AFRICA UNIVERSITY

(A United Methodist-Related Institution)

EFFECTIVENESS OF THE NYANGA SEED POTATO QUARANTINE AREA FOR THE PRODUCTION OF AA GRADE POTATO (*Solanum tuberosum* L.) SEED IN ZIMBABWE

BY

TINEYI CHAKANYUKA

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF PHILOSOPHY IN CROP PRODUCTION IN THE FACULTY OF AGRICULTURE AND NATURAL RESOURCES

2016

ABSTRACT

In Zimbabwe, potato (*Solanum tuberosum* L.) is becoming a major staple food due to increasing uptake of products such as French fries and crisps. The availability of good quality seed has been a major challenge and potato farmers have resorted to farmer based seed systems where potato varieties listed in the official variety catalogue were becoming unpopular. Those varieties perceived to be popular were not on the official seed production program. Farmers were claiming that the quality of seed from the official seed program was affecting their yields. This, coupled with an increase in complaints received by the Seed Certifying Authority on the quality of potato seed necessitated this study to investigate the suitability of continued use of the designated Nyanga Seed Potato Quarantine Area (SPQA) for the production of foundation and AA grade seed. The study monitored the prevalence of scheduled pests and diseases of the SPQA and characterized existing planting material for purity and compliance to the statutory requirements. The objective was to derive policy implications on the continued use of the Nyanga SPQA as a seed potato quarantine designated production area.The study was comprised of a longitudinal survey, regular seed crop inspections in the SPQA and field trials at ART Farm in Harare and Divonia farm in Acturus, from January 2012 to December 2014. A total of 59 ha out of 876 ha registered for inspection and a total of 199.2mt of seed was rejected during 2012, 2013 and 2014 production seasons in the SPQA. The production systems found in the SPQA affected the quality of seed being produced in the area but the seed certification scheme was managing to control the quality of seed that enters into the seed market. The bacterium *Ralstonia solanacearum* was detected at five farms out of 22 farms and *Clavibacter michiganensis* subsp. *sepedonicum* was detected at one farm out of 22 farms. The detected diseases were concentrated on a portion of six neighbouring farms. This resulted in the recommendation for suspension of those farms from production of seed until research establishes total eradication of the diseases in the areas. Overall the study concludes that the SPQA is still functioning in the exclusion of diseases of quarantine importance.

Key Words: Nyanga Seed Potato Quarantine Area, scheduled pests of Nyanga SPQA, potato seed quality, AA grade seed.

DECLARATION

I declare that this dissertation is my original work except where the sources have been cited and acknowledged. The work has never been submitted, nor will it ever be submitted to another university for the award of a degree.

Student's Full Name	Student's Signature (Date)
Main Supervisor's Full Name	Main Supervisor's Signature (Date)

COPYRIGHT

ACKNOWLEDGEMENTS

I greatly appreciate the assistance and support I received from My supervisor Dr W. Manyangarirwa and my boss Dr C. Mujaju. I particularly value their unwavering and insightful guidance of my work that made me feel at home and removed any doubt that I would complete my study.

My heartfelt thanks also go to the following people and institutions: ART Farm manager Mr L. Mutemeri and staff, Pannar Seeds research staff and Divonia farm staff, SPQA farmers for cooperating during the survey, Tobacco Research Board, Crop Breeding Institute and Plant Protection Research Institute for helping me with facilities to conduct laboratory diagnosis of the insect pests and diseases.

Lastly I would like to thank my late husband, Joshua and my children, Adeline and Ordain for the support and encouragement that I received from them during pressure of work and study.

DEDICATION

The work is dedicated to my late husband, my father and my children.

LIST OF ACRONYMS AND ABBREVIATIONS

AMA	Agricultural Marketing Authority
ANOVA	Analysis of Variance
APHIS	Animal and Plant Health Inspection Services
ART farm	Agricultural Research Trust farm
CIP	International Potato Centre
DAP	Days after planting
DUS	Distinctiveness, Uniformity and Stability
GoZ	Government of Zimbabwe
SPQA	Seed Potato Quarantine Area
OECD	Organisation for Economic and Cooperation and Development
VCU	Value for Cultivation and Use

DEFINITION OF KEY TERMS

AA grade	Class of seed
The Certifying Authority	Seed Services
Seed Certifying Agencies	Seed Companies
Second Schedule	national variety catalogue

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER ONE

1.0 INTRODUCTION

The Irish potato (*Solanum tuberosum* L.) is an annual crop of the family Solanaceae, or nightshade family commonly grown for its starchy tuber. Potato is the world's most widely grown tuber crop, and the fourth largest crop in terms of starch sources (after rice, wheat, and maize) (Langer, 1975; Acquaah, 2011; Steyn, 2012). Potato originated in South America where it became part to the culture of the Andes, in which farmers grow many different varieties that have a remarkable diversity of colours and shapes. Potatoes spread to the rest of the world after European contact with the Americas in the late 1400s and early 1500s and have since become an important field crop worldwide (Langer, 1975; Acquaah, 2011, Steyn, 2012).

In Zimbabwe, potato is becoming very popular with its importance continuing to rise due to the ever increasing urbanisation and uptake of potato products such as French fries and crisps. In 2005, potato was declared a national food security crop with a national target of 30 000 hectares which translates to 60 000mt of the crop per year to meet the country's needs. Its consumption increased from 32 000mt in the year 2000 to 397 600mt in the year 2014 (AMA, 2014). The increase in consumption meant that it has a major position in terms of realised and possible contributions to food security, poverty eradication and economic development in the country consequently leading to growth in demand for both ware and seed potato. Currently it is the best paying crop in the country with a guaranteed market. Due to its high demand, there has been growing attraction to potato production. The area under potato production is steadily increasing from 2 000 ha in the year 2000 to 11

360ha in 2014 (AMA, 2014). Furthermore in Zimbabwe potato production is based on tubers for seed and the demand for seed tubers is also increasing.

Seed Potato (*Solanum tuberosum* L.) production in Zimbabwe is governed by three acts of parliament namely; the Plant Pests and Diseases Act (Chapter 18:08), Plant Breeders Rights Act (Chapter 18:16) and the Seeds Act (Chapter 19:13) with the relevant enabling regulations. The objective of these pieces of legislation is to ensure the production of quality seed varieties, protecting farmers against the risk of using poor quality seed and ensuring a continuous and a sustainable national potato production system.

1.1 Background to the Study

Potatoes were established in Zimbabwe by the early twentieth century. Variety trials started in 1911 in Zimbabwe with recorded yields of up to 6t/ha. The yields rose to around 15 t/ha in the late 70s (Joyce, 1988). In 1956, a breeding program was started at Inyanga Research Station. The program expanded and was responsible for the country's seed requirements (Joyce, 1984). Yields at Inyanga Research Station consistently exceeded 50 t/ha in the early 80s (Joyce, 1982a and 1984). Since the 1960s, only the national breeding program was authorized to import potatoes under rigid quarantine procedures only for breeding and evaluation purposes (Joyce, 1982b).

Zimbabwe's emphasis on breeding and seed production was largely based on the need to avoid the introduction of insect pests and pathogens through imported seed potatoes viewed to potentially threaten tobacco production, a very significant cash crop for the country (Joyce,1982a, 1982b, 1988). Since its inception, the breeding program has produced 400 potential varieties, 70 of which have been evaluated in variety trials, out of which more than 12 have so far been distributed to commercial producers (Joyce, 1988). In 1975 the International Potato Centre (CIP) began supplying true seed to the national breeding program (Joyce, 1982a). Joyce (1988) reports average yields of 15 t/ha, up from 6 t/ha in 1970, attributed primarily to the success of the national breeding program.

In 1955 the Rhodesia Seed Potato Association was established with the aim of producing virus free basic potato seed stocks on the highlands of the Eastern Districts for use in the major potato producing areas at lower altitudes (Hanssen, 1970). This association was mainly concerned with production and marketing of good quality potato seed. To strengthen the seed supply system, a seed potato quarantine area was established in 1975.

The introduction of the potato quarantine area was supported by the listing of some injurious organisms (pests and diseases) in the Plant Pest and Diseases Act, the act of pests as scheduled pests, the controlling of import and export of potato plant materials and compulsory certification of potato seed to ensure the production of high quality disease free potato seed in the country.

A farmer within this Quarantine area is not allowed to cultivate any potato plant other than for the production of foundation seed or AA grade seed potatoes or any other crop other than, *Eragrostis curvula* (Schrad) Nees, *Chloris gayana* Kunth, *Eucalyptus* spp. and *Pinus* spp. trees and *Prunus* sp, *Malus* sp. and *Acacia mearnsii* (black wattle). Where a farmer needs to introduce other crops, or use the same piece of land for seed production without rotating, authority must be sought from Plant

Protection Research and Seed Services Institutes respectively. Farmers are obliged to disinfect all equipment used and discouraged from borrowing such equipment from other farmers to ensure that all farm equipment used in seed potato fields do not transmit viruses, fungi and bacterial pathogens. Varieties that are listed in the National Second Schedule of the Seeds (Certification Scheme) Notice, 2000 are the only ones that are allowed to be multiplied as seed in this area. Potato breeders are the only ones who are allowed to import seed potato tubers (mother plants) into the quarantine area, but are required to subject them to virus screening before bulking into the seed potato quarantine area as specified in the Plant Pests and Diseases (Seed Potato Protection) Regulations, 1982.

1.2 Statement of the Problem

Potato production has been expanding in Zimbabwe for the past several years on both large scale commercial and small holder farms. Some of the farmers were relying on farmer based seed systems which was characterised by self-supply of seed and mostly the varieties were of uncertain origin, generally not certified at the same time, the number of complaints on the quality of potato seed were increasing. This has led to inconsistencies between the farmer based seed system and the official seed potato program. Potato varieties included in the official seed production program were becoming unpopular with some farmers, whilst those varieties perceived to be popular were not on the official seed production program. The farmers were claiming that the yields they were getting from the official varieties were no longer impressive due to the quality of seed they were getting.

1.3 Justification for the Study

In the year 2000, the Government of Zimbabwe (GoZ), introduced the land reform programme throughout the country with the aim of equitably distributing land (correcting the historical land ownership imbalances) to the majority of the disenfranchised population. This programme included land redistribution in the seed potato quarantine area. However, the new farmers in this area were not made aware of the production rules and regulations that bound this area. Because seed potato is a high input crop and they could not afford the requirements, they started producing crops such as maize, table potato, cabbages and other crops that are not allowed to be grown in the area without seeking authority from the relevant authorities. Also proper insect pest and disease control regimes, and crop rotations were not adhered to. Farming equipment was being exchanged from one farmer to another without proper disinfection of the equipment. Some of the seasoned farmers took advantage of the confusion to illegally import potato seed and mini tubers from unknown sources into the area without subjecting them to virus screening.

Because of the economic hardships experienced between 2000 and 2010, Seed Services (the Certifying Authority) and Plant Quarantine Institutes were unable to monitor the area as frequently as they should, thus instead of two field inspections per seed crop cycle, only one inspection was conducted (Nyamutukwa, 2010). After harvesting, seed sold at farm gate in the SPQA is supposed to be inspected and certified before selling it to other farmers. However, during this time seed sold at farm gate was not being inspected at all thus risking contaminating clean farms with seed borne or soil borne diseases.

The seed potato quarantine area requires full participation by the responsible institutes and farmers in that area. Non-compliance by even one farmer creates opportunities for pathogen build up in the area. Consequently, the reasons for developing and implementing phytosanitary policies include the desire to prevent pathogens being introduced (entering and establishing in an area), the protection of local and export markets, and the lack of effective control measures on diseases that are of economic importance.

A quarantine status is assigned to diseases that are not yet present or present but not yet established in the region and can potentially cause serious economic damage in this region (IPPC, 1999). The emergence of a quarantine disease in a country involves the imposition of a national control policy which aims at eradication of the disease and prevention of new introductions (Breukers *et al*., 2006). It is thus justifiable to carry out the study to establish if the seed potato quarantine area is still free from those diseases and to come up with recommendations where necessary on corrective measures for the production of quality disease free seed. Such recommendations will restore farmer confidence on certified seed produced in the Nyanga seed potato quarantine area. The study will also provide valuable data upon which the decision for recirculation of potato seed stocks can be based.

1.4 Main objective of the Study

To evaluate the suitability of Nyanga Quarantine designated area for the production of ***AA*** grade seed potato in Zimbabwe.

1.5 Specific objectives of the Study

I. To determine current seed production systems in the Nyanga seed potato quarantine area in relation to the national potato seed certification scheme.

II. To evaluate the prevalence of pest and diseases in relation to quarantine regulations.

III. To characterize existing planting material for purity and compliance to the statutory requirements.

IV. To analyze the policy implications of continued use of the Nyanga area as a suitable site for potato seed quarantine.

1.6 Hypotheses

I. Current seed production systems in the Nyanga seed potato quarantine area do not have negative implications on seed quality.

II. Insect Pests and diseases of potato in the SPQA do not exceed quarantine regulations thresholds.

III. The existing planting materials are not compliant to purity and statutory standards.

IV. The continued use of Nyanga seed potato quarantine designated area does not have negative policy implication on seed being produced in the area.

1.7 Delimitation of the Study

The study excluded participation of farms that were identified with the diseases of quarantine importance in the SPQA as source of seed into the field trials study since they had the potential of introducing the diseases into the research sites that were used for the field trials. This compromised the selection of a true representative for the categorised farmers to compare competency of farmers in the production of quality seed as those found with diseases of quarantine importance were excluded from the purity and statutory compliance trials.

1.8 Limitation of the Study

The study could not establish fully the literature on the intensity of the occurrence and damage caused by bacterial wilt disease (*Ralstonia solanaceaerum*) and bacterial ring rot (*Clavibacter michiganensis* subsp. *sepedonicum*) diseases of quarantine importance with reference to Zimbabwe as there is limited literature that gives the extent of their damage. There is a conception that admitting their presence politically affects trans-boundary trade relations of the country.

CHAPTER TWO

2.0 REVIEW OF RELATED LITERATURE

2.1 Quarantine status

The enforcement of a quarantine disease in a country involves the imposition of a national control policy which aims at eradication of the disease and prevention of new introductions (Breukers *et al.,* 2006). In countries that are free from the disease, quarantines can help prevent their introduction whilst countries where their occurrence is localised, quarantines can prevent further spread. For example, quarantines that were imposed after the initial discovery of *Globodera rostochiensis* on Long Island delayed the spread of the nematode to the mainland (Evans and Stone, 1977). Quarantine pests and diseases comprise a distinct class of plant diseases (Heesterbeek and Zadoks, 1987).

2.2 Establishment of a Seed Potato Quarantine Area in Zimbabwe

The Seed Potato Quarantine Area (SPQA) was established in Inyanga for the production and multiplication of virus tested foundation seed and AA grade seed (Joyce, 1982b). The establishment was done in order to ensure the production of high quality, disease and pest free seed potato, at the same time avoiding the loss of vigour during seed multiplication. It is located at 2000m above sea level (altitude) with the trigonometry points specified in the Plant Pests and Diseases [Seed Potato Protection] Regulations 1982 amendments. At that time, the mean daily maximum temperatures ranged from 16^0C in July to 22.6^0C in October and an average annual precipitation of 1120mm (Joyce, 1982b). The high winds and heavy rainfall at this high elevation made the area free from aphid especially the *Myzus persicae,* the main viral vector, because these climatic conditions were not conducive for its survival and spread. Rules and regulations were formulated to ensure that the potato quarantine area is kept clean from diseases. The seed potato quarantine area is required to be completely free of other solanaceous plants, and contract farmers are restricted from growing even a small crop of ware potatoes for home consumption (Plant Pests and Diseases [Seed Potato Protection] Regulations, 1982). The seed crop was inspected throughout the growing season and off-type plants are rogued out (Joyce, 1982b).

Generally in this area one crop was produced each year with planting occurring after the onset of the spring rains which usually occurs in mid November, but at times it occurs as early as September and as late as mid- December (Joyce, 1982b). Harvesting took place from March to July, cool temperatures and lack of rainfall permitting extended harvest. The cool temperatures, dry soils and isolation from viruses made it possible for harvest of AA grade seed to be spread out from March to July without seed quality deterioration (Joyce, 1984).

2.3 Seed Potato Production in Zimbabwe

Seed Potato Production in Zimbabwe is governed by three acts namely; Plant Pests and Diseases Act (Chapter 18:08), Plant Breeders Rights Act (Chapter 18:16) and the Seeds Act (Chapter 19:13) with the relevant enabling Seed Certification Scheme Notice, 2000. The main objective of these pieces of legislation is to ensure the use of quality seed varieties with proven performance thus protecting farmers against the risk of using poor quality seed and ensure a continuous and sustainable national potato production system.

