INFLUENCE OF PHOSPHOROUS FERTILIZER AND LIME ON SEED QUALITY OF SOYBEAN (*Glycine max* (L.) Merrill) IN WESTERN KENYA

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DECLARATION

Declaration by the Candidate

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DEDICATION

I dedicate this piece of academic work to my family - the invaluable support I got from my spouse, Rose Chepatei, and my sons Charlton Toroitich, Lawrence Pkorir and Martin Pkalya were priceless and inexpressible. The success of this work will always be cherished as a well walked journey and a motivation for my siblings to aim higher in their academic journey.

ABSTRACT

Soybean (*Glycine max* (L.) Merrill) is a versatile crop useful in the economy as human diet, animal feed and for industrial purposes. However, production has been dwindling due to poor seed quality among other constraints. Therefore, a field experiment was conducted from June-November 2015 at University of Eldoret farm in Uasin Gishu County and Agricultural Training Centre (ATC) farm in Busia County. The aim of the study was to study the influence of phosphorous fertilizer and lime in improving the seed yield, quality and storability of soybean cultivars. A factorial experiment was laid out in RCBD with three replicates involving: two varieties of soybean; SB 19 (proteinous) and SB 133 (oily), three P fertilizer rates at 0, 30 and 60 kg P ha^{-1} and two levels of lime at 0 and 2 ton ha^{-1}. All the agronomic practices were carried out as recommended, the seeds were harvested and sundried to 13 % moisture content. The parameters measured before storage were seed yield, 1000 seed weight (g), initial electrical conductivity, percent germination, seed oil and protein content. The seed were subjected to storage treatment under controlled temperature at 10 ˚C and ambient condition for a period of 6 months, after which seed vigour and viability were determined. All the data collected was subjected to analysis of variance and significant differences ($p < 0.05$) separated using Tukey's HSD in R® statistical package version 3.3.1. Seed yield was significantly influenced by phosphorous fertilizer, where yield increase was highest at 30 kg P ha^{-1} of 39 % in SB 133 in Busia and 37 % in SB 19 in Eldoret. Lime increased seed yield for SB 19 by 27 % and 4 % in Busia and Eldoret respectively. Seed oil content was influenced by phosphorous fertilizer and lime in Busia where high value of 21.92 % recorded at 60 kg P ha^{-1}. Seed protein increased with phosphorous fertilizer to 40.40 % in SB 19 and 39.64 % in SB 133 in Eldoret. Lime application was effective in both sites and increased seed protein content. Seed electrical conductivity responded to phosphorous fertilizer where high value of 107.93 and 120.75 µ S cm^{-1} g^{-1} was recorded at 60 kg P ha^{-1} implying seed vigour loss. Seed germination was not influenced by phosphorous fertilizer and lime. Seed storability as measured by vigour and viability was influenced by cultivar, storage duration and condition. Oily seeds (SB 133) deteriorated rapidly compared to proteinous as storage duration increases and more rapidly in ambient condition. Deductions from this study indicates that high phosphorous level is detrimental to seed yield and physiological quality. It recommends that the application rate of phosphorous fertilizer should not exceed 30 kg P ha^{-1} in ferralsols soil of Western Kenya. Finally, the study suggests further research on different phosphorous fertilizer rates at different agro-ecological zones to ascertain optimum P application rates that guarantees optimal seed yield and quality.

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LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

ADP	Adenosine diphosphate
AGRA	Alliance for a Green Revolution in Africa
ANOVA	Analysis of Variance
AOSA	Association of Official Seed Analysts
ATC	Agricultural Training Center
ATP	Adenosine Triphosphate
BIDCO	Bidco Oil Refineries Limited
CIAT	Centro Internacional de Agricultura Tropical
CIDP-UG	County Integrated Development Plan
DAP	Di-ammonium Phosphate
DNA	Deoxyribonucleic acid
EC	Electrical conductivity
FAO	Food and Agricultural Organization of the United Nations
FAOSTAT	Food and Agricultural Organization statistics
GOK	Government of Kenya
HSD	Honest Significant Difference
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	International Institute of Tropical Agriculture
IPNI	International Plant Nutrition Institute
ISTA	International Seed Testing Association
NACOSTI	National Commission for Science, Technology and Innovation
NH_4	Ammonium

