agro-ecological zones and regions in western Kenya during the short rain season of 2013



Appendix 12: Early leaf blight disease intensity of groundnuts in different agro-ecological zones and regions in western Kenya during the short rain season of 2013



Appendix 13: Late leaf blight disease intensity of groundnuts in different agro-ecological zones and regions in western Kenya during the short rain season of 2013



Appendix 14: Ascochyta leaf spot disease intensity of groundnuts in different agro-ecological zones and regions in western Kenya during the short rain season of 2013.