According to the Seeds Act (Chapter 18:16), seed production has to be done under a registered Seed Certifying Agency. For a variety to be marketed in Zimbabwe, it should have undergone and passed the Distinctiveness, Uniformity and Stability (DUS) test, Value for Cultivation and Use (VCU) test and be registered in the Second Schedule (national variety catalogue) of the Seeds (Certification Scheme) Notice, 2000. Only thereafter can the variety be multiplied and marketed as seed in the country. The seed multiplication process should adhere to the Zimbabwean Seeds (Certification Scheme) Notice of 2000 or the Organisation for Economic and Cooperation and Development (OECD) seed schemes for varietal certification and this is mainly important for seed intended for international trade. The seed should be highly traceable to the source.

Seed potato production in Zimbabwe is centred on the use of tubers on a limited generation system, Seeds (Certification Scheme) Notice, 2000, which means that seed passing inspections, must advance to a lower class with each generation of production.

The modelled seed potato chain in Zimbabwe (Figure 1) starts with the production of elite parental material and breeder's seed of a released variety at Nyanga Experiment Station which is monitored by the government national breeding programme. After testing, the virus-free seed tubers are distributed to certifying agents for distribution to their certified contract farmers in the potato quarantine area (Eastern highlands) who bulk the seed five times to produce **AA3** grade seed. The **AA3** seed is then distributed to farmers outside the seed potato quarantine area, who bulk it to produce **A** grade seed (Joyce, 1982b). The **A** grade seed is then bulked for at most 3 generations into certified seed which will be grown as commercial crops for consumption and processing. A seed crop for each generation cannot be maintained at a specific class or move to a higher class but moves to a lower grade.

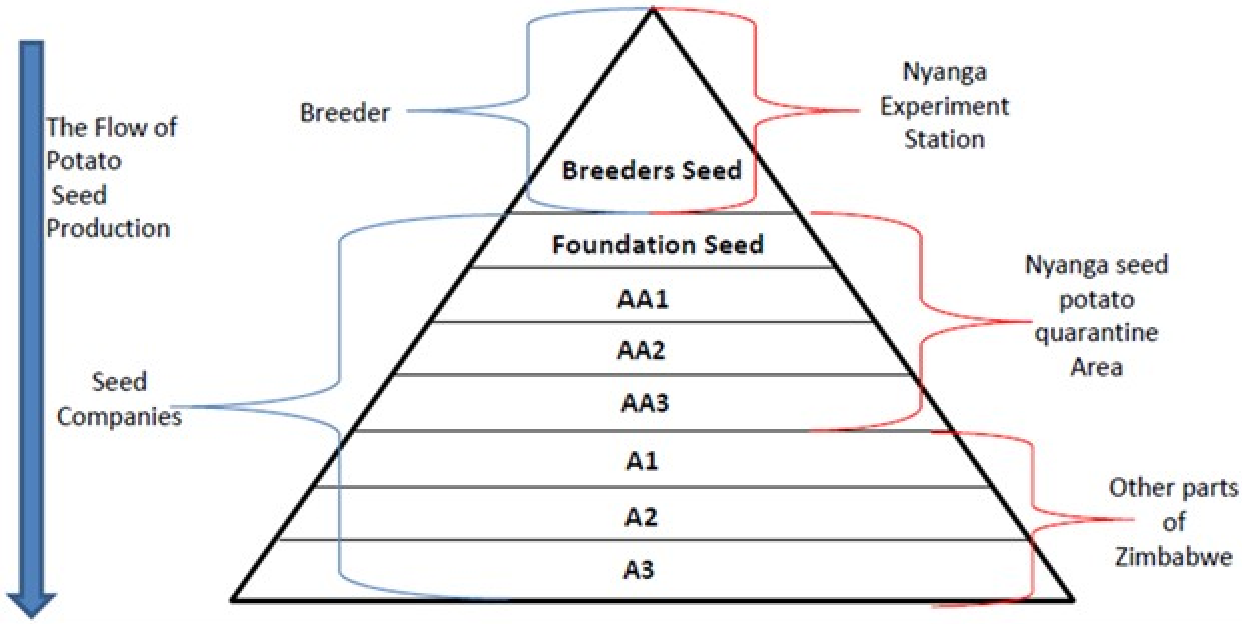


Figure 1. Classes of potato seed produced in Zimbabwe (Source: Chakanyuka, T.)

The Seeds Act regulates the production and registration of all seed in the country and is enforced by Seed Services Institute. Under this act the Seed Potato Regulations and the Seeds (Certification Scheme) Notice, 2000 were enacted as the Seeds Act's enabling regulations for potato seed production. The Seed (Certification Scheme) Notice specifies the field crop standards and tuber standards for seed potatoes. Seed Services Institute registers seed crops and certifies all seed grown for adherence to the production standards. The seed crop registrations are done through registered certifying agencies. The certifying agencies through their company seed inspectors are responsible for monitoring all seed production activities by the farmer at the same time ensuring compliance to the set standards in the Seeds (Certification

Scheme) Notice of 2000. The certifying agency inspector is also responsible for ensuring that their seed is certified at the appropriate stages and time.

2.4 Seed Certification

Seed is one of the most important factors that determine the productivity of the potato crop. By using high quality seed, of the right variety at the optimum planting time, backed by the latest package of technology, farmers could attain the potential yield of a crop (Hussain and Faroq 1995). Certified seed ensures the maintenance and production of a healthy crop. Seed certification therefore helps to reduce the tuber-borne inoculum and also ensures the quality of seed stocks of the desired variety (Wangai and Lelgut, 2001).

According to Daniels (2000), the quality of seed potatoes is crucial in achieving satisfactory productivity, and thus cultivation, harvesting and storage must be conducted under rigorous conditions in order to prevent infection by viruses, bacteria fungi and other pests. For this reason, good quality seed potatoes can only be guaranteed through regular seed certification inspections during all stages of production to ensure minimal levels of infection (Ricardo *et. al.,* 2009)

Certification in Zimbabwe starts with the registration of growers. All seed potato growers have to be registered with the Seed Services Institute through their associations or companies that are gazetted as certifying agencies for seed potatoes production. The certifying agency seed inspector must supply the cropping history of the proposed field and the seed source at the time of registering a prospective seed grower. The grower must attest to the absence of bacterial wilt, state the variety and hectares to be grown. The potato seed certification requirements are stated in the

Seeds (Certification Scheme) Notice, 2000. According to the Seeds (Certification Scheme) Notice 2000, no seed shall be certified as Zimbabwean seed and Zimbabwean foundation seed unless the requirements of the Scheme in respect of seed of the kind and variety have been complied with. The seed conforms to the requirements of the Scheme in respect of the kind and variety concerned and the seed has been produced by a registered grower.

The Zimbabwean certified seed potato production system is based on a generational system, whereby a very small quantity of nucleus of a variety is bulked up to commercial quantities over 6 to 7 generations. The quality standards are very high in the early generations, and are gradually relaxed as the stock proceeds through the generations and are bulked up. It is important to have the seed crop inspected at all the stages recommended in the Seed Certification Scheme Notice (2000).

2.5 Seed Potato quality

Seed quality is an important determinant for the quality and quantity of tuber yield in potato production (Struik and Wiersema, 1999; Acquaah, 2011). According to Morrenhof (1998), in order to grow a successful ware potato crop, there are many conditions that must be met. Conditions such as weather, soil conditions and occurrence of diseases cannot or can only be controlled by the farmer to a limited extend. Although a successful ware crop production depends greatly on the farmer's skills, thus how well he will be able to deal with the above conditions and be able to make the right decision at the right time, another factor that has a great impact and which seems easy to control is the quality of seed planted (Morrenhof, 1998). The initial process of potato production should involve the use of pathogen free seed potato tubers (Filgueira, 2003; Nortje, 2012). The use of pathogen free seed potato tubers gives the crop a good start whereas the negative effect of using seed of poor quality is difficult or impossible to correct later in the season (Sahajdak A, 2003). A yield difference of between 20 to 50% can be attributed to the difference between using inferior quality seed and good quality seed (Morrenhof, 1998). Sometimes good quality seed is not readily recognisable and farmers have to rely on the guarantee provided by the certification system in existence.

Seed certification is the process of assuring the quality of seed potatoes being marketed according to nationally regulated standards (Thiart, 2012; UNECE, 2014). The standard sets out minimum requirements for certifying high quality seed potatoes and it covers varietal identity and purity, genealogy and traceability, seed health status, physical defects and the size of tubers.

Varietal purity is an important requirement for quality seed lots. Admixtures of other varieties result in varying requirements with respect to production practices like fertiliser requirements, moisture requirements and harvest time. If not sorted out after harvest, they will also affect the marketing and price. Consumers prefer to buy products which not only look uniform, but which also have uniformity with regards to cooking quality, good taste and characteristic possibilities for a good shelf life (Morrenhof, 1998).

Potatoes are susceptible to many insect pests and diseases. Some diseases are soil-borne, but many are transmitted through seed (NIVAP, 2005). The importance of the health status of the seed is that they affect the growing capacity and subsequently the yield of the potato crop. Insect pests and diseases also affect potato germination, sprout growth and crop development (Morrenhof, 1998).

According to Morrenhf (1998), cuts, bruises, skin abrasions, sun and frost injury negatively affect the suitability for storage due to direct physical and physiological effects by making the tubers vulnerable to bacterial rotting, easily accessible to fungal diseases and insect pests. At planting the damage increases the risk of unsuccessful germination and growth of the crop.

2.6 Zimbabwean statutory requirements for potato seed in the field

Land intended for the production of potato shall be free from any other solanaceous plants. There shall be a minimum interval of three harvest season between the seed crop and any previous crop of the same species unless in particular case permission has been obtained from Seed Certifying Authority for a lesser interval (Seed Certification Scheme Notice, 2000).

The Seeds (Certification Scheme) Notice 2000 stipulates that a potato seed crop should be grown with the following requirements on isolation and pest tolerance: a) A class of seed shall be grown at least 100m away from any other class of seed or crop grown for uncertified purpose, b) if different varieties, in the same seed class are grown, a minimum distance of 2 m or 2 ridges shall be maintained between each variety. Seed crop shall not contain: i) more than 0.5% of any other variety or distinguishable off-type, ii) more than 0.25% leaf roll, severe mosaic viruses, iii)2% visible mild mosaic virus, iv) more than 0.01% bacterial wilts at 1st inspection or any at the second inspection, v) more than 0.01% leaf roll or severe mosaic viruses, vi) more than 0.01% mild mosaic viruses.

2.7 Potato Seed quality requirements for tubers

The maximum permitted percentage tolerance for diseases, pests and faulty tubers recommended in Seed potato are as follows; 1) not more than 1.00% of tubers infested with live tuber moth 2) not more than 2% severe tuber moth damage 3) *nil* bacterial wilt infested 4) not more than 2% severe black scurf 5) *nil* root knot nematode infestation, 6) severely mechanically damaged (more than ¼ of the eyes or more than 2 tubers), 7) not more than 0.5% late blight, 8) not more than 1% spindle tubers and not more than 0.5% distinguishable off-types.

The Zimbabwean regulations require that all crops intended for seed production should meet the stipulated requirements in the Seed Certification Scheme Notice, (2000) and therefore should be inspected for certification at the stipulated time and intervals. In respect to potato seed production, in the case of foundation seed, at least three inspections of the crop shall be carried out before senescence shows in foliage. In respect to tubers, one or more inspections shall be carried out, but this should be done 14 days after the crop has been lifted from the ground, (Seed Certification Scheme Notice, 2000). In addition tuber inspections of the seed crop shall take place at a 21 day interval if the seed crop remains unsold.

2.8 The Plant Pests and Disease Act [Chapter 19:08]

The Act was enacted to safeguard the introduction and spread of insect pests and diseases in Zimbabwe and from other countries. The enforcement of the Act is done by the Plant Protection and Plant Quarantine Institutes. Under this Act, the Plant Pests and Diseases [Seed Potato Protection] Regulations, were enacted in order to ensure the production of high quality, disease and pest free seed potato and avoid the loss of vigour on multiplication. The establishment of the quarantine area, listing pests as scheduled pests and the controlling of import and export of potato plant materials, are the requirements of this act.

2.8.1 Plant Pests and Diseases (Seed Potato Protection) Regulations, 1982

Section 3 of the regulations stipulated under Statutory Instrument 679 of 1982 as amended states that an owner or occupier of land within an area specified in the Schedule shall not cultivate any- potato plant other than for the production of foundation seed or AA grade seed potatoes, or any other crop other than *Eragrostis curvul*a (Schard.) Nees and *Chloris gayana* Kunth.

2.8.2 Scheduled Pests

Some injurious pests and diseases are listed in the Plant Pests and Diseases Act and these are referred to as Scheduled Pests and are generally known as pests of quarantine importance. Areas found to have these pests are by the order of the Minister of Agriculture quarantined and the movement of plants, manure, growing media, compost and any other material to and from the infested area is prohibited, restricted or regulated. Scheduled pests for potato are: Bacterial wilt (*Ralstonia solanacearum*), Potato bacterial ring rot (*Clavibacter michiganensis* subsp. *sepedonicum*), Potato wart disease (*Synchytrium endobioticum*) and Cyst nematode (*Globodera* sp.).

These pests have so far not been reported in the Nyanga SPQA. However, bacterial wilt (*Ralstonia solanacearum*) occurs in the surrounding areas outside the Quarantine area. When such pests are observed or are for some reason believed to be present in some area, it should be reported to the Inspector or Plant Protection office in the earliest time possible. In order to safeguard their introduction into the quarantine area, no vegetative plant material nor compost, soil, or other growth media is allowed to be taken into the quarantine area. Seed potato of any class is not to be grown in an area in which any one of the scheduled pests is known to have occurred in the last five years.

2.8.3 Bacterial wilt (*Ralstonia solanacearum*)

According to Martin and French (1995), bacterial wilt limits the production of potatoes, especially seed potatoes worldwide with extensive losses on potato being reported in Greece in 1951-1953 (Zachos, 1957). The brown rot of potato caused by *Ralstonia solanacearum* race 3 biovar2 is among the most serious diseases of potato worlwide, and is responsible for an estimated $950 million in losses each year (Ephinstone, 2005; Gouws and van der Waals, 2012). It is cold tolerant and is classified as a quarantine pathogen (Milling, Meng, Dennyand Allen, 2009). Bacterial wilt affects more than 50 plant families. Race 3 maybe spread more easily with surface water when infested *Solanum dulcamara* grows with its roots floating in water.

2.8.4 Epidemiology and survival of *Ralstona solanacearum*

The bacterria is tuber borne and is predominatly disseminated through infested tuber in potato production (French *et al*.,1975; Champoiseau *et al*., 2010). Potato tubers carry the bacterium in the vascular tissue, lenticels and on the surface (Sunaina *et al*., 1989). In cool conditions infected but symptomless plants may harbour the bacterium and then transmit the pathogen to progen tubers as latent infection leading to severe outbreaks when grown at warmer locations.

Infested soil and water are the other sources of innoculum. The bacterium may subsequently be spread to other hosts when contaminated surface water is used for irrigation (Olsson, 1976). Bacterial ooze can enter the surrounding soil or water contaminating farming equipment and at times it is spread by insects vectors such as nematodes (Denny, 2006). Nematodes (*Meloidogyne* spp.) facilitate infetion of *Ralstonia solanacearum* and increase disease severity of brown rot (Chindo *et al*., 1991).

When introduced, the pathogen can survive at 1m soil depth or more since microbial competition is low or as slimy masses in the upper soil layers (Champoiseau *et al*., 2009). *Ralstonia solanacearum* can overwinter in soil, plant debris or diseased plants, wild hosts, seeds or vegetative propagative organs like tubers. Survival of the brown rot bacterium is impaired by the presence of antagonistic microorganisms, extreme cold, in high pH (around pH8) and low pH (around pH4) soils (Kelman, 1953; Sonoda *et al*., 1979; Martin and French, 1985; Hayward, 1991; Milling *et al*., 2009).

High temperature and high moisture mainly affect the aggressivenesss of the pathogen as they promote its survival, reproduction, infectivity and spread of the bacterium hence disease development (Martin and French, 1985). Temperature is the most important factor affecting host-pathogen interaction and survival in soil.