RCBD	Randomized Complete Block Design
RNA	Ribonucleic acid
SB 133	Soybean Cultivar that is high in Oil referred to as Saga
SB 19	Soybean Cultivar that is high in Protein
SSA	Sub-Saharan Africa
TSBF	Tropical Soil Biology and Fertility Institute
TSP	Triple Super Phosphate
USDA	U.S. Department of Agriculture

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CHAPTER ONE

INTRODUCTION

1.0 Background Information

Soybean (*Glycine max* (L.) Merrill) is a leguminous crop grown for its beans which are valued for its nutritional attributes. It comprises of 38-45% protein, 18-20% edible oil (where 85% is composed of cholesterol-free unsaturated fats), 24-26% carbohydrate and vitamins on dry matter basis (Wilcox & Shibles, 2001; Achakzai *et al.*, 2002; Morshed *et al.*, 2008). It exhibits multiple uses as a source of feed for livestock and fish, protein and oil for human diet, and bio-energy for industrial purposes among other uses (Myaka *et al.*, 2005; Morshed *et al.*, 2008; Macák & Candráková, 2013)

Soybean is processed into products such as flour, soymilk and yoghurt, soy meat, oil, soy beverages, fried soybeans, snacks and chunks which have differential tastes and long shelf life in storage (Chianu *et al.*, 2009). These products are cholesterol-free, with lower levels of saturated fats, high levels of phosphorus, calcium, iron, fibre, essential minerals and vitamins (Wafula & Riungu, 1999; BIDCO, 2005), as well as amino acid required for optimum body growth and development thus offering solution to protein-calorie malnutrition (Ngare & Muttunga, 1999; Burstin *et al.*, 2011).

Consumption of soybean has been associated with a number of health benefits. For instance, persons suffering from digestive problem such as babies with lactose intolerance will benefit from taking soymilk (Greenberg & Hartung, 1998). Furthermore, the presence of bioactive isoflavones has been reported to prevent or treat cancer (breast, colon and prostate), diabetes, hypertension, heart diseases and easing symptoms of menopause condition in women (Chianu *et al.*, 2008; Mahasi *et al.*, 2010).

In many cropping systems, soybean supplies significant amounts of nitrogen through biological fixation to intercrop and to the subsequent crops in the rotation. This helps in reducing the cost of production for resource-poor farmers who cannot afford sufficient mineral fertilizers for sustainable agricultural intensification (Peoples & Craswell, 1992; Rao & Teddy, 2010; Sanginga *et al.*, 2003). This will therefore contribute significantly to the economic situation of a country and the livelihoods of the growers as the demand for the soybean products increases (Jagwe & Owuor, 2004).

Soybean production in Kenya has been rising steadily but at a very slow pace due to low on farm productivity and marketing challenges. This is in contrast to the Nigerian situation where farmers have overcome production and marketing challenges by adding value to soybean locally in homestead. For instance, production of “Awara” or Tofu (Japanese), a cottage cheese-like product formed into a cake, which is precipitated from soy milk by a calcium salt or previously fermented starchy water has become a game changer in promoting soybean production raising the demand of soybean beyond the current supply (Abubakar Husseini - Personal communication).

The low production in Kenya has negated the efforts of the numerous researches and funded projects supporting the adoption of the crop in Kenya besides the ever appreciating demand for soybean products. This research acknowledges the existence of the challenges affecting soybean production such as, limited production resources, poor marketing channels, insufficient extension information, poor yielding varieties, and low application of fertilizers as well as inadequate utilization of rhizobia inoculants.

Previous and current researches have largely dwelled on studying the effects of phosphorous fertilizer and lime on seed yield, whereas limited study had been done on seed quality. This research therefore seeks to study the influence of phosphorous and lime on seed quality.

1.1 Statement of the Problem

Soybean production in Kenya has been very low with an average production of 715 kg ha^{-1} (FAO, 2009) and 450 kg ha^{-1} in Western Kenya (Chianu, 2009). This production is much lower than the crop's potential of 3000–3600 kg ha^{-1}. The low yields have been attributed by farmers to among many other constraints to poor seed quality since majority of them plant seeds from unknown sources and quality. These seeds are either acquired from open air market, own saved seeds or exchange from fellow farmers where the cultivar attributes such as genetic purity, yielding potential, tolerance to diseases and maturing stage are not well unknown.