Currently, there is no known effective chemical control measure for bacterial wilt, and management is reliant on intergrated control components which include the use of resistant varieties, use of disease free tubers, crop rotations, good crop management, strict sanitary measures on farm implements and at the farm, nematode control and strict quarantine measures (EPPO,2004, Champoiseau et al., 2010).

2.8.5 Potato bacterial ring rot (*Clavibacter michiganensis* subsp. *sepedonicum*),

According to Manzer and Genereux (1981), potato bacterial ring rot disease derived its name from its characteristic of internal breakdown in the vascular ring of an infected tuber which can be seen as a brown, cheesy decay of the vascular tissue. Above ground, the disease is usually seen as a progressive wilt (Lelliott and Stead, 1987). The causal agent for the destructive potato disease, bacterial ring rot is *Clavibacter michiganensis* subsp. *sepedonicum* (Spieck & Kotth) Davis (Cms) (Davis *et al*., 1997; Franc, 1999). The *Clavibacter michiganensis* (Cms) is highly infectious and can cause extensive losses to infected crops (Rich, 1983; Rowe *et al*., 1995).

The disease is economically devastating to seed potato growers since infected seed potatoes produce infected plants (DEFRA, 2002). After planting, bacteria multiply and spread to the vascular tissue of stems, petioles, roots and developing tubers. Symptoms do not usually develop quickly and infections generally remain latent for long periods. Some varieties are tolerant to the extent that infection symptoms may not develop for several plant generations, even though the bacteria can multiply in both plants and tubers. The latent period may encompass almost the entire period of host growth from vegetative propagule to mature plant (Bishop and Slack, 1987).

Bacterial ring rot is most significantly spread through the planting of infected seed potatoes and contamination of containers, equipment and premises. When an infected seed piece is planted, bacteria move from the seed through the vascular tissue into the stem and lower leaves of the growing plant (Babadoost, 1990). The plant will start to show foliar and stem symptoms mid- season or later (Davis *et al*., 1997). Late in the season, bacteria migrate from the stem down into the stolons, contaminating the new tubers (Babadoost, 1990). Internal symptoms may be present within tubers at harvest but are more commonly observed toward the end of the storage period (Lelliott and Stead, 1987).

Disease spread in the field from plant to plant is usually poor, but there is experimental evidence that some insects, including the potato flea beetle, *Epitrix cucumeris* (Harris), the Colorado potato beetle, *Leptinotarsa decemlineata* (Say), the green peach aphid, *Myzus persicae* (Sulzer) and the fruit fly are possible vectors of *Cms* (Christie *et al*., 1991; Christie *et al*., 1993; De Boer *et al*., 1990).

The bacteria can also survive and remain viable for several years on potato bags, bulk bins, store walls and other surfaces that have been contaminated by rotting ooze. The bacterium is able to overwinter in the soil, usually in association with unharvested potatoes from the previous crop and debris from infected crops. Infected groundkeepers lifted with an otherwise clean seed or ware crop can infect that crop (DEFRA, 2002). The pathogen can survive in water for more than a month but there is no known aquatic weed host to build up inoculum levels. Contaminated wash water from infected tuber lots can transmit the pathogen to subsequent lots washed in the same water (DEFRA, 2002).

When foliar symptoms appear, they usually occur mid-season or later and are first seen on nearly full-grown plants (Davis *et al*., 1997). Lower leaves usually wilt first, becoming slightly rolled upward at the margins, and are paler green than healthy leaves (Rowe *et al*., 1995). As wilting progresses, the leaf margins and interveinal regions become chlorotic, then necrotic, turning the leaves brown as if burnt (Rowe *et al*., 1995; ACP, 2003). Whole stems can wilt and die, but it is not common for all the stems on a plant to be destroyed (DEFRA, 2002). Normally, only one or two stems per plant develop symptoms and, in some cases there are no aboveground symptoms at all (Glick *et al*., 1944). In advanced stages of the disease, the vascular tissue near the base of an infected stem turns brown and exudes a milky bacterial ooze when squeezed (Babadoost, 1990; Lelliott and Stead, 1987).

2.8.6 Potato wart disease (*Synchytrium endobioticum*)

Synchtrium endobioticum, the causal agent of potato wart disease is the most important worldwide quarantine plant pathogen infecting potato. *S. endobioticum* is on the United States Select Agent list and was recently evaluated as a top tier threat to agriculture on the Animal and Plant Health Inspection Services (APHIS) list of Regulated Pests (Rossman *et al.,* 2006).

The presence of the pathogen does not affect the safety of potatoes for consumption, but causes cauliflower like deformities to grow on potatoes making them unmarketable and reduces yield. The pathogen affects the growing points on the potato plant such as eyes, buds and stolon tips. At the end of the growing season, resting spores are produced that can remain viable in the field soil for more than 40 years, thus successfully removing infested fields from commercial potato production (Franc, 2007). The intense regulatory scrutiny is based on the latent persistence of resting spores, scarcity of resistant varieties and lack of effective chemical control.

Potato plants infected by *S. endobioticum* do not usually show symptoms on above ground parts, though in some instances there maybe reduction in vigor and rarely development of small green –yellow warty growth in the stem base. Normally all symptoms are confined to below ground parts of the plant and no evidence of infection is seen until potato tubers are harvested (DEFRA, 2011; Hapson, 1993).

2.8.7 Cyst nematode (*Globodera* sp.)

The cyst nematodes were initially discovered in Germany in 1913. By that time, it had spread throughout Europe (Wallace, 1964). In South Africa its presence was reported in 1971 from an irrigated farm near Pretoria and small farms around Johannesburg and Bon Accord (Knoetze *et al.,* 2006).

According to Mai, Lear, (1953) and Mai, (1977) there are commercial crops that are hosts of the potato cyst nematode and these are; potatoes, tomatoes and eggplants. However numerous weeds are also known to be hosts of these nematodes (Goodey and Franklin, 1958, 1959).

Generally the potato cyst nematode survives in any environment where potatoes can be grown. According to Chitwood and Buhrer (1945), a period of 38-48 days (depending on soil temperature) is required for a complete life cycle of the potato cyst nematode.

2.9 Degeneration of Seed Stocks

According to Morrenhof (1998), when a crop is infested with virus, its yield will be affected. The losses due to viruses are usually quantifiable but some causes qualitative losses as well. The losses due to one or more viruses infecting potato vary from low to very high, thus infections of PVY and PLRV have the potential to reduce yields up to 80% while mild viruses such as PVX, S and M, also depress yields by as much as 30% in infected plants (Khurana, 2000). The rate at which the yield loss will take place depends on the intensity of the infection, the type of virus and the combination of other yield affecting factors that are present. A crop that is already under stress from other factors will suffer more from virus infection. If no specific measures are taken to control the spread of the viruses, the infection level will tend to increase progressively from one generation to the next when the potatoes are reproduced. Gradually a reduction in productivity of the crop is observed in successive generations (Morrenhof, 1998). This process is called degeneration.

The degeneration rate is the most important factor determining whether seed can be produced in certain areas and how many generations can successfully and safely be grown. Often degeneration rates are found to be high in warm production areas or seasons and are lower under cooler conditions. For seed production, the areas and seasons with a low degeneration pressure are most suitable (Ali et *al*, 2013).

The degeneration of potato seed stock is generally minimised if the initial seed is of high health standards and when integrated management of viruses is routinely practiced (Khurana and Garg, 1992).

2.9.1 Viruses of economic importance in degeneration of potato seed stock

Virus infection can be serious in vegetatively propagated plants and unless special measures are taken, all propagules taken from an infected plant will be affected (Walkey, 1980; Thompson, Visser and Bellstedt, 2012).

In Zimbabwe, potatoes are a vegetatively propagated crop and many disease causing organisms including several viruses are disseminated in tubers. The important role that tubers play in the spreading of viruses is recognised by the strict requirements for foundation or certified seed in the country. In the Zimbabwean scheme the potato viruses PVY^O, PVY^N, PVX, PVM and PLRV are the most important virus diseases of potato but PVS and PVM are not considered to be serious enough to warrant inclusion in the virus testing program (Chikwati, J. 1993, unpublished report).

Potato leafroll virus (PLRV) causes an important disease of potato seed, affecting quantity and quality of production. Primary infection occurs when an initially healthy plant is inoculated through aphids during the current season. Symptoms first show where inoculation appears. The upper leaves become pale, upright, rolled and shows some reddening of the tissue around the leaf often with pink-reddish margins. Stunted chlorotic plants with older leaf stiff, dry leathery and rolled with pink to brownish margins. Plants grown from infected tubers are stunted, leaflets rolled upwards (Wangai and Lelgut, 2001).

Potato virus Y potyvirus (PVY) symptoms vary with strains/ variety from mild to severe. Plants are stunted, twisting of leaves with slight inverted cupping of leaflets with older leafs collapsing or showing mild mosaic (Thompson *et al*., 2012).

2.10 Import and Export of Plant Material

The Control of Goods (Import and Export) (Agriculture) Regulations, 2007 regulates the import and export of plants and plant material. These regulations work together with the Plant Pests and Disease (Importation) Regulations of 1958 in enforcing the control of agricultural imports and exports. In regards to the importation of potato tubers, submission of a phytosanitary certificate dated not more than 30 days before the dispatch of the consignment is required. This should be accompanied with an additional declaration that; (i) the potatoes were grown in land certified by the plant protection authority as free from potato root nematode (*Globodera rostochiensis* Wollenw) and other cyst-forming nematodes; (ii) A. Wart disease (*Synchytrium endobioticum* (Schilb.) Percival) and bacterial ring rot (*Clavibacter michiganensis* subsp. *sepedonicum* (Spieck & Krotth.) (Skaptason &Burkholder) do not occur within five miles of the place where the potato were grown, and no case of wart disease was observed in that area by plant protection authority during the ten years preceding the date of the certificate; or **B.** Wart disease and ring-rot did not occur in the country of origin (Plant Pests and Disease (Importation) Regulations, 1958).

Basically seed certification systems have been put in place in most of the seed producing countries to ensure the production insect and pest disease free seed (Sahjdak and Uznanska 2003).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study sites

A baseline survey and crop inspections were carried out in the Nyanga Seed Potato Quarantine Area (SPQA). The SPQA is found in Inyanga, an area in the Eastern highlands of Zimbabwe as shown in the map below (Figure 2).The SPQA is located at 2000m above sea level (altitude) with the trigonometry points specified in the Plant Pests and Diseases [Seed Potato Protection] Regulations 1982 amendments. Its soil types vary from black loamy to red clay soils. The area is in Natural Region I with an annual precipitation of 1 120mm (Joyce, 1982).

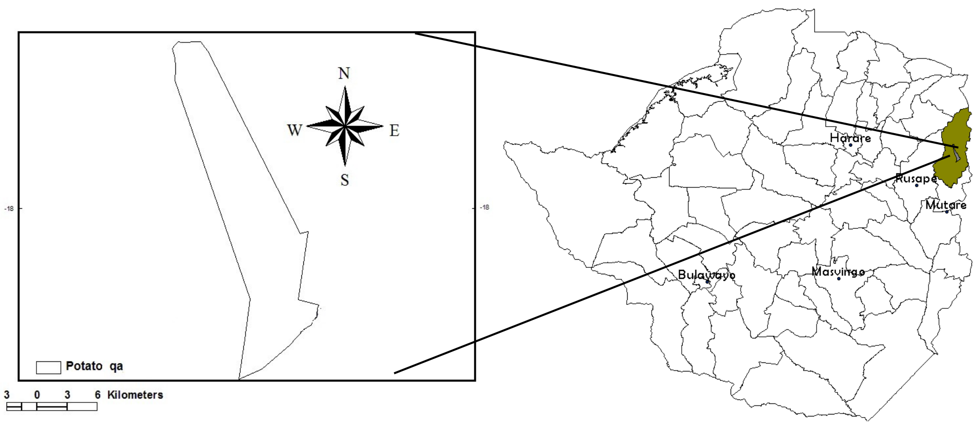


Figure 2. Map of Zimbabwe showing the study area in Nyanga district.

Field trials were conducted in Harare at two different research stations namely Agricultural Research Trust farm (ART farm) (GPS coordinates $17^{0}70'1.29''$S and $31^{0}05'86.35''$E) and Pannar Seeds research farm (Divonia), (GPS coordinates of 17°43'7.52"S and 31°23'44.14"E) as winter and summer crops in 2012, 2013 and 2014. The types of soils at ART farm are Feriallitic soils while Divonia farm has Paraferralitic soils (Nyamapfene, 1991).

3.2 Methodology

The study involved a longitudinal survey, seed crop inspections and field trials. A longitudinal survey was conducted on all the 22 farmers in the Nyanga SPQA from the 23rd to the 27th of January 2012. The aim was to determine the farmer's time of settlement at the farm, their land holdings, find facts on their seed production systems, assess the prevalence of insect pests and diseases at their farms as well as collecting data which was used to categorise the farmers for the field trials.

Upon arrival at a farm, one on one interview to farmers and farm workers were conducted using laid down questions on the questionnaires (Appendix 1). This was followed by a general appraisal of crops being produced at the farm and collection of soil, plant and tuber samples. The collected soil, plant and root samples were tested for the presence of soil borne diseases and potato cyst nematode.

Regular seed crop inspections were carried out at a 3 weeks interval throughout the study period on all seed crops in the SPQA so as to assess genetic purity, insect pests and diseases prevalence especially scheduled pests of the quarantine area. Insect specimen, plant and soil samples were also collected during this process.

Seed of four different varieties namely BPI, Amethyst, Diamond and KY20 was collected from the identified representative farmers drawn from the categorised groups and used for the field studies as grow-out trials. Breeder's seed collected form the potato breeder at the Nyanga Experimental Station was used as control in the field trail. These farmers' fields were also used as study area for further monitoring on the pest and diseases prevalence using the stratified sampling methods. Two (AA2 and AA3) classes out of the four classes of seed grown in the SPQA were evaluated in the field trials. Morphological and physiological characterisation was conducted using the UPOV guidelines for Distinctiveness Uniformity and Stability testing (DUS) see annexure 2. Evaluation of parameters was done at all growth stages of the crop.

3.3 Field trial layout and management

Field trials were carried out in 2012, 2013 and 2014. The field trials were set up as a split plot design where the source of seed was the split whilst the variety was the plot and replicated three times. The main plot (variety) had 16 rows by 2m each spaced at 0.9m and the split (source) had 4 rows by 2m each spaced at 0.9m inter row (Appendix2). The net plot was 2 rows by 2m each spaced at 0.9m inter row with in row spacing of 0.25m.

Prior to planting, the seed was subjected to natural sprouting in a well ventilated room. Soil samples were taken for laboratory analysis. The land was deep ploughed, rolled, disked and treated with Nemacur at five weeks before planting. Planting furrows were opened and potato blend (8:18:24) was applied at the recommended rate of 1500 kg/ha after soil nutritional analysis and slightly covered followed by the placement of tubers in the fallows at an in row spacing of 0.25m. The layout of the experiment is presented in Annexure 1. The trial was then irrigated to field capacity.

Twenty-five days after planting 150kg Ammonium Nitrate (35% N) ha-1 was applied as top dressing. Weeding and the first hilling-up were done at 25 DAP, at the same time as the top dressing. The second hilling-up was done at 40 DAP. Crops were sprayed regularly during the growing season using Mancozeb fungicide to control late blight (*Phytophthora infestans*) and Profenofos insecticide to control insect pests such as thrips, tuber moth, leaf miner and Aphids. Evaluation of parameters was conducted at a fortnightly interval.

3.4 Laboratory diagnosis of Insect pest specimens

Insect pest specimens were collected systematically from the farmers' fields in the quarantine area and preserved in glass vials in 70% ethyl alcohol solution. However the specimens were very few because most farmers rely on the preventive program of managing pests and diseases. Identification of insect specimens was conducted using a stereo microscope and using standard taxonomic keys. Besides specimens of insect pests, specimens of biological control agents were also collected and identified using the appropriate taxonomic keys. The Sugar Floatation Technique was used for nematode identification.

3.5 Diagnosis of pathogen specimens

Firstly plant pathogens were classified under the main categories of viral, fungal and bacterial pathogens.

3.5.1 Diagnosis of Bacterial Pathogens

On collection of wilted plants samples in the field, a Vascular Flow Test was conducted so as to rule out confusion of the causes of wilting with that of pathogens such as that of *Fusarium eumartii, Verticillium sp., Erwinia chrysanthemi,* mechanical damage or insect damage (Champoiseau *et al*, 2010). This involved cutting a piece of sterm3cm long from the base of the wilting potato plant, suspending it in a water glass of clear water whilst holding it with an opened paper clip to maintain a vertical position. Smoke-like milky threads streaming downwards from the cut were observed and this confirmed the presence of *R. solanacearum* within the vascular system (CIP, 2007).

On tuber samples found with symptoms, the KOH Test was conducted to differentiate ring rot caused by *Clavibacter michiganensis* pathogen wilting from that caused by *R. solanacearum* pathogen. This involved placing two drops of 3 % potassium hydroxide (KOH) on the ooze and mixed it using a wooden toothpick for 10 seconds. For the *R. solanecearum,* milky threads were noticed upon lifting the toothpick whilst *C. michiganensis* did not produce the thread. Definitive diagnoses were conducted using primers on polymerase chain reaction (PCR) analysis.

3.5.2 Diagnosis of Viral Pathogens

Viruses were tested using ELISA (enzyme linked immunosorbent assay) where appropriate and hypersensitive tests were conducted using appropriate indicator plants as listed in table 1.

Table 1. Indicator plants used for virus the hypersensitive tests (Albrechtsen, 2006).

Virus name	**Indicator plant used for testing**
PVY^0	*Solanum demissum*
PVY^N	Burley Tobacco
PVX	*Gomphrena globosa*
PVS	*Nicotiana debneyi*

3.6 Data Analysis

For the survey data, the Statistical package for Social Sciences (SPSS) was used to find out the co-relationship between the time of occupation, production system and insect pests and diseases found in the SPQA. GENSTAT was used for the field trials and the data was subjected to ANOVA and where treatment effects were significantly different at $P \leq 0.05$. The means were separated using the Least Significant Difference (LSD).

CHAPTER FOUR

4.0 DATA PRESENTATION, ANALYSIS AND INTERPRETATION

4.1 The current seed production systems in the Nyanga seed potato quarantine area in relation to the national potato seed certification scheme

As shown in Figure 3, six out of the twenty two farmers settled in the Nyanga SPQA before the land reform, whilst 9 settled between 2000 and 2005 and the remainder 7 settled between 2005 and 2010.

Figure 3. Time of occupation in the SPQA

The old farmers have land holdings of between 90 to 400 Ha of arable land whereas the newly resettled farmers range from 20 to 200 Ha of arable land. The area under seed potato production from the newly resettled farmers ranged from 1 to <50 ha compared to between 33 to 90 ha of different varieties from old farmers (Table 2). One farmer in the old farmers category had 35 Ha of unregistered potato crops of unrecognised varieties whilst 9 farmers from the newly resettled farmers had 33Ha of unregistered potato crops of recognised varieties combined together (Table 2).

Table 2. Land holdings and varieties of potatoes being produced in the SPQA

Farmer	Year of settlement	Total Land Holding (Ha)	Total Arable (Ha)	Area under seed potato (Ha)	Area under unregistered potato crop (Ha)
Nyamoro	1970	194	90	0	0
Kylyn Orchards	1979	200	120	33.2	0
Tsatsati	1984	1000	500	50	0

Muozi	1984	480	375	91.7	0
Barons Down	1990	250	250	50	35
Pfumarungu Ranch	1998	800	400	54	0
Mugombe	2000	40	35	2.7	2
Muchangu	2001	120	54	21	0
Nyahukwe	2001	105	65	2	3
Muzoro (Nyangui)	2002	150	100	10	11
Gwezere	2002	20	20	1	1
Mutiro	2002	300	200	10	0
Muzoro (Mahachi)	2002	125	90	4.5	1
Fruitcosa	2003	200	60	15.1	0
Nyanga Downs	2003	283	100	17	0
Mahogany Ridge	2006	249	100	5	8
Nyamurindi	2006	250	150	50	0
Chipindura	2008	175	80	3	0
Hamandishe	2008	150	40	10	0
Zororo	2008	30.7	30	0	6
Muomba	2009	40	35	1.5	1
Kwayedza Muzoro	2010	109	85	11	0

During the study it was noted that with the arable land holdings of the farmers (Figure 4) and current production scale (Figure 5), the farmers could manage to follow the 1 year seed potato and 3 years weeping love grass rotational scheme required in the Zimbabwean seed certification scheme. Despite having adequate lands for a proper rotational regime, most farmers both new and old farmers were following a rotation scheme of 2 years potato seed and 3 year love grass instead of the 1 year seed crop and 3 years love grass (Figure 6). They were practising this without approval from the relevant authorities as required by the Seed Certification Notice (2000). At times when they seek for the approval, it emerged that the authorities were sometimes approving for second year cropping without making the relevant investigations.

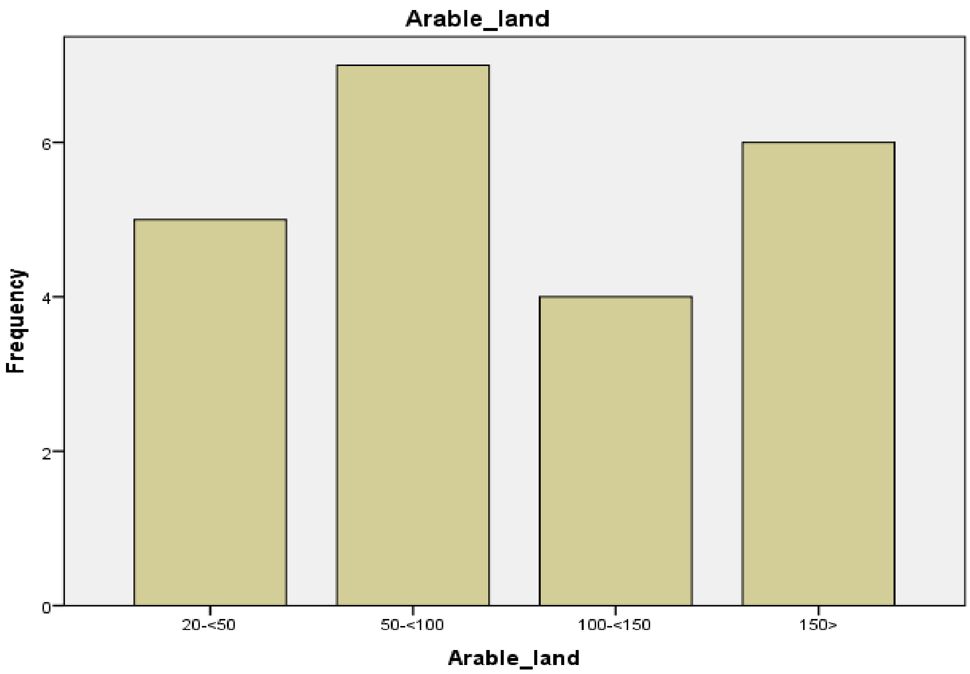


Figure 4. Proportion of arable landholdings in the SPQA

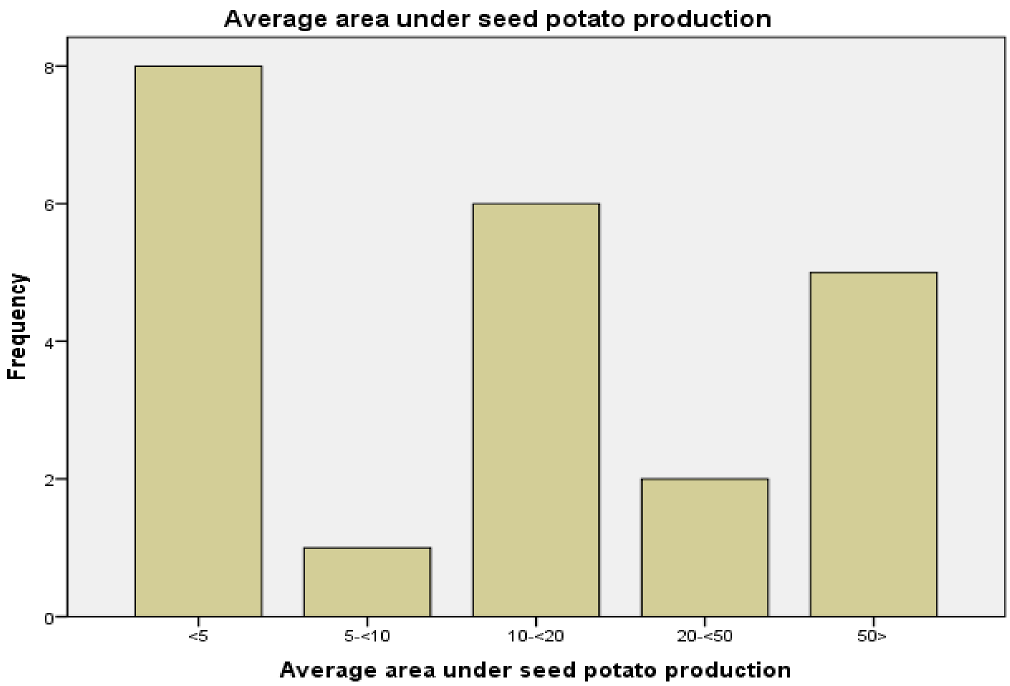


Figure 5. Proportion of land under potato seed production (hectares)

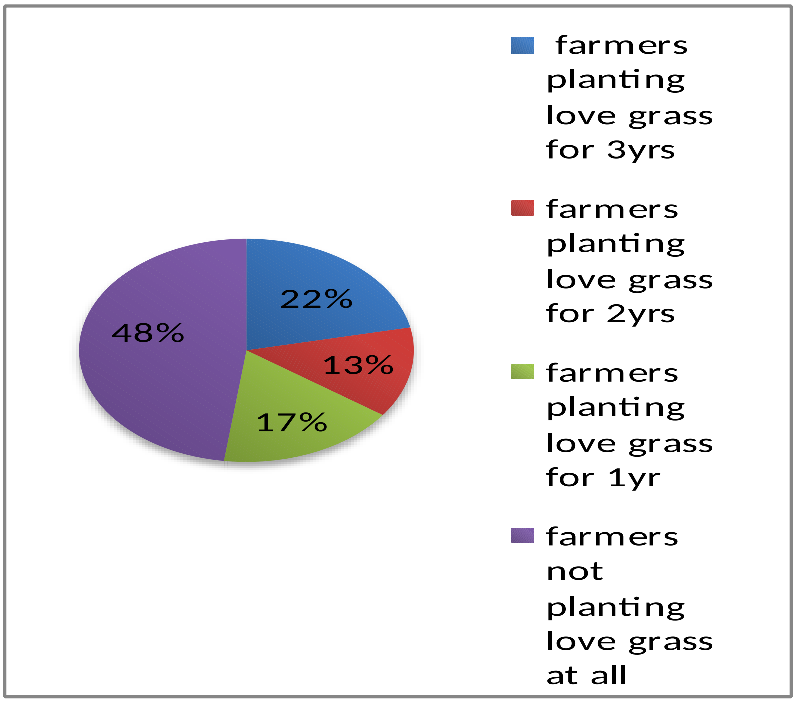


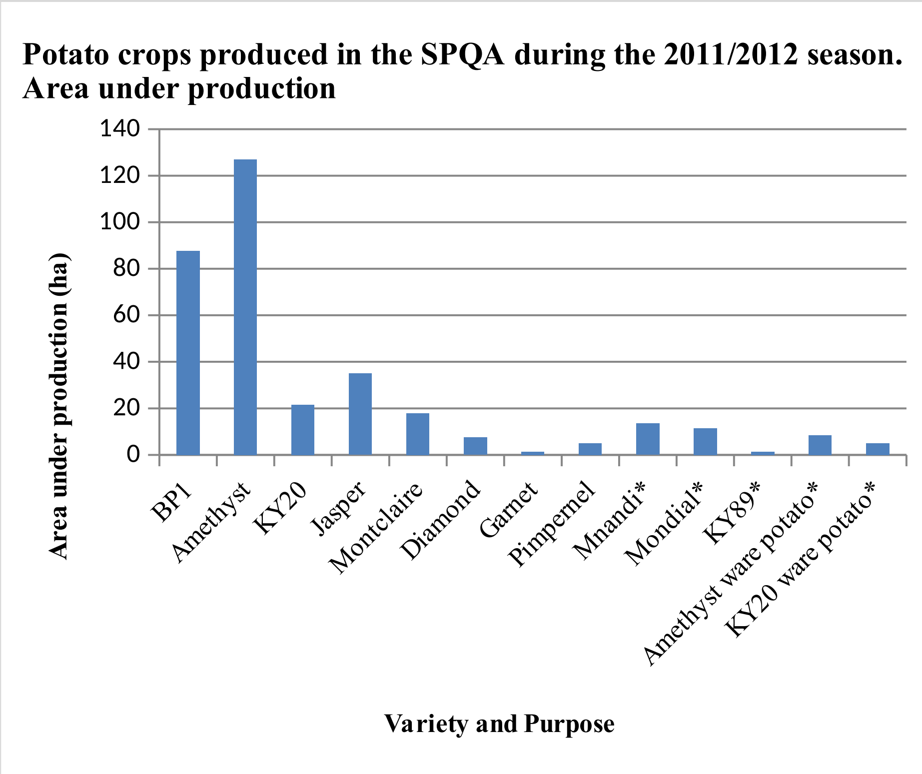
Figure 6. Percentage of farms under love grass rotation.

In some instances when the farmers had the seed potato crop break in their rotation regime, they were not planting the weeping love grass as a rotational crop but rather leaving the land fallow. The land would be left with volunteer potato crops from the previous seasons growing on the fields as shown in Figure 7. Farmers would leave these volunteer crops so that farm workers can harvest them at physiological maturity and use them as table potato.

Figure 7.Volunteer potato plants in land with a crop break (Source: Chakanyuka, T.).

Three farms in this area were having more than one cycle of seed crops per year as they have resorted to supplementing with irrigation during the dry months.

During the 2011/2012 summer season different classes of seed of different varieties were grown in the SPQA. The varieties included BP1, Amethyst, Jasper, KY20, Montclaire, Diamond and Garnet. However unrecognised varieties like Mnandi, Mondial, KY89 were being grown as seed whilst registered varieties like Amethyst, KY20 and BP1 were being grown in the SPQA as table (ware) potato for sale inside and outside the SPQA as shown in figure 8. The production of unregistered varieties and ware potato in the SPQA was in violation to the Plant Pests and Diseases (Seed Potato Protection) Regulations of 1982.



*varieties not registered for seed production

Figure 8. Potato varieties produced in the SPQA during the 2011/2012 season.

Most farmers (both old and new) in the SPQA were producing other crops like maize, potato, pumpkins and vegetable crops (crops that are not part of the area's mandatory seed potato) without the permission from the respective institutes. Figure 9 shows the proportion of farmers (new and old) who were producing the other crops.

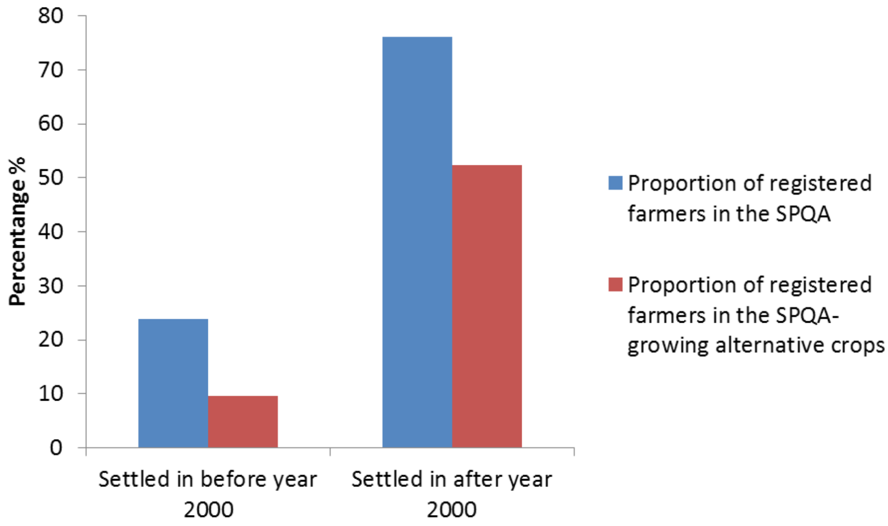


Figure 9. Proportion of farmers in the SPQA growing seed potato.

During the survey it was noticed that on 50% out of the 22 farmers in the SPQA had all the important required farm implements while the other 50% had some of the farm implements which were not adequate for their farming operations (Figure 10). Those that did not have all the implements relied on borrowing from neighbouring farms, with some even borrowing outside the SPQA.