Availability and use of good quality seeds is an important agronomic input that determines the success of crop production system. Unfortunately, soybean seeds stores poorly and deteriorate more rapidly in cultivars with high oil than protein content (Nagel and Borner, 2010). In this regard, a few recent studies on seed physiology have pointed out that phosphorous is also important in influencing the seed quality of soybean (Goggi *et al.*, 2013). However, previous research laid more emphasis on unravelling the relationships that existed between phosphorous and yield thereby widening inequalities in understanding the influence of phosphorous on seed physiological quality and storability.

Furthermore, the soils in Western Kenya are predominantly acidic with highly reactive Aluminium (Al^{+}) and Iron (Fe^{3+}) ions which fixes and holds P in immobile pools. These reactions makes P unavailable for plant uptake thereby retarding the role it plays in enhancing plant's physiological performance such as improving nodulation and symbiotic relationship, hastening maturity and enhancing tolerance to environmental stresses (Gangasuresh *et al.*, 2010; Shahid *et al.*, 2009) which ultimately results in reduced crop yields. Other studies have shown escalated demands for phosphorous during pod and seed filling of up to 60 % of the total P absorbed in the plant which is used in the synthesis of protein, seed oils, phospholipids and phytin (Shahid *et al.*, 2009; Uchida, 2000). This implies that an interference in P supply in the soil will directly affect the soybean seed quality and yields. A field experiment was therefore conducted to examine the influence of phosphorous fertilizer and lime on yield and seed quality of soybean cultivars when produced in two agro-ecological zones.

1.2 Justification

Seed of high quality are of great socio-economic significance in agricultural production systems since it reflects what the final yield would be when other factors of production are held constant. Nutritionally, soybean has a high composition of protein and oil, thereby presenting an invaluable opportunity of alleviating abject food and nutritional insecurity, poverty and increasing household income. In spite of the essential functions that soybean is contributing in the domestic and industrial uses, decline in production as attributed by poor seed quality and inadequate fertilizer use is the most impeding challenge.

Phosphorous is an important element that plays a fundamental role in seed quality development. In this regard, it promotes crop performance such as vigorous growth, increased nodulation and improved symbiotic relationship, early maturity and improved tolerance to environmental stresses which ultimately improves on the seed quality (Gangasuresh *et al.*, 2010; Shahid *et al.*, 2009). Furthermore, it has been shown that the demand of P in soybean increases to the peak during pod and seed filling where it is used in the synthesis of proteins, phospholipids and phytin (Shahid *et al.*, 2009; Uchida, 2000), thus making the review of P influence and lime on seed quality imperative.

However, in Western Kenya, the soils are predominantly acidic where in Busia and Eldoret are Orthic ferralsols which limits P availability through fixation. Such soils have high levels Al^{3+} and Mn^{2+} toxicity which retards soybean growth and development (Kiplagat *et al.*, 2010). Likewise, soybean is more sensitive to high levels of soil acidity and thus performs poorly with increasing acidity. To ameliorate this condition, it is important to apply lime so as to neutralize the effect of soil acidity and avail P and other essential elements fixed in the soil for plant uptake and use. Depending on the liming material, it can supply sufficient amounts of Ca and Mg that helps in displacing H^+, $Al^{3+}$and Fe^{3+}, ions from the soil colloids (Kisinyo *et al*., 2013), thereby raising the soil *p*H and preventing it from reaching levels that are toxic to plants (Kiplagat *et al*, 2010). With ever appreciating demand for soybean and its by-products in the Kenyan economy, there is a need to increase on-farm production and seed quality of soybean. In this regards, this research undertook an experiment to determine the effect of P fertilizer and lime and recommend threshold level where seed yield and quality is optimized.