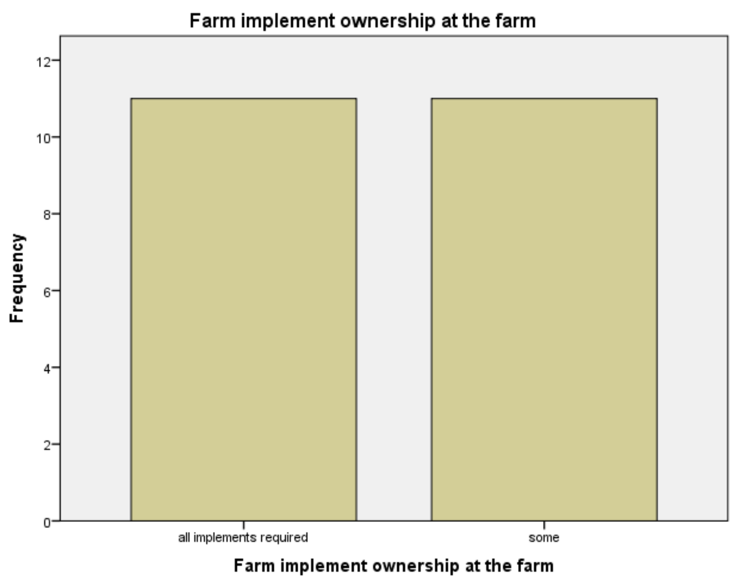


Figure 10. Farm implements ownership in the SPQA

Growers in the SPQA are supposed to have clear field map of the fields on their farm. These maps help the Certifying Authority, the Certifying Agency and the farmer in identification of the plots when verifying rotational schedules of lands in a particular season. During the study it was discovered that 78% of the farmers had no field maps on their fields and as a result fields were being randomly named during the particular season subsequently making record keeping on land use difficult.

It was also noted that farmers were not getting adequate advisory from the seed company inspector in all stages of seed crop multiplications. The seed company inspector is supposed to monitor and give advice to farmers during the whole circle of seed crop multiplication. However the inspector is based at the seed company business premises in Harare and rarely visit the farmer and at times when he visits them, it will be in the company of seed certification inspectors during field seed crop certifications. As a result farmers are just doing what they perceive to be right without prior knowledge of the requirements.

It was noted that seed sold in the seed potato quarantine area was only inspected for certification in the field and tuber inspection certifications were not being done and yet most of the farmers have no access to foundation seed as it is always in limited supply and usually given to less than 4 farmers who then multiply it and supply it to other farmers in the area for further multiplication. The certifying authority was not following up on rejected seed crops as a result the rejected crop was being sold to unsuspecting farmers.

Although most farms were well fenced, they were no sanitation measures at the point of entry at all the farms in the seed potato quarantine area. Very few new farmers had all the farm implements at their farms, thus they were relying on borrowing and exchanging the implements with neighbouring farmers.

4.2. The prevalence of pest and diseases in the seed potato quarantine area in relation to quarantine regulations

Two out of the four scheduled pests and disease of the SPQA diseases were identified (Table 3). *Ralstonia solanacearum* was identified on five farms whilst *Clavibacter michiganensis* was identified on one farm out of the twenty one farms.

Table 3. Insect Pests and diseases of quarantine importance found in the SPQA

Disease	Identified in the seed potato quarantine area (Yes/no)	No of farms the disease was identified on	No of records the disease has been recorded before
Bacterial wilt (*Ralstonia solanacearum*)	Yes	5	1
Potato bacterial ring rot (*Clavibacter michiganensis* subsp. *sepedonicum*)	Yes	1	0
Potato wart disease (*Synchytrium endobioticum*)	No	N/A	N/A
Cyst nematode (*Globodera* sp.)	No	N/A	N/A

Some of the samples that were collected in the SPQA, showed positive presence of some of the schedule pest of the SPQA after testing. Figure 11 shows a crop wilting which was identified in some of the field. The samples tested positive of bacterial wilt caused by *Ralstonia solanacearum* which was identified on 5 farms out of the

21 farms in the seed potato quarantine area. *Clavibacter michiganensis* was identified on one farm in the SPQA (Figure 12).

Figure 11. Wilting plants showing symptoms of bacterial wilt (source: Chakanyuka T. 2012)

Figure 12 Sliced tubers from the wilting plants infected by Clavibacter michiganensis (source: Chakanyuka T.2012)

Figure 13 shows the map of the SPQA and the doted area shows the points where the bacterial diseases were found. The diseases were concentrated in the south eastern part of the SPQA.

As shown in the map, 4 farms that had the disease are in the same surrounding whilst the other 2 share boundaries and are not very far from the other farms that were found with the bacterial diseases. These farms share farm implements.

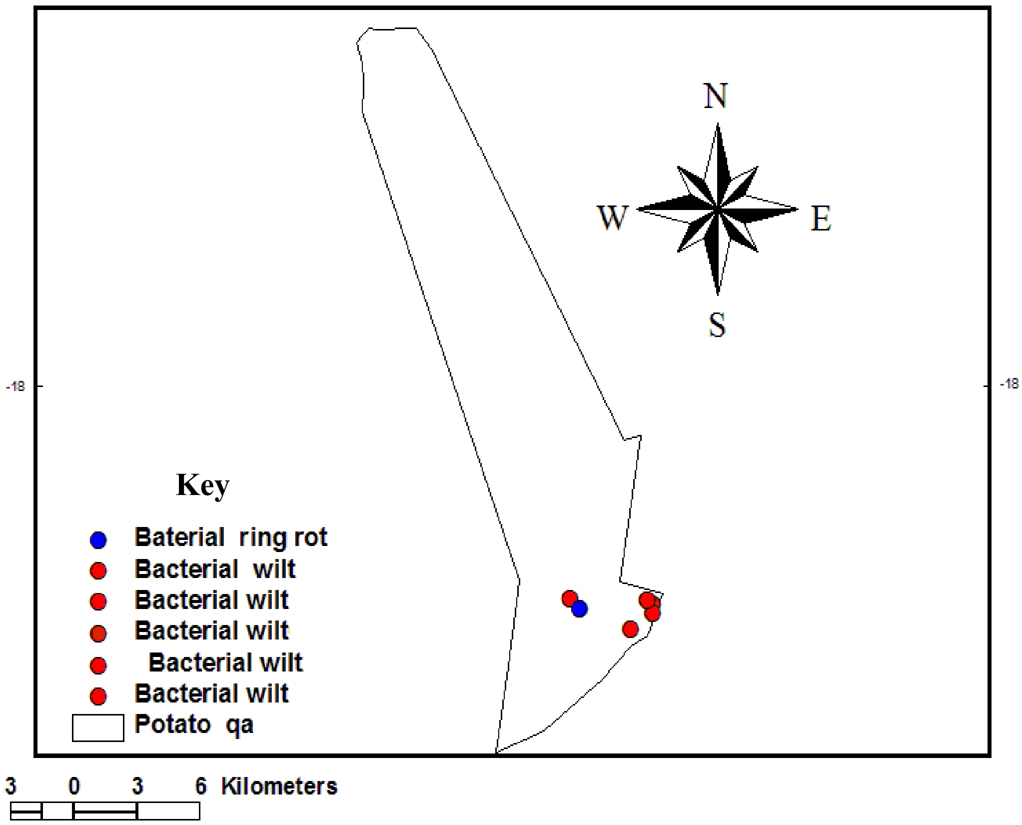


Figure 13. Areas where scheduled pests were detected in the SPQA

Other insect pests and diseases that are of no quarantine importance were also identified as shown in Table 4. Despite using the preventive method of controlling insect pests and diseases at the farms, above 83% farms in the SPQA had these insect pest and diseases were detected on them.

Table 4. Other diseases and insect pests identified in the SPQA

Pest/Pathogens	**No of farms where it was identified**	**Percentage of farms identified with the disease/insect pest**
Rhizoctonia solani	23	100%
Phytophthora infestans	23	100%
Fusarium spp.	23	100%
Alternaria solani	23	100%
*Potato leaf roll virus (*PLRV)	4	17.4%
*Potato virus Y (*PVY)	9	39.1%
Pectobacterium carotovorum	6	26%
Meloidgyne chitwoodi	15	65.2%
American leaf miner	23	100%

4.3 Purity of seed and compliance to the statutory requirements

The total hectares of seed crops that were rejected whilst still in the field due to off-type plants that were way above tolerance level at the time of inspections and not following the stipulated rotation regime are shown in Table 5.

Table 5. Area rejected due to purity statutory violation in the seed potato quarantine area

Year of production	Class of seed	Ha approved	Ha down graded	Ha rejected
2012	Foundation	17.7	7.3	1.2
	AA grade	254.2	0	10.3
2013	Foundation	15.6	5.1	0.7
	AA grade	243.96	0	16.5
2014	Foundation	14.59	0	0.4
	AA grade	342.695	0	30.4

Table 6 shows information on the quantities of potato seed tubers produced in Nyanga SPQA but rejected during tuber inspections at the seed company warehouse due to pests and disease infestation is highlighted in. These had initially passed the field inspection during field growth yet tuber inspections were not being done on seed sold at farm gate.

Table 6. Quantities of potato seed from the SPQA rejected

Year	Quantity (mt)	Reason for rejection		
		Root knot nematode	**Late blight**	**Wet rot**
2012	67	93%	-	6%
2013	65	90%	2%	8%
2014	66.2	96%	1%	3%

4.4 Field trial results on morphological characterisation of potato varieties

The trial to evaluate on the competency of seed farmers in the SPQA through comparing the performance of Amethyst (1), Diamond (2), BP1 (3) and KY20 (4) shows that on the KY20 variety there was no significance difference in its performance as per farmer even though it was the least yielding variety of the **AA2** class of seed as shown in Table 7, 8 and 9. Amethyst out yielded the other varieties significantly across site and in both seasons. There was a significant difference on the performance between amethyst seed sourced from farmer 2 and 3 with that from farmer 1 and 4.

Table 7. ART Farm (2013) Effect of source of seed potato and variety on yield of seed potato (AA2)

Source	**Varieties**			
	Amethyst	**BP1**	**Diamond**	**KY20**
1	59.70a	42.89a	45.87a	40.86a
2	47.33bc	38.43b	41.59b	39.08ab
3	44.02c	39.75ab	41.38b	35.91b
4	50.13b	40.95ab	40.54b	37.56ab
P value	0.001			
LSD	3.736			
CV%	7.5%			

Means within the same column having a common letter (s) do not differ significantly.

Table 8. Divonia Farm (2013) Effect of source of seed potato and variety on yield of seed potato (AA2)

Source	**Varieties**

	Amethyst	BP1	Diamond	KY20
1	60.53a	41.32a	45.93a	40.18a
2	47.68b	37.96b	42.25ab	38.12ab
3	44.22c	40.66a	40.79b	35.23b
4	50.49b	41.06a	40.27b	37.59b
P value	0.001			
LSD	3.115			
CV%	7.9%			

Means within the same row having a common letter (s) do not differ significantly

Table 9. ART Farm (2014) Effect of source of seed potato and variety on yield of seed.

Source	**Variety**			
	Amethyst	**BP1**	**Diamond**	**KY20**
1	59.70a	44.28a	44.98	40.79a
2	47.33c	39.10b	41.71	38.89ab
3	44.02c	39.90b	43.23	35.21b
4	51.24b	40.31b	41.54	37.30ab
P value	0.001			
LSD	3.884			
CV%	7.4%			

Means within the same column having a common letter (s) do not differ significantly.

Table 10 shows the effect of source on yields. Source 1 had the highest yielding seed followed by 4 and 2 respectively with 3 having the lowest yielding seed.

Table 10. Cross site. Analysis of variance on the effect of source of seed on yield of AA2 grade potato seed.

Source	**Site**		
	ART Farm 2013	**Divonia Farm 2013**	**ART Farm 2014**
1	47.33a	46.98a	47.36a
2	41.61b	41.48b	40.94bc
3	40.26c	41.22b	40.13c
4	42.30b	42.24b	42.07b
LSD (0.05)	1.942	1.868	1.558
CV%	7.4%		

Means within the same column having a common letter (s) do not differ significantly.

In the AA3 class, Amethyst still out yielded the other varieties though yield differences were not exhibited on the same variety coming from the different sources see Table 11, 12 and 13 below. Diamond was the second highest yielder, followed by BP1 with KY20 yielding the lowest. In terms of the source, seed from source 1 gave the best performance followed by 4 and 2 respectively with 3 having the lowest yielding seed, see Table 14 in the AA3 class of seed.

Table 11. ART Farm (2013) Effect of source of seed potato and variety on yield of AA3 grade seed

Source	Varieties			
	Amethyst	BP1	Diamond	KY20
1	59.70a	42.89a	45.87a	40.86a
2	48.03c	38.66bc	41.59bc	39.08a
3	43.94d	39.75b	42.07b	35.91c
4	50.28b	40.63b	40.54c	37.56bc
P value	0.001			
LSD	1.902			
CV%	7.5%			

Means within the same column having a common letter (s) do not differ significantly.

Table 12. Divonia Farm (2013) Effect of source of seed potato and variety on yield of AA grade seed

Source	Varieties			
	Amethyst	BP1	Diamond	KY20
1	60.53a	41.27a	45.93a	40.18a
2	47.33c	38.23b	42.25b	38.12b
3	44.02d	40.23a	41.38bc	35.23c
4	50.13b	40.95a	40.27c	37.59b
P value	0.001			
LSD	1.902			
CV%	7.5%			

Means within the same column having a common letter (s) do not differ significantly.

Table 13. ART Farm (2014) Effect of source of seed and variety on yield of AA3 grade seed.

Source	Varieties

	Amethyst	BP1	Diamond	KY20
1	57.70a	44.28a	44.67a	40.79a
2	47.53c	38.23c	41.71b	38.89b
3	44.02d	39.90b	41.38b	35.21d
4	50.84b	40.31b	40.86b	37.30c
P value	0.001			
LSD	1.526			
CV%	7.6%			

Means within the same column having a common letter (s) do not differ significantly.

Table 14. Cross site Effect of source of seed on yield of AA3 grade seed in 2013 and 2014

Source	Site		
	ART Farm 2013	**Divonia Farm 2013**	**ART Farm 2014**
1	47.33a	46.98a	46.86a
2	41.61c	41.48bc	41.59b
3	40.26d	41.22c	31.05d
4	42.30b	42.24b	39.63c
LSD $_{(0.05)}$	0.951	0.915	0.763
CV%	7.7%		

Means within the same column having a common letter (s) do not differ significantly.

As shown in Table 14, the source of seed had no effect on the tuber size of the seed harvested from the field trial, However the variety had a significant difference on the tuber size with Diamond having an average bigger tuber size followed by BP1 and amethyst, whilst KY20 had the smallest average tuber size (Table 15).

Table 15. Effect of variety and source of seed on tuber size (mm diameter)

		Tuber Size (mm)
Variety	Amethyst	413.3b
	BP1	420.8ab
	Diamond	438.3a
	KY20	339.2c
	Grand Mean	402.9
	p-value	<0.001
	LSD	20.94
	CV(%)	9.3
Source	1	403.3
	2	399.2
	3	395.0
	4	414.2
	Grand Mean	402.9
	p-value	0.631
	LSD	31.45
	CV(%)	9.3

Means within the same column having a common letter (s) do not differ significantly.

Figure14 shows the viral disease incidence identified during the field trial. Disease scoring was done using a scale of zero to eight with zero representing relatively clean seed whilst eight represents highest number of disease incidences. Seed from farmer 3 had the highest disease incidences followed by farmer 2 and 4 while seed from farmer 1 was clean.

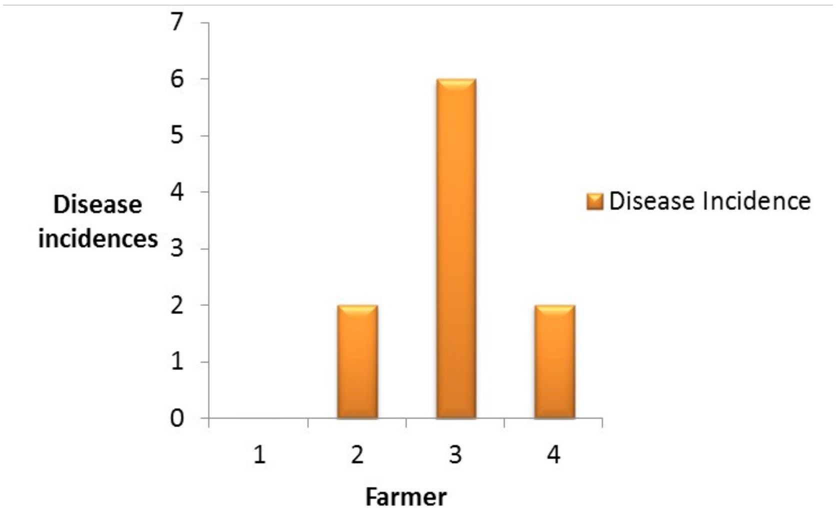


Figure 14. PLRV and PVY combined incidences during the field trials

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Cropping sequence and length of rotation play an important role in seed potato production as they impact on nematode populations and are important considerations for the management of potato nematodes (Hopkins, *et al*., 2004). Increasing frequency of potatoes in a cropping system results in increased pressure from nematodes. Increasing the time between potato crops, particularly with rotation crops that are poor hosts, results in reduced risk of nematode damage. Table 6 shows that during the 2011/2012 summer cropping season in the SPQA, more than 199.2mt of seed was rejected due to root knot nematode, wet rots and late blight infestation since the Seed Certification Scheme has a zero tolerance level on root knot nematodes. The presence of the root knot nematodes could be attributed to the cropping sequence and the shorter rotation periods being practised in the area. High cropping frequency of potatoes, particularly continuous cultivation, can lead to physical and economical losses because the population densities of soil-borne pathogenic organisms are enhanced (Vos *et al.* 1989).

5.2 Discussion

Despite having sufficient arable land, both new and old farmers in the SPQA were following a rotation scheme of 2 years potato seed and 3 year love grass instead of the 1 year seed crop and 3years love grass. These shorter rotation intervals were mostly being followed without approval from the relevant authorities. The practice was in response to the increased market demand of potatoes and farmers were reluctant to invest in opening new fields for rotating the seed crop as they perceive that potato yields were very low in the first year of using the new land. The farmers did not realise that shorter rotations result into pest and disease build up which subsequently drive up input costs and lowering seed quality resulting in an unsustainable cropping system. The farmers were not considering the losses due to increased pest damage, decreased soil health, and increased operating costs in response to the negative impacts as well as the risk of developing pesticide resistance due to frequent use of pesticides as they were focusing more on their immediate problems.

At most farms although they had a crop break for rotation purpose, they were not planting the weeping love grass as a rotational crop but rather leaving the land idle but with volunteer potato crops growing in it. Subsequently it means that there was no rotation at all on these fields. This cropping sequence caused the trueness to type contamination of varieties in the fields that were rejected during seed certification inspection (Table 5) due to off-type plants that were way above tolerance level of nil in foundation seed crops and 0.50% in AA grade seed. In 2014 a total of 30.4ha was rejected, thus depriving the nation about 600 t of seed. The quantity may seem low, but considering the low multiplication rate of potatoes, it is worth a lot since the country's seed demand is not usually met.

However although a total of 59ha and 1 982mt were rejected during the 2012,2013 and 2014 cropping season on seed produce in the SPQA (Table 5 and Table 6), this should not cause alarm on the quality of potato seed found on the market. Seed certification is meant to qualify or disqualify seed before it goes to the seed market therefore the disqualifications means that only quality seed enters into the market (Seeds Act, 2001). Basing on these figures, it means that strict monitoring should be done on all seed produced in this is required so as to make sure only quality seed comes out from this area as well as reducing unnecessary costs incurred from seed crop rejections and transport costs for seed which will be rejected at the company warehouse which is located more than 270km from the production area.

Most farmers (both old and new) in the SPQA were producing other crops like *Zea mays*, ware potato, pumpkins and vegetable crop than the mandatory seed potato in this area without the permission from the respective institutes as per the requirement of the Plant Pests and Diseases (Seed Potato Protection) Regulation, 1982. This kind of production needs to be regularised as this will encourage the multiplication of pests and diseases especially with crops such as table potato and pumpkin considering they do not undergo certification inspection. Occurrence of pest and diseases of quarantine importance might not be noticed in time and as a result pests could spread to areas where there was no infection. Also possible spread of diseases could be propagated by old farmers who were producing and selling unregistered varieties and uncertified seed to the new farmers in the seed potato quarantine area since such crops are not certified for genetic purity and seed health.
According to Joyce (1982b), the SPQA used to have one crop cycle produced each year with planting starting after the onset of the spring rains. This allowed a potato break period which is key in breaking insect pests and diseases cycles. Nevertheless three farms in this area were having more than one cycle of seed crops per year as they have resorted to supplementing with irrigation during the dry months. This practice allowed a continuous presence of potato crops in the SPQA.

The bacterium *Ralstonia solanacearum* was identified on 5 farms out of the 21 farms in the SPQA whilst the bacterium *Clavibacter michiganensis* was identified on 1 farm. The 2000 land reform could have introduced the diseases in the SPQA since some of the farmers who were found with the diseases on their farms were coming from neighbouring communal lands where the disease has already been identified in the area. Some of those farmers were holding dual lands, thus one in the quarantine area and another one in the communal area where they had been resettled from and were using the same farm implements in their home area and the farm in the SPQA. Five of the farms that had the identified diseases of quarantine importance are neighbouring farms and are all part of the new farmers who at times share farm implements. The majority of the new farmers in this SPQA did not have farm implements and the few that have them were not adequate for their farming operations and they relied on borrowing from neighbouring farms and this could have caused the contamination of the farms from one farm to another after sharing the implements. Although the bacterria is tuber borne and is predominatly disseminated through infested tuber in potato production (French *et al*., 1975; Champoiseau *et al*., 2010), infested soil and water are the other sources of its innoculum. According to Denny (2006), bacterial ooze can enter the surrounding soil or water contaminating farming equipment thus the exchanging of implements escalated the spread of the disease since they are localised in the same area and at times exchange farming implements.

As alluded by Ricardo *et al.* (2009) good quality seed potatoes can only be guaranteed through regular seed certification inspections during all stages of seed production to ensure minimal levels of infection. It was noted that from 2007 to 2012, the seed company failed to facilitate tuber inspections as a result seed sold in the SPQA was only inspected for certification in the field and tuber inspection certifications were not being done and yet most of the farmers have no access to foundation seed as it is always in limited supply and usually given to less than 4 farmers who then multiply it and supply it to other farmers in the area for further multiplication. Filgueira (2003) indicated that the initial process of potato production should involve the use of pathogen free seed potato tubers. The exchange of seed in the SPQA without the tuber certification means that these farmers have limited guarantee on the quality of seed. Since potato is prone to seed borne and soil borne diseases, these farmers also risk permanently contaminating their fields with the diseases of quarantine importance. This could also have been the source of contamination on the farms that were found to have *Pectobacterium carotovorum, Potato virus Y, Potato leaf roll virus Meloidgyne chitwoodi* and the *Phytophthora infestans*. The Seed Certification Scheme Notice (2000) requires that all potato seed tubers sold should be inspected for certification at least more than 14 days after harvesting and when not sold within 21 days of inspection, it must be inspected before selling as they are prone to post harvest diseases and very sensitive to post harvest conditions. However farmers indicated that with seed sold in the SPQA, at time when inspected the inspection was being done before the 14 days have elapsed and never re-inspected since the Certifying Authority was centralised in Harare thus exposing seed farmers within the SPQA to seed of poor sanitary quality that have the potential of contaminating their fields..

The evaluation on the competency of seed farmers in the SPQA which was done through comparing the performance of Amethyst, BP1, Diamond and KY20 of the AA2 and AA3 classes of seed from different sources showed that KY20 was the lowest yielding variety and had no significance difference in its performance across farmers. Amethyst out yielded the other varieties significantly and there was a significant difference on the performance of seed between amethyst seed from farmer 2 and 3 with that from farmer 1 and 4 in both AA2 grade and AA3 grade of seed. Although there were yield differences between farmers, the varieties were still yielding within their yield potential. There were very few cases of genetic impurities recorded on the field trial using the morphological characterisation. This could have been attributed to the fact that the seed used for planting the trial had undergone the certification process, thus it had already undergone genetic impurity screening before planting resulting in the use of already clean seed. Genetic finger printing could have given a definite answer on varietal purity if there are any slight changes in the genetic makeup of the varieties. The difference in performance of the seed from the different farmers and between the different classes could be attributed to the traces of viruses found in their seed since those that had lower performance had virus diseases detected in them.

The establishment of the SPQA, developing and implementing phytosanitary policies was meant to prevent the scheduled pathogens from being introduced in the area so as to protect local and export markets considering there is lack of effective control on the disease. However this can only be effective if there is full participation of farmers in adhering to the SPQA regulations, the seed company in monitoring seed production and facilitating timely inspections at the required stages of certification.

5.3 Conclusion: Seed production systems on quality of seed in the SPQA

The high cropping frequencies of potatoes, particularly continuous cultivation affect seed quality at the same time causing physical and economical losses due to the increased population densities of insect pests and diseases soil-borne pathogenic and genetic impurities of seed produced in the SPQA. However other insect pests of the potato are still within the quarantine thresholds even though the bacterium *Ralstonia solanacearum* and *Clavibacter michiganensis* were identified in the SPQA, the existing planting materials are still compliant to purity and statutory standards.

5.4 Policy implications of continued use of the Nyanga area as a suitable site for potato seed quarantine

As indicted in the IPPC, (1999) framework, quarantine status is assigned to diseases that are not yet present or present but not yet established in the region and can potentially cause serious economic damage in this region. The identification of the diseases in the SPQA means that the area is no longer safe for the production of the AA grade seed. However the diseases are localised on a certain portion of land in the SPQA therefore if there is means of managing the clean area, there might be need for remapping the SPQA leaving out the infected area. According to Breukers *et al.* (2006), eradication of the disease and prevention of new introductions of the diseases of quarantine importance are key, therefore farmers and the relevant authorities should aim at the same. There is also need for the introductions of other technologies such like micro propagation mini tubers production.

5.5 Policy Recommendations from the study

From the study, it is recommended that:

I. Although Bacterial wilt (*Ralstonia solanacearum*) and Potato bacterial ring rot (*Clavibacter michiganensis* subsp. *sepedonicum*) were identified in the SPQA, these diseases were identified on a localised portion as shown in Table 6, therefore only the areas identified with these diseases should be suspended from producing seed potatoes, ware potatoes or other crops from the Solanaceae family until a study has confirmed total eradication of the disease in those farms is recommended

II. There is need for decentralisation of seed certification services to the Nyanga area so as to strictly monitor the production of **AA** grade seed in the SPQA.

III. There is need for capacitating the Nyanga Experimental Station so as to enable them to produce more foundation seed so that each farmer can be given his own foundation seed to start the seed multiplication process in order to minimise chances of spreading diseases from one farm to another within the SPQA.

IV. The introduction of new technologies like production of minitubers as it reduce the seed multiplication cycle resulting in the reduction in spreading of pest and disease through the prolonged multiplication of seed from one farm to another

5.6 Suggestions for Further Research

Further research is recommended on:

i. Incidence and severity of Bacterial wilt (*Ralstonia solanacearum*) and Potato bacterial ring rot (*Clavibacter michiganensis* subsp. *sepedonicum*), distribution in Zimbabwe.

ii. Evaluation / selection of Bacterial wilt (*Ralstonia solanacearum*) and Potato bacterial ring rot (*Clavibacter michiganensis* subsp. *sepedonicum*) resistant cultivars.

iii. Potato breading programs that promote breading of varieties that are resistant to *Ralstonia solanacearum* and *Clavibacter michiganensis* subsp. *Sepedonicum*

iv. The quality of potato seed being produced outside the SPQA since potato seed production starts in the SPQA and goes to areas that are outside the SPQA before it is sold as seed on the market.

v. To look on the spread and risk map of Bacterial wilt (*Ralstonia solanacearum*) and Potato bacterial ring rot (*Clavibacter michiganensis* subsp. *sepedonicum*) in Zimbabwe.

REFERENCES

Acquaah, G., (2011). Principles of Crop Production: Theory, Techniques and Technology. (2nd Ed.). PHI Learning, Pvt. Ltd. New Delhi. pp. 666- 678.

Ali S., Kadian M.S., Ortiz O., Singh B.P., Chandla V.K., and Akhtar M., (2013). Degeneration of potato seed in Meghalaya and Nagaland states in north-eastern hills of India. *Potato Journal*, **40:** 122–7.

Albrechtsen SE (2006). Testing methods for seed transmitted viruses. Principles and Protocols. CABI Publishing, Wallingford pp. 47-81.

ACP (Atlantic Committee on Potatoes) (2003). Bacterial Ring Rot. Atlantic Provinces Agricultural Services Coordinating Committee. http://www.gnb.ca/0029/00290033-e.asp

Agricultural Marketing Authority (2014). Commodities Market monitoring (unpublished).

Babadoost, M., (1990) Bacterial Ring Rot of Potato. University of Illinois, Department of Crop Science, Extension.

Bishop, A.L. and Slack, S.A., (1987).Effect of inoculum dose and preparation, strain variation, and plant growth conditions on the eggplant assay for bacterial ring rot. *American Potato Journal,* **64:** 227-234.

Breukers, A., Kettenis, D.L., Mourits, M., Van Der Werf, W. And Oude Lansink, A., (2006), Individual-based models in analysis of disease transmission in plant production An application to potato brown rot. *Agricultural Systems*, **90:** 112-131

Champoiseau, P. G., Jones, J. B., & Allen. C. (2009). *Ralstonia solanacearum* Race 3biovar 2 causes tropical loses and temperate anxieties [Online]. Available at http:/www.apsnet.org/online/feature/Ralstonia/ (Accessed 15 November 2014). American Phytopathological Society. Madison, WI.

Champoiseau, P. G., Jones, J. B., Momol, T. M., Pingsheng, J., Allen, C., Norman, D. J. and Caldwell, K. (2010). *Ralstonia solanacearum* Race 3biovar 2 causing brown rot of potato, bacterial wilt of tomato and southern wilt of geranium [Online]. American Phytopathological Society. Madison, WI.

Chindo, P.S., Khan, F. A and Erinle, I.D. (1991) Reaction of three tomato cultivars to two vascular diseases in presence of root-knot. *Meloidogyne incognita* race1. *Crop Protection*, **10:** *62-64*

Chitwood, B, G., and E.M. Buhree. (1945). "Summary of soil fumigant tests made against the golden nematode of potatoes (*Heterodera rostochiensis,* Wollenweber), 1942-1944"

Christie, R.D., Schulz, J.T. and Gudmestad, N.C., (1993) Potato flea beetle (Coleoptera: Chrysomelidae) evaluated as a possible vector of ring rot bacterium in potatoes. *Journal of Economic Entomology,* **86(4)**: 1223-1227.

Christie, R.D., Sumalde, A.C., Schulz, J.T. and Gudmestad, N.C., (1991) Insect transmission of the bacterial ring rot pathogen. *American Potato Journal,* **68**: 363– 372.

CIP. (2007). *Procedure for standard evaluation trials of advanced potato clones. An International Cooperators' Guide.* CIP, Lima, Peru. 124 pages

Control of Goods (Import and Export) (Agriculture) Regulations, (2007)

Daniels, J. (2000). Evaluation of potato genotypes for resistance to potato virus Y. *Hortic. Bras.* **18**: 145-147

Davis, R.M., Nunez, J. and Smart, C., (1997) UC IPM pest management guidelines: Potato. The University of California, USA. http://www.ipm.ucdavis.edu/PMG/r607100211.html

De Boer, S.H., and McCann, M., (1990) Detection of *Corynebacterium sepedonicum* in potato cultivars with different propensities to express ring rot symptoms. *American Potato Journal,* **67**: 685-694

DEFRA (2011). Department for Environment, Food and Rural Affairs http://www.fera.defra.gov.uk/plants/publiations/documents/factsheets/pwd.pdf.

DEFRA (2002). Potato ring rot. (Department of Environment, Food and Rural Affairs), The United Kingdom. http://www.fera.defra.gov.uk/plants/plantHealth/pestsDiseases/potatoRingRot.cfm.

Denny T., (2006). Plant Pathogenic *Ralstonia* species. In: Gnamanicham, S. S. Plant-Associated bacteria. Dordrecht, Springer. Pp.1-62

Ephinston, J. G. (2005). The current bacterial wilt situation: a global overview. pp 9-28 in: Bacterial Wilt: The disease and the *Ralstonia solanacearum* Species Complex. C. Allen, P. Prior, and A.C. Hayward, eds. American Phytopathological Society, St. Paul, MN.

EPPO. (2004). *Ralstonia solanacearum. European Mediterranean Plant Protection Organisation Bulletin* **34,** 173-178.