1.3 General objectives

The objective of this study was to improve the seed yield, quality and storability of soybean cultivars produced in Busia and Uasin Gishu counties through phosphorous fertilizer and lime

1.3.1 Specific objectives

i. To evaluate the influence of phosphorous fertilizer and lime on seed yield of soybean cultivars produced in Busia and Eldoret.

ii. To determine the influence of phosphorous fertilizer and lime on seed crude oil, protein content, vigour and viability of soybean cultivars produced in Busia and Eldoret

iii. To evaluate the influence of storage duration and condition on seed vigour and viability of soybean cultivars produced in Busia and Eldoret.

1.4 Hypothesis

1. Phosphorous fertilizer and lime significantly affects the seed yield of soybean cultivars.
2. Phosphorous fertilizer and lime significantly influences seed oil content, protein content, vigour and viability of soybean cultivars
3. Storage duration and condition significantly influences seed vigour and viability of soybean cultivars.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soybean Production in the World

In the world, soybean is the largest source of edible oils amongst the major oilseed crops in the world such as cottonseed, sunflower-seed, canola, rapeseed, and peanuts. In the United States, soybean is a dominant oil seed accounting for 90% of total produced oil production (USDA, 2008). In regard to global soybean production, USA is the major grower producing between 40 to 45% of the world's total production of 189 million tons. Food and Agricultural Organization (FAO) statistics indicates that the top ten major producers in the world producing about 98% of production (185 million MT) includes; USA, Brazil, Argentina, China, India, Paraguay, Canada, Bolivia, Indonesia, and Nigeria in that order (FAO, 2008;2011).

In Africa, soybean is not a major crop where its production has been less than 1 % of total world soybean production compared to USA, South Latin America and Asia. Nigeria, South Africa, Uganda, and Zimbabwe are among the main producers in Africa. Nonetheless, soybean production in Sub-Saharan Africa (SSA) has shown an increasing trend in cultivated area and production. Increase in population in this countries had tremendously raised the demand for soybean products beyond the current supply thus leading to massive imports from these countries to fill the gap.

Efforts have been made by funding institutions to support collaborative researches in soybean production. Amongst the fronted interventions explored include; development of varieties with good yielding abilities and tolerant to wide environmental factors, building farmers' capacity through training of households on soybean agronomy, utilization, health benefits, value addition and marketing (Chianu *et al.*, 2009). The most notable funding agencies and research institutions in Sub-Saharan Africa include; the Rockefeller Foundation, Melinda and Bill Gates Foundation and Howard Buffet Foundation, Alliance for a Green Revolution in Africa (AGRA), Tropical Soil Biology and Fertility institute of International Centre of Tropical Agriculture (TSBF-CIAT), N2Africa, International Institute of Tropical Agriculture (IITA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and International Plant Nutrition Institute (IPNI) among other national agricultural research centers.

2.2 Soybean production in Kenya

Kenya is among the countries benefiting from the concerted efforts of the regional research institutions that have been in SSA for a long time promoting the legume research, production and consumption. However, the production of soybean in this country has been very low, given that the bulk of the producers are smallholder farmers (with 0.1 to 0.2 ha), who have limited production capacity. Production constraints especially in the small holder farms have been a pressing issue in spite of the government identifying soybean as a pillar of economic growth in her Vision 2030 plan (G.O.K, 2007). The lack of sufficient agronomic information, access to production inputs and improved varieties have in the 1990s held the national average production stagnant at 800 kg ha^{-1} (FAO, 2008) despite on-farm demonstration plots indicating a high potential yields of between 3000-3600 kg ha^{-1} from improved varieties (GOK, 2009). Kenya has been increasing her annual imports every year to satisfy the local demand of between 100

000 MT to 150 000 MT since the local production is still very low at 6000-7000 MT (Jagwe and Owuor, 2004; Tinsley, 2009; FAO, 2011).

2.3 Ecological requirements

Soybean is fairly a drought tolerant crop that makes efficient use of available soil water resources and can grow in relatively poor soils (Sanginga & Woomer, 2009). The crop can grow to a height of between 60-120 cm to within a maturity period of 3 to 6 months, depending on the variety and the agroecological zone in an altitude ranging from 0-2200 meters above the sea level (Mathu *et al.,* 2010). Altitude plays an important role in hastening the crops life cycle such that at low altitude, the crop maturity period is shortened compared to high altitude where it fails to flower and remains vegetative. Soybean is sensitive to water stress and performs well in rainfall range of 300-1200 mm (Mathu *et al.*, 2010) under well textured soils of *p*H range of between 5.5-8.5 (Kamara *et al.,* 2007).