Evans, K., and Stone, A, R. (1977). A review of the distribution and biology of potato cyst nematode *Globodera rostochiennsis* and *G. pallida*. PANS, **23**, 178-189.

Franc, G. (2007). Potato Wart. Online. APSnet Features. Doi:

10.1094/APSnetFeature-2007-0607

Franc, G.D., (1999), Persistence and Latency of *Clavibacter michiganensis* subsp. *Sepedonicus* in Field-Grown Seed Potatoes. *Plant Disease,* **83**: 247-250.

French, E. R., Gutarra, L., and Vilchez, G. (1975). Field survival of *Pseudomonas solanacearum* race 3 in Peru. *CIP Technical Information Bulletin,* **7:**1-6.

Goodey, J. B., and Franklin, M. T., (1958). pp. 140. *The Nematode Parasites of Plants Catalogued under their Hosts.* Farnham, England; Commonwealth Agricultural Bureaux.

Goodey, J. B., and Franklin, M. T., (1959). *The Nematode Parasites of Plants Catalogued under their Hosts, 1955-1958.* Farnham, England; Commonwealth Agricultural Bureaux. pp 66.

Gouws, R. and van der Waals, J.E. (2012). Occurrence and Control of Bacterial Diseases. Chapter 12. In: Denner, F.D.N., Venter, S.L. and Niederweiser, J.G. (eds.). Guide to Potato Production in South Africa. Potatoes South Africa, Pretoria. pp. 157-165.

Hapson M.C. (1993). History, biology and control of potato wart disease in Canada. *Canadian Journal of Plant Pathology*, **15**: 223-244

Hanssen, K.B. (1970). Seed control- meaning and purpose behind testing and certification *Rhodesia Agricultural Journal*, **67**: 45-50

Hayward A.C., (1991). Biology and epidemiology of bacterial wilt caused by *Pseudomonas solanacearum. Annual Review of Phytopathology,* **29**: 65-87

Heesterbeek, J.A. P. and Zadoks, J. C., (1987). Modelling pandemics of quarantine pests and diseases: problems and perspectives. *Crop Protection,* **6**: 211-221

Hopkins, G. B., Hutchinson, P. J. S., Patterson, P., Miller, J., Thornton, M., Hafez, S., and Alvarez, J. (2004). *Cropping Sequence and Rotation: Impact on Potato Production and Soil Condition*. Paper presented at the Idaho Seed Potato Conferences, Idaho

Hussain, A. and Faroq, K., (1995). *Seed* potato *systems in Pakistan*. Pakistan Agricultural Research Council; Pakistan, Islamabad. International Plant Protection Convention (IPPC). (1999): New Revised text approved by the FAO Conference at its 29th session.

Joyce, M.J., 1982a. *Potato Production in Zimbabwe.* In: S. Nganga (Ed.), Potato Development and Transfer of Technology in Tropical Africa. International Potato Center, Addis Ababa.

Joyce, M.J., 1982b. *Some Aspects of Seed Potato Production in Zimbabwe*. International Potato Course: Production, Storage, and Seed Technology. Report of Participants. International Agricultural Centre, Wageningen, The Netherlands.

Joyce, M.J., (1984). Country Presentation: Zimbabwe. Country Report Presented at the Regional Post-Harvest Workshop, 18-22 June 1984, Nairobi, Kenya. International Potato Centre, Region III.

Joyce, M.J., (1988). Potato Varietal Development Programme in Zimbabwe. Paper Presented at the Regional Seed Potato Workshop, Harare, Zimbabwe, 22-27 February 1988

Kelman, A. (1953). The bacterial wilt caused by *Pseudomomas solanacearum. North Carolina Agricultural Experiment Station Technical Bulletin N*o. **99**, 1-194

Khurana, S.M.P. and. Garg, I.D., (1992). *Potato mosaics*. Plant diseases of international importance, Vol II. Disease of vegetable and oilseeds, Prentice Hall, USA.

Knoetze, R., Malan, A.P., Mouton C. (2006). Differentiation of South African potato cyst nematode (PCN) by analysis of the DNA internal transcribed spacer *region. African Plant Protection* **12**; 103-110.

Langer, W.L., (1975) American foods and Europe population growth 1750–1850. *Journal of Social History*, **8(2):**51-66.

Lelliott, R.A., Stead, D.E., (1987). Methods in Plant Pathology Volume 2, Methods for the Diagnosis of Bacterial Diseases of Plants, Chapter 3 Diagnostic procedures; 3.5.7. Bacterial ring rot of potatoes (*Clavibacter michiganese* subsp. *sepedonicum* syn. *Corynebacterium sepedonicum*). Blackwell Scientific Publications. Pp. 97-101.

Mai, W.F., and B. Lear. (1953). "The golden nematode." Cornell Extension Bulletin. **870**.32 (Reprint No. 718).

Mai, W.F. (1977). "Worldwide distribution of potato-cyst nematodes and their importance in crop production." *Journal of Nematology*. **9**:30-34.

Manzer, F.E., Genereux, H., (1981) Compendium of Potato Diseases, Part I. Disease in the Presence of Infectious Pathogens, Bacterial Ring Rot. The American Phytopathological Society. pp. 9-10.

Martin, C. and French, E. R. (1985). Bacterial wilt of potato: *Pseudomonas solanacearum.* Technical Information Bulletin 13. International Potato Center, Lima, Peru. 16 pp.

Martin, C. and French, E. R. (1995) Covered-field host range for *Pseudomonas solacearum* race 3/biovar 2. ACIAR *Bacterial wilt newsletter* No 129.

Morrenhof, J., (1998). *The road to seed potato production, hettema 100 years.*Den Hang, The Netherlands: NIVAA, pp. 1-70

Milling A., Meng F., Denny T., Allen C. (2009). Interactions with hosts at cool temperatures,not cold tolerance, explain the unique epidemiology of *Ralstonia solanacearum* race 3 biovar 2

NIVAP (Netherlands Potato Consultative Foundation) (2005). The Inspection of Dutch Seed Potatoes: the importance of approval. http://www.aardappelpagia.nl/uk. Accessed 18 June 2014

Nortje, P. F., (2012). The Seed Programme and Certification of Seed Potatoes. Chapter 3. In: Denner, F.D.N., Venter, S.L. and Niederweiser, J.G. (eds.). Guide to Potato Production in South Africa. Potatoes South Africa, Pretoria. pp. 47-51.

Nyamapfene, K. (1991). Soils of Zimbabwe. Nehanda Publishers, Harare. 179 pp.

Nyamutukwa, S. (2010). Seed Production Constraints in the Nyanga Seed Potato Quarantine area, Seed Services Annual report, Zimbabwe, Department of Research and Specialists Services, Ministry of Agriculture, Mechanization and Irrigation Development.

Olssson, K. (1976) Overwintering of *Pseudomonas solanacearum* in Sweden. In *International Planning Conference and workshop on the ecology and control of bacterial wilt Caused by Pseudomonas solanacearum.* (Ed. By Sequueira, L; Kelman, A.), pp.105 109. North Carolina State University, Raleigh, USA.

Plant Breeders Rights Act [Chapter 18:16], (2001)

Plant Pests and Diseases Act [Chapter 19:08], (1989).

Plant Pests and Diseases (Seed Potato Protection) Regulations, (1982).

Plant Pests and Disease (Importation) Regulations, (1958) Ricardo, M.C., Jose E.D.P.P., Valdemar. F., Ce'sar, A. B. P. P., Erika, S. R., (2009). The production of seed potato by hydroponic methods in Brazil: Fruits, vegetables and biotechnology. Global Science Books **1**: 133-139

Rich, A.E., (1983). Potato Diseases, Chapter 2 Bacterial Diseases, Ring Rot. Academic Press Inc. pp. 20-25.

Rossman, A.Y., Britton, K., Luster, D., Palm, M., Roger, M. and Sherald, J. (2006). Evaluating the Threat posed by Fungi on the APHIS List of regulated Pests. Plant Management Network, Published 5/5/06

Rowe, R.C., Miller, S.A. and Riedel, R.M., (1995) Bacterial Ring Rot of Potatoes. Extension Fact Sheet, Ohio State University. http://ohioline.osu.edu/hyg-fact/3000/pdf/3103.pdf

Sahajdak A, Uznaska B (2003) Potato health requirements arising from EU regulations and the Treaty of Accession. Ochrona Roslin.

Sunaina, V., Kishore, V., and Shekhawat, G. S. (1989). Latent survival of Pseudomonas in potato tubers and weeds. *Journal of Plant Disease Protection,* **96**: 361-364.

Seeds Act [Chapter 19:13]. (2001).

Seeds (Certification Scheme) Notice,(2000)

Sonoda, R.M, Augustine, J.J and Volin, R,B. (1979) Bacterial wilt of tomato in Florida: history, status, and sources of resistance. *Proceedings of the Florida State Horticultural Society* **92:** 100-102

Steyn, P.J. (2012). Overview of the Potato Plant and Production. Chapter 2. In. Denner, F.D.N., Venter, S.L. and Niederweiser, J.G. (eds.). Guide to Potato Production in South Africa. Potatoes South Africa, Pretoria. pp. 19-249.

Struik, P.C. and S.G. Wiersema. (1999). Seed potato technology. Wageningen, Wageningen University Press.

Thiart, S., (2012).Seed Potato Production and Cultivar Trends in South Africa. Chapter 5. In: Denner, F.D.N., Venter, S.L. and Niederweiser, J.G. (eds.). Guide to Potato Production in South Africa. Potatoes South Africa, Pretoria. pp. 53-59.

Thompson, G.J., Visser, D. and Bellstedt, D.U., (2012). Viral Diseases of Potatoes. Chapter 11. In: Denner, F.D.N., Venter, S.L. and Niederweiser, J.G. (eds.). Guide to Potato Production in South Africa. Potatoes South Africa, Pretoria. pp. 147-155.

UNECE (2014) Guide to Seed Potato Diseases, Pests and Defects. (United Nations Economic Commission for Europe, Switzerland.http:www.unece.org/trade welcome/steering-committee-on-trade-capacity-and-standards/tradeagr/brochures-and-publications/potato- diseases-and- pests.html).

Vos, J., and Loon, C. D. (1989). Effects of Cropping Frequency on Potato Production. In J. Vos, C. D. Loon & G. J. Bollen (Eds.), *Effects of Crop Rotation on Potato Production in the Temperate Zones: Proceedings of the International Conference on Effects of Crop Rotation on Potato Production in the Temperate Zones, held August 14–19, 1988, Wageningen, The Netherlands* (pp. 1-23). Dordrecht: Springer Netherlands.

Walkey, D.G.A. (1980). Production of virus-free plants. *Acta Hort.,* **88:** 23-31.

Wallace, H. R. 1964. Pp. 152-162, *The Biology of plant parasitic nematode*. New York: St Martin's Press.

Wangai, A and Lelgut, D., (2001), Status of potato virus in Africa: Kenya Agricultural Research Institute IN Plant Virology: In: Sub Saharan Africa, Proceedings of a Conference Organised by International Institute of Tropical Agriculture eds. Hughes J.A. and Babajide, O. Odu (4-8 June 2001), 458-465

Zachos, D.G. (1957) The brown rot of potatoes in Greece, *Annales de I'Institut Phytopathologicaque Benaki,* New Series 1, 115-117.

APPENDIX 1 Survey Instrument

DATA COLLECTION SHEET FOR THE PREVALENCE OF PEST AND DISEASE IN THE NYANGA SEED POTATO QUARANTINE AREA

1) Name of farmer Mr/Mrs/Ms/Dr/Prof)…………………………………….……….

2) Farm/ Plot Name………………………………………………………………..

3) Physical Address………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

Tel/Fax …….. ……………………………. E-mail…………………………………

4) Year of occupation of the farm …………………….. …………………….

5) Farming System…………………………………………………………………

6) Farm size……………average area under potato seed production/year……..

7) Soil type…………………………………………………………………………

8) Level of Education (specify area studied)…………………….....................

………………………………………………………………………………………..

…………………………………………………………………………………………

9) Employed somewhere/ Not employed somewhere…………………………..

10) Who runs the farm?...

……………………………………………………………………………………….

11) If someone runs the farm, what is his level of education?................................

…………………………………………………………………………………………

……………………………………………………………………………………

…………………………………………………………………………………………

12) Number of years in potato seed production…………………………………...

13) Farm implements available at the farm (specify)…………………………….

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

……………………………………………………………………………………….

…………………………………………………………………………………………
……………………………………………………

14) Do you borrow farm implements Yes/ No

15) If yes from whom?..

…………………………………………………………………………………………

…………………………………………………………………………………………

16) Crops grown at the farm (specify if it is for seed or not………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

17) Do you irrigate your crops? ……………………………………………….

18) If yes please specify the source of your irrigation water……………………

………………………………………………………………………………

………………………………………………………………………………

19) If its seed potato, please specify your source of parent material

Variety	**Hactares**	**Source**

20) Rotation regime practiced at the farm…………………………………………

………………………………………………………………………………………

21) Output of previous season

Crop (seed/commercial)	Variety	Yield

22) What measures are implemented on the farm to control soil borne diseases?(**please tick)** No control/ Chemical control/ Cultural

23) Knowledge on Pest (insects, diseases and weeds)

How do you manage potato seed crop at:

i. Before planting………………………………………………………

……………………………………………………………………………

…………………………………………………………………………………

ii. At planting ………………………………………………………….

…………………………………………………………………………………

iii. During the vegetative stage………………………………………

……………………………………………………………………………

…………………………………………………………………………………

Pest and disease control practices…………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

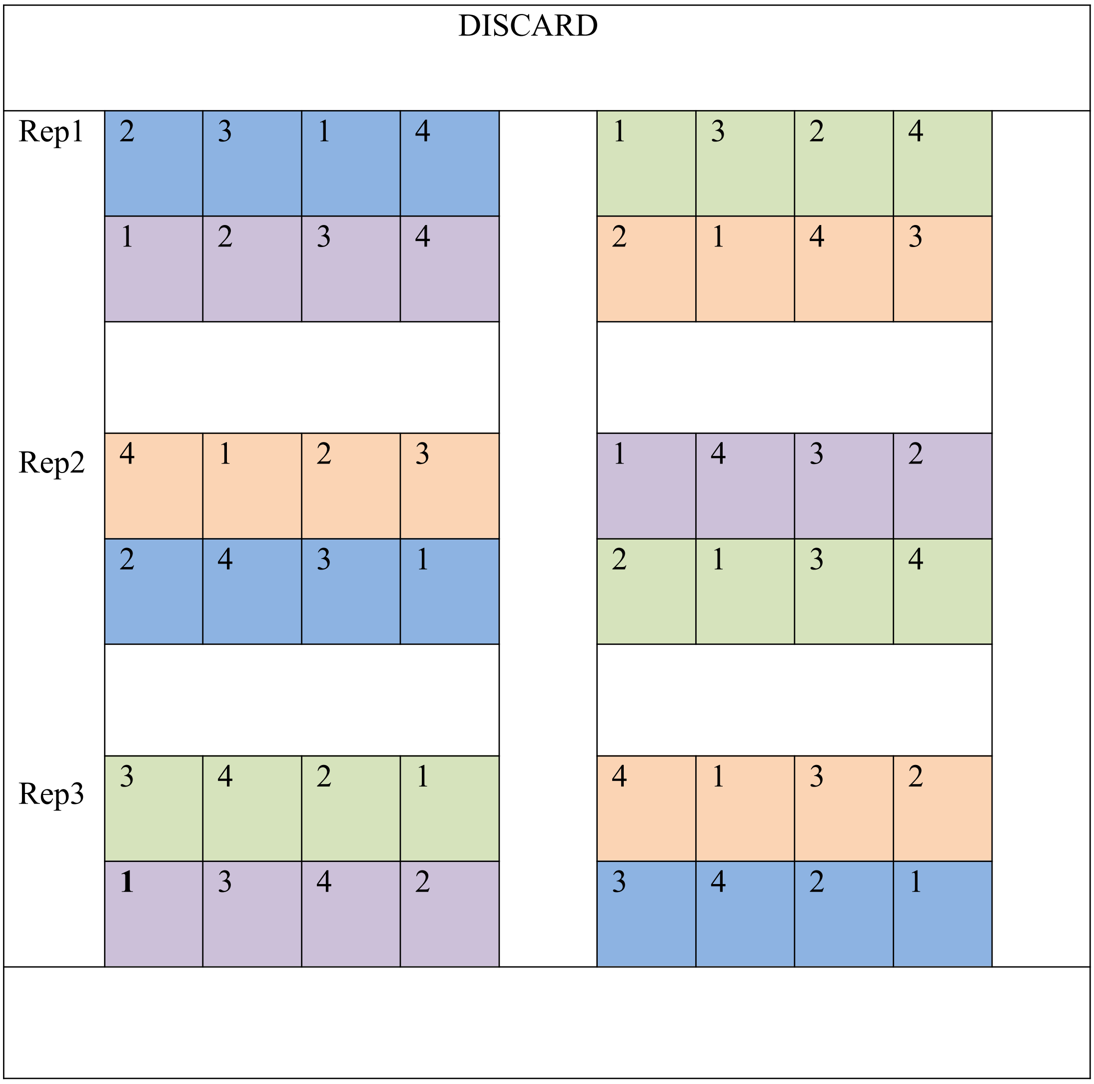
24) Pest and diseases samples collected

Yes	No

25) Sample I. D number

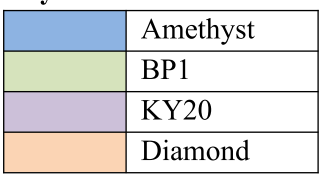
Sample description	I.D number	Estimated average disease severity

APPENDIX 2: Field trial layout



Main plot = 16rows x 0.9m x 2m long
Split (source) = 4 rows x0.9m x 2m

Key



Source of seed: 1, 2, 3, 4

APPENDIX 3: ANOVA Outputs from field data analyses

B-1 Artfarm 2013 trial

Variate: Yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.158	0.579	0.12	
Block.*Units* stratum					
Source	3	343.089	114.363	22.78	<.001
Variety	3	976.897	325.632	64.86	<.001
Source.Variety	9	190.907	21.212	4.23	0.001
Residual	30	150.616	5.021		
Total	47	1662.668			

Tables of means
Variate: Yield
Grand mean 42.88

Source	1	2	3	4
	47.33	41.61	40.26	42.30

Variety	1	2	3	4
	50.30	40.51	42.35	38.35

Source	Variety	1	2	3	4
1		59.70	42.89	45.87	40.86
2		47.33	38.43	41.59	39.08
3		44.02	39.75	41.38	35.91
4		50.13	40.95	40.54	37.56

Least significant differences of means (5% level)

Table	Source	Variety	Source Variety
rep.	12	12	3
d.f.	30	30	30
l.s.d.	1.868	1.868	3.736

Standard errors of means

Table	Source	Variety	Source Variety
rep.	12	12	3
d.f.	30	30	30
e.s.e.	0.647	0.647	1.294

Standard errors of differences of means

Table	Source	Variety	Source Variety
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.915	0.915	1.829

Analysis of variance

Variate: Offtypes

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.0417	0.0208	0.09	
Block.*Units* stratum					
Source	3	1.3958	0.4653	1.91	0.149
Variety	3	1.0625	0.3542	1.46	0.246
Source.Variety	9	2.1875	0.2431	1.00	0.461
Residual	30	7.2917	0.2431		
Total	47	11.9792			

Information summary
All terms orthogonal, none aliased.
Message: the following units have large residuals.

Block 1 *units* 4	-0.979	s.e.	0.390
Block 1 *units* 11	1.354	s.e.	0.390
Block 2 *units* 12	1.292	s.e.	0.390
Block 3 *units* 4	1.021	s.e.	0.390

Tables of means

Variate: Offtypes

Grand mean 0.146

Source	1	2	3	4
	0.000	0.000	0.167	0.417

Variety	1	2	3	4
	0.250	0.000	0.333	0.000

Source	Variety	1	2	3	4
1		0.000	0.000	0.000	0.000
2		0.000	0.000	0.000	0.000
3		0.000	0.000	0.667	0.000
4		1.000	0.000	0.667	0.000

Standard errors of means

Table	Source	Variety	Source Variety
rep.	12	12	3
d.f.	30	30	30
e.s.e.	0.1423	0.1423	0.2846

Standard errors of differences of means

Table	Source	Variety	Source Variety
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.2013	0.2013	0.4025

Least significant differences of means (5% level)

Table	Source	Variety	Source Variety
rep.	12	12	3

d.f.	30	30	30
l.s.d.	0.4110	0.4110	0.8221

Analysis of variance

Variate: Disease

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.7917	0.3958	0.86	
Block.*Units* stratum					
Source	3	3.2292	1.0764	2.33	0.095
Variety	3	2.3958	0.7986	1.73	0.183
Source.Variety	9	2.1875	0.2431	0.53	0.844
Residual	30	13.8750	0.4625		
Total	47	22.4792			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

Block 2 *units* 11 1.854 s.e. 0.538

Block 2 *units* 15 -1.479 s.e. 0.538

Block 2 *units* 16 1.188 s.e. 0.538

Block 3 *units* 15 1.646 s.e. 0.538

Tables of means

Variate: Disease

Grand mean 0.229

Source	1	2	3	4
	0.000	0.083	0.667	0.167

Variety	1	2	3	4

	0.083	0.000	0.250	0.583	
Source	Variety	1	2	3	4
1		0.000	0.000	0.000	0.000
2		0.000	0.000	0.000	0.333
3		0.333	0.000	1.000	1.333
4		0.000	0.000	0.000	0.667

Standard errors of means

Table	Source	Variety	Source Variety
rep.	12	12	3
d.f.	30	30	30
e.s.e.	0.1963	0.1963	0.3926

Standard errors of differences of means

Table	Source	Variety	Source Variety
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.2776	0.2776	0.5553

Least significant differences of means (5% level)

Table	Source	Variety	Source Variety
rep.	12	12	3
d.f.	30	30	30
l.s.d.	0.5670	0.5670	1.1340

B-2: Divonia 2013

Analysis of variance

Variate: Yield_2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block_2 stratum	2	3.465	1.732	0.32	
Block_2.*Units* stratum					
Variety_2	3	1098.850	366.283	67.50	<.001
Source_2	3	314.343	104.781	19.31	<.001
Variety_2.Source_2	9	252.478	28.053	5.17	<.001
Residual	30	162.792	5.426		
Total	47	1831.928			

Information summary
All terms orthogonal, none aliased.
Message: the following units have large residuals.

Block_2 1 *units* 2	-4.42	s.e.	1.84
Block_2 3 *units* 3	-4.19	s.e.	1.84

Tables of means
Variate: Yield_2
Grand mean 42.73

Variety_2	1	2	3	4
	50.50	40.17	42.46	37.78

Source_2	1	2	3	4
	46.98	41.48	40.22	42.24

Variety_2	Source_2	1	2	3	4
1		60.53	47.33	44.02	50.13
2		41.27	38.23	40.23	40.95

3	45.93	42.25	41.38	40.27
4	40.18	38.12	35.23	37.59

Standard errors of means

Table	Variety_2	Source_2	Variety_2 Source_2
rep.	12	12	3
d.f.	30	30	30
e.s.e.	0.672	0.672	1.345

Standard errors of differences of means

Table	Variety_2	Source_2	Variety_2 Source_2
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.951	0.951	1.902

Least significant differences of means (5% level)

Table	Variety_2	Source_2	Variety_2 Source_2
rep.	12	12	3
d.f.	30	30	30
l.s.d.	1.942	1.942	3.884

B-3: AA2 grade ART Farm 2014

Analysis of variance

Variate: Yield_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	5.365	2.683	0.77	
Block.*Units* stratum					
Source_1	3	360.698	120.233	34.44	<.001
Variety_1	3	1005.330	335.110	96.00	<.001
Source_1.Variety_1	9	188.096	20.900	5.99	<.001
Residual	30	104.723	3.491		

Total	47	1664.211

Information summary
All terms orthogonal, none aliased.

Tables of effects

Variate: Yield_1

Block.*Units* stratum

Source_1 effects, e.s.e. 0.539, rep. 12

Source_1	1	2	3	4
	4.59	-1.23	-2.65	-0.70

Variety_1 effects, e.s.e. 0.539, rep. 12

Variety_1	1	2	3	4
	7.52	-2.09	-0.70	-4.73

Source_1.Variety_1 effects, e.s.e. 1.079, rep. 3

Source_1	Variety_1	1	2	3	4
1	4.82	-0.98	-1.99	-1.84	
2	-1.73	-1.21	0.87	2.08	
3	-3.63	1.87	1.96	-0.19	
4	0.54	0.33	-0.83	-0.04	

Tables of means
Variate: Yield_1
Grand mean 42.77

Source_1	1	2	3	4
	47.36	41.54	40.13	42.07

Variety_1	1	2	3	4
	50.30	40.68	42.07	38.05

Source_1	Variety_1	1	2	3	4
1	59.70	44.28	44.67	40.79	
2	47.33	38.23	41.71	38.89	
3	44.02	39.90	41.38	35.21	
4	50.13	40.31	40.54	37.30	

Standard errors of means

Table	Source_1	Variety_1	Source_1 Variety_1
rep.	12	12	3
d.f.	30	30	30
e.s.e.	0.539	0.539	1.079

Standard errors of differences of means

Table	Source_1	Variety_1	Source_1 Variety_1
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.763	0.763	1.526

Least significant differences of means (5% level)

Table	Source_1	Variety_1	Source_1 Variety_1
rep.	12	12	3
d.f.	30	30	30
l.s.d.	1.558	1.558	3.115

Stratum standard errors and coefficients of variation

Variate: Yield_1

Stratum	d.f.	s.e.	cv%
Block	2	0.409	1.0
Block.*Units*	30	1.868	4.4

B-4: AA3 grade Divonia 2013

Analysis of variance

Variate: Yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	3.465	1.732	0.32	
Block.*Units* stratum					
Variety	3	1098.850	366.283	67.50	<.001
Source	3	314.343	104.781	19.31	<.001
Variety.Source	9	252.478	28.053	5.17	<.001

Residual	30	162.792	5.426
Total	47	1831.928	

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

Block 1 *units* 2	-4.42	s.e.	1.84
Block 3 *units* 3	-4.19	s.e.	1.84

Tables of means

Variate: Yield

Grand mean 42.73

Variety	1	2	3	4
	50.50	40.17	42.46	37.78

Source	1	2	3	4
	46.98	41.48	40.22	42.24

Variety	Source	1	2	3	4
1		60.53	47.33	44.02	50.13
2		41.27	38.23	40.23	40.95
3		45.93	42.25	41.38	40.27
4		40.18	38.12	35.23	37.59

Standard errors of differences of means

Table	Variety	Source	Variety Source
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.951	0.951	1.902

B-5: AA3 grade ART Farm 2013

Analysis of variance

Variate: Yield_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block_1 stratum	2	1.158	0.579	0.12	

Block_1.*Units* stratum

Source_1	3	343.089	114.363	22.78	<.001
Variety_1	3	976.897	325.632	64.86	<.001
Source_1.Variety_1	9	190.907	21.212	4.23	0.001
Residual	30	150.616	5.021		
Total	47	1662.668			

Information summary
All terms orthogonal, none aliased.
Message: the following units have large residuals.

Block_1 1 *units* 2	-4.06	s.e.	1.77
Block_1 3 *units* 3	-4.66	s.e.	1.77

Tables of means
Variate: Yield_1
Grand mean 42.88

Source_1	1	2	3	4
	47.33	41.61	40.26	42.30

Variety_1	1	2	3	4
	50.30	40.51	42.35	38.35

Source_1	Variety_1 1	2	3	4
1	59.70	42.89	45.87	40.86
2	47.33	38.43	41.59	39.08
3	44.02	39.75	41.38	35.91
4	50.13	40.95	40.54	37.56

Standard errors of differences of means

Table	Source_1	Variety_1	Source_1 Variety_1
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.915	0.915	1.829

B-6: AA3 grade ART Farm 2014

Analysis of variance
Variate: Yield_2
Source of variation d.f. s.s. m.s. v.r. F pr.

Block_2 stratum	2	5.365	2.683	0.77	
Block_2.*Units* stratum					
Variety_2	3	1005.330	335.110	96.00	<.001
Source_2	3	360.698	120.233	34.44	<.001
Variety_2.Source_2	9	188.096	20.900	5.99	<.001
Residual	30	104.723	3.491		
Total	47	1664.211			

Information summary
All terms orthogonal, none aliased.
Message: the following units have large residuals.

Block_2 1 *units* 2	-3.91	s.e.	1.48
Block_2 2 *units* 2	3.33	s.e.	1.48
Block_2 3 *units* 3	-4.50	s.e.	1.48

Tables of means
Variate: Yield_2
Grand mean 42.77

Variety_2	1	2	3	4
	50.30	40.68	42.07	38.05

Source_2	1	2	3	4
	47.36	41.54	40.13	42.07

Variety_2	Source_2 1	2	3	4
1	59.70	47.33	44.02	50.13
2	44.28	38.23	39.90	40.31
3	44.67	41.71	41.38	40.54
4	40.79	38.89	35.21	37.30

Standard errors of differences of means

Table	Variety_2	Source_2	Variety_2 Source_2
rep.	12	12	3
d.f.	30	30	30
s.e.d.	0.763	0.763	1.526
Effect			

APPENDIX 4: SPSS Analysis Frequencies

Frequency Table

Year of occupation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	before 2000	6	27.3	27.3	27.3
	2000-2005	9	40.9	40.9	68.2
	2006-2010	7	31.8	31.8	100.0
	Total	22	100.0	100.0	

Farming_system

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	mixed farming	15	68.2	68.2	68.2
	sole seed potato	7	31.8	31.8	100.0
	Total	22	100.0	100.0	

Arable_land

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	20-<50	5	22.7	22.7	22.7
	50-<100	7	31.8	31.8	54.5
	100-<150	4	18.2	18.2	72.7
	150>	6	27.3	27.3	100.0
	Total	22	100.0	100.0	

Average area under seed potato production

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	<5	8	36.4	36.4	36.4
	5-<10	1	4.5	4.5	40.9
	10-<20	6	27.3	27.3	68.2

		Frequency	Percent	Valid Percent	Cumulative Percent
	20-<50	2	9.1	9.1	77.3
	50>	5	22.7	22.7	100.0
	Total	22	100.0	100.0	

Level of Education

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	elementary	2	9.1	9.1	9.1
	high school	7	31.8	31.8	40.9
	college	10	45.5	45.5	86.4
	university	3	13.6	13.6	100.0
	Total	22	100.0	100.0	

Type of farmer

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Full time farmer	14	63.6	63.6	63.6
	part time farmer	5	22.7	22.7	86.4
	visiting farmer	3	13.6	13.6	100.0
	Total	22	100.0	100.0	

Number of years in seed potato production

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1-5	4	18.2	18.2	18.2
	6-10	8	36.4	36.4	54.5
	11-15	4	18.2	18.2	72.7
	above 15	6	27.3	27.3	100.0
	Total	22	100.0	100.0	

Farm implement ownership at the farm

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	all implements required	11	50.0	50.0	50.0
	some	11	50.0	50.0	100.0

Total	22	100.0	100.0	

Do you borrow implements

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	11	50.0	50.0	50.0
	no	11	50.0	50.0	100.0
	Total	22	100.0	100.0	

If_yes

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	one fixed person	2	9.1	16.7	16.7
	different	10	45.5	83.3	100.0
	Total	12	54.5	100.0	
Missing	System	10	45.5		
Total		22	100.0		

For what purpose are the potato grown at your farm

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	seed	11	50.0	50.0	50.0
	ware	2	9.1	9.1	59.1
	both	9	40.9	40.9	100.0
	Total	22	100.0	100.0	

Are there any other crops grown at your farm?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	13	59.1	59.1	59.1
	no	9	40.9	40.9	100.0
	Total	22	100.0	100.0	

If yes, are they (regulated/not)

	Frequency	Percent	Valid Percent	Cumulative Percent

Valid	not regulated crops in the SPQA	14	63.6	100.0	1
Missing	System	8	36.4		
Total		22	100.0		

Do you irrigate your crops

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	3	13.6	13.6	13.6
	no	19	86.4	86.4	100.0
	Total	22	100.0	100.0	

If yes, please specify the type of irrigation water

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	reservoir	3	13.6	100.0	100.0
Missing	System	19	86.4		
Total		22	100.0		

Rotation regime practised

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1yr potato, 2yrs love grass	2	9.1	9.1	9.1
	1yr potato, 3yr love grass	6	27.3	27.3	36.4
	2yrs potato, 3yrs love grass	5	22.7	22.7	59.1
	2yrs potato, 4yrs love grass	1	4.5	4.5	63.6
	1yr potato, 2yrs fallow	1	4.5	4.5	68.2
	2yrs potato, 3yrs fallow	7	31.8	31.8	100.0
	Total	22	100.0	100.0	