2.4 Constraints to soybean production

A number of challenges have hampered the production of soybeans negating the desire for developmental practitioners to promote the crop to improve the lives and livelihood of the majority of small holder poor farmers. These constraints have been identified to be in play at every level of production and consumption, thus perpetuating uncertainty and possible abandonment of the crop by farmers. Scholars have identified that lack of involvement of farmers at all levels of production from variety testing and release has led to most of the varieties falling short of their expectation resulting in poor penetration and adoption (Mahasi *et al.*, 2009). Woomer *et al.* (2012) identified limited production resources, poor marketing channels, insufficient extension information, poor yielding varieties, low application of fertilizers and inadequate utilization of rhizobia inoculants as the major constraints perpetuating poor production of soybean. Thus development of soybean policy need to be established that will poise the crop to be considered important by all the stakeholders.

2.4.1 Poor soybean seed quality

Access to quality seeds and improved varieties with desirable traits such as tolerance to extreme temperatures, high yields, resistance to soybean mosaic disease, blight, leaf spots and tolerance to acid soils has been a perennial challenge for a long time for growers in Western Kenya. The unavailability of certified seeds have prompted incessant use own farm saved seeds or sourcing from open markets which sometimes are mixed, of unknown qualities and often produce low yields (Odendo *et al.*, 2008).

2.4.2 Limited technological know-how

Limited knowledge and information on soybean production agronomy coupled up with insufficient extension services have seen the crop perform dismally besides the ever rising cost of production thus making soybean farming uncompetitive and virtually an unprofitable venture. These production hitches arising from high cost of ploughing, purchase of inputs (especially fertilizers) and crop protection (weeding, pest and disease control) has led to low plant density, low fertilizer use, and inefficient use of farm resources resulting to low yields and declining incomes. Chianu, (2009) noted that beside the demand for soybean for human and animal nutrition, the production in Western Kenya was still very low at 450 kg ha^{-1}, a situation attributed to escalated production cost and limited access to production inputs.

2.4.3 Lack of clear marketing channels

Limited information flow from the service providers for input and output market has seriously affected the production of soybean in spite of there being higher yielding and adaptable varieties. Karuga & Gachanja, (2004) isolated lack of awareness on production, processing, marketing, and limited policy advocacy as the main reasons for the failure of most of the past projects aimed at promoting soybean in Kenya. The linkage between agricultural growth and access to output market is widening, thus affecting the sale of surplus production thereby reducing the flow of income and incentives to the farmer. It is likely that limited information on the utilization of soybean has led to concerns such as unpleasant tastes, difficulty in cooking and believes that markets does not exist to negatively affect soybean production.

2.5 Role of soybean in soil fertility improvement

Soybean is a multi-purpose legume with the advantage of providing nutrition for humans, livestock and improving soil fertility. The symbiotic relationship between legumes and rhizobia are responsible for fixing atmospheric nitrogen thereby providing reasonably low-cost soil fertility enhancement (Sanginga & Woomer, 2009). Biological nitrogen fixation has been identified to contribute significantly to the accumulation of large amounts of fixed nitrogen in farming systems (Giller, 2001). This improves the production of cereals especially where intercropped with or rotated with soybean. For instance, (Chianu & Vanlauwe, 2006) showed a 25% increase in maize yield when maize was grown after soybean. In another study, Sanginga *et al.* (2003) determined the amount of N fixed ranged between 44 to 103 kg N ha^{-1} annually in some soybean varieties.

2.6 Phosphorous availability in the soil

Phosphorous is an important growth-limiting nutrient for plants in the world. Besides its abundance in the tropical soil in both inorganic and organic forms, it stands out as an important fertility problem because the forms available for plants use are not adequate (Nekesa *et al.*, 2007; Haru & Ethiopia, 2012). Phosphorous unavailability in the soil is further perpetuated by the soil chemical condition such that, highly reactive Aluminium (Al^{+}) and Iron (Fe^{3+}) in acidic soils and Calcium (Ca^{2+}) in calcareous or normal soils undergoes precipitation reaction with phosphorous thus holding them in immobile pools (Hao *et al.*, 2002).

Microbial community plays an important role in decomposition, mineralization, storage and release of nutrients that improves the general soil condition. They avail phosphorous through mineralization of organic phosphorous and solubilising of precipitated phosphates in the soil (Chen *et al.*, 2006; Pradhan & Sukala, 2005). Provision of supplemental phosphorous to the crop is desirable only if the soil chemical condition is tested and found limiting may be in vain and painfully expensive.

2.6.1 Pathways of phosphorous absorption in plants

Phosphorous enters into the plant via root tips, root hairs, and the epidermal layer of the root cells where it is stored or translocated to other parts of the plant. Because of the various physiological functions it plays in the plant body, phosphorous is incorporated in a series of chemical reactions that results to its integration into organic compounds that includes phospholipids, sugar phosphate compounds, nucleic acids (DNA and RNA) and phosphoproteins (Bashir *et al.*, 2011). Phosphorous plays an invaluable role in driving all the biochemical reactions in the plant that requires heat transfer through the phosphorylation of high-energy phosphates such as adenosine diphosphate (ADP) and adenosine triphosphate (ATP) molecules.

2.6.2 Role of phosphorous in plant growth and development

Nitrogen, Phosphorus and Potassium (NPK) are among the 17 essential nutrients for plant growth that are classified as a major nutrient because they are required by crops in relatively large amounts. Besides other plant nutrients, phosphorous plays a distinctive function in the plants physiology that cannot be replaced by any other nutrient, thus, adequate supply is required for optimum plant growth and reproduction (Uchida, 2000).

Plants need phosphorus for growth throughout their life cycle, and more importantly during the early growth and development stage to facilitate adequate root system development. It is required in large quantities in young cells of the shoots and root tips where rapid cell division and high metabolism is actively going on and at later stage in seed filling and maturation (Sanginga *et al.*, 1997).

Phosphorus is involved in a number of cellular functions such as energy transfer, photosynthesis, transformation and utilization of sugars and starches, cell division and organization, nutrient translocation and transfer of genetic information (Uchida, 2000). It plays a role in crop performance such as improving root system, stalk and stem vigour, flower and seed formation, crop maturity and resistance to pests and diseases which ultimately translates to increased crop biomass and yield (Gangasuresh *et al.*, 2010).

2.6.3 Role of phosphorous in nitrogen fixation and utilization

Legumes require relatively high amounts of phosphorus since it is involved in formation of the root system including the nodule necessary for symbiotic nitrogen fixation (Leidi

& Rodriguez-Navarro, 2000). It has been established that phosphorous affects the time needed for developing nodules to become active as well as increasing their numbers and sizes thus influencing the density of rhizobia bacteria in the soil and ultimately the amounts of nitrogen fixed (Bashir *et al.*, 2011). Thus, it is worth noting that the role of phosphorous in biological nitrogen fixation is very significant. Though the process is energy intensive, phosphorus has been identified as an important ingredient used by Rhizobium bacteria in the synthesis of nitrogenase enzyme. This enzyme plays an integral role in catalysing the conversion process of atmospheric N_2 to ammonium (NH_4) which is readily available for plant use (Tsvetkova & Georgiev, 2003; Haru & Ethiopia, 2012). Availability of adequate amounts of P improves the relationship between the root bacteria and the leguminous plants and to a greater extent helps in supporting soybean plant's tolerance to stress conditions. In situations where P is limiting, the root growth is restricted thus affecting other biological process in the plant such as photosynthesis and translocation of sugars that ultimately undermine the process of nitrogen fixation by legume plants (Olivera *et al.*, 2004). It is therefore important that to ensure enhanced plant growth and increased efficiency of biological nitrogen fixation, supplementation with inorganic phosphorous fertilizer is essential on P deficient soils.

2.6.4 Symptoms of phosphorous deficiency in plants

Phosphorous deficiency in the soil is directly expressed in a plant in a number of ways which are typically observable. Deficiency symptoms are seen due to poor supply of available phosphorous that severely retards the process of biological nitrogen fixation thus deteriorating physiological functions and restricting plant growth. Notable effects includes reduction in leaf numbers, leaf expansion and leaf surface area, restricted root growth that leads to declining shoot-root ratio that affects water and nutrient absorption (Uchida, 2000; Bekere & Hailemariam, 2012). Other studies suggest that insufficient phosphorous slows down the process of carbohydrates utilization, which is exhibited in the crop as dark green coloration as seen in legumes or purple in cereals (Uchida, 2000). These foliar deficiency symptoms are first observed in the older lower leaves indicating that phosphorous is very mobile within the plant tissues and thus easily move from older to young and actively dividing meristematic tissues. In legumes, insufficient supply of P decreases nitrogenase activity and ATP concentration in nodules which degrades the ability of the plant to fix nitrogen. If nothing is done to ameliorate the condition, then phosphorous deficiency is serious and will lead to crop failure, increased susceptibility to pests and diseases, delayed crop maturity and production of low quality seeds.

2.7 Role of phosphorous in seed quality development and yield

Phosphorus plays a cardinal role in seed quality development due to its involvement in fruiting, seed formation and filling, that ultimately improves the crops quality. The demand for phosphorous during pod and seed development is very high, estimated to be up to 60 % of total P absorbed in the plant. The effective translocation of phosphorous makes it possible to satisfy the soybean seed demand in production of protein, seed oils, phospholipids and phytin (Shahid *et al.*, 2009; Uchida, 2000).

Soybean yield is a dependent variable that is affected by plant growth factors as well as yield contributing components, such as; plant density, number of branches per plant, pods per plants, seeds per pod and seed weight (Dahmardeh *et al.*, 2010). Studies have documented a positive correlation between crop yield and the level of phosphorous supplied. In this respect, increasing the P supply has been identified to enhances the plant's performance such as vigorous growth, increased nodulation and improved symbiotic relationship, development of quality seeds and fruits, early maturity and improved tolerance to environmental stresses (Shahid *et al.*, 2009; Gangasuresh *et al.*, 2010). On the other hand, low P levels have been associated with retarded growth rate, low rhizobia nitrogen fixation which eventually results in production of poor yield and low quality seed. Thus, application of phosphorous and bio-fertilizers is important in ensuring optimized quality parameters.

2.8 Role of liming in soil amelioration

The soil pH plays irreplaceable role in the accessibility of phosphorous in the soil. Unavailability of phosphorous for plant use occurs at high and low *p*H levels. Nitisols, Acrisols and ferralsols are the predominant soil types in the humid tropics constituting a bigger percentage of arable land. These soils are characterized to be acidic indicating an inevitable need for application of soil amendment if crop production has to be feasible (Brett *et al.*, 2005). Soybeans are more sensitive to high levels of soil acidity than most of the field crops such that even the best yielding varieties cannot perform well without soil fertility amendments. The crops sensitivity to soil pH is well documented with literature pointing out an optimum pH range of between 5.5 and 8.5 as suitable for better crop's response to phosphorous and good yields (Kamara *et al.*, 2007). As the pH level lowers, the crop performance is dramatically hindered due to unavailability of essential plant nutrients (N, P, K, Mg, Ca, Cu, Zn and Mo among others) and increased Al and Mn toxicity which reduces root growth.

To amend low soil pH, liming has been explored as the most appropriate procedure for neutralizing soil acidity by displacing H^+, Fe^{2+}, Al^{3+}, Mn^{4+} and Cu^{2+} ions from soil adsorption site as well as supplying significant amounts of Ca and Mg, depending on the soil type (Onwonga *et al.*, 2010). This increases availability of P, Mo and B, and improves the soil conditions which make it even more favourable for microbial mediated reactions such as nitrogen fixation and nitrification, as well as enhancing the soil structure (Nekesa *et al.*, 2005).

2.9 Effect of seed oil content on soybean seed quality

Lipids are relatively unstable and spontaneously undergo physical, physiological and chemical changes as a result of lipid peroxidation and higher levels of enzymatic activity leading to increase permeability of membranes during storage and formation of various hydroperoxide products (Harrington, 1972; Balešević-Tubić *et al.*, 2005; Walters *et al.*, 2005). These compounds adversely affects the seed quality even under ambient conditions by decomposing rapidly into ketones, aldehydes, hydrocarbons, alcohols, esters, lactones and furans, resulting in degradation of the quality of fats and oils thus producing unpleasant odour in storage bins (Harrington, 1972). The ease of oxidation of soybean and other oil crops makes them very sensitive to adverse storage conditions such as high moisture and temperatures. In this respect, an increase in storage temperature and moisture contents promotes enzyme lipases in free fatty acids (FFAs) and glycerols to hydrolyse lipids, leading to rapid loss of seed health status (Copeland & McDonald, 1995; Kausar *et al.*, 2009) and loss in seed germination and vigour (Le Van *et al.*, 2008). These biochemical changes adversely affect storability and physiological quality of seed lots (Smith & Berjak, 1995; Sharma *et al.*, 2006; Balešević-Tubić *et al.*, 2010). In another study, Nagel and Borner, (2010) observed a strong negative relationship between oil content to absolute seed longevity and rapid viability loss in oily seeds as compared to seeds with high carbohydrate or protein content. The seed deterioration as observed in excessive lixiviates of the electrical conductivity are directly linked to membrane integrity of the seeds (Bewley & Black, 1994). It is apparent that to maintain high seed quality during storage then the storage environment needs to be designed to comply with Harrington rule of thumb (Harrington, 1972).

2.10 Effect of seed protein content on soybean seed quality

Storage protein is an important food reserve that provides essential amino acids for germination and seedling growth. Its synthesis is regulated by plant nutrition such as nitrogen availability, and in those containing cysteine and methionine, adequate amounts of sulphur will be required. Proteins affects generally the seed chemical composition in such a way that at high levels, the seeds tends to exhibit better storability and rapid water absorption during imbibition as compared to those with low content (Shewry *et al.*, 1993).

2.11 Effect of storage condition on seed quality

Maximum seed quality, expressed by seed germination and vigour, is reached at physiological maturity a stage beyond which seed starts to seed deteriorate (Bewley & Black, 1994). Delouche, (1968) defined seed deterioration as an inexorable process that cannot be reversed but whose rate can be slowed by controlling the conditions of the storage environment. Storage temperature and relative humidity are believed to be the most essential factors to consider while designing an optimum storage condition for soybean seed. Temperature influences relative humidity of the storage environment which affects the seed moisture content thereby directly affecting the seed viability, vigour and alteration of seed colour and composition. While studying storage environment factors, Harrington (1959, 1972) established three distinctive “rules of thumb” that describe the relationships of storage conditions that affect seed deterioration in storage. These stated that, (i) for each 1% decrease in seed moisture content, the life of the seed is doubled, (ii) for each 10° F (5.5° C) decrease in storage temperature, the life of the seed is doubled and (iii) the sum of temperature in degrees Fahrenheit and relative humidity in percentage should not exceed 100, and seeds should not be stored in temperatures above 50°F (10° C). Beside the effect of physio-chemical environment of the storage environment other factors which affects seed quality in storage are the initial seed moisture content (Bhattacharya & Raha, 2002), initial seed quality before storage (Bewley & Black, 1994) and the genetic constitution (Gupta, 1976; Shelar *et al.,* 2008) and seed size (Baskin et al. 1998). Many other studies have reported seed deterioration in storage to be as a result of change in seed biochemical process (Baskin & Delouche, 1973; Ellis *et al.*, 1989; Brooker *et al.*, 1992; Balešević-Tubić, 2001; Acasio, 2010).

2.12 Effect of storage duration on soybean seed quality

How long seeds are kept in storage has a bearing on seed quality deterioration. Seed deterioration starts immediately after the seed attains physiological maturity in the field and continues declining gradually (Bewley & Black, 1994). When the storage duration increases, it has been shown that several physical, chemical and biochemical alterations continues to take place which perpetuates changes such as increased enzymatic activities, depletion of food reserve, increased fat acidity and declining membrane integrity which eventually affects seed physiological quality (Harrington, 1972; Narayan, 1988; Brooker *et al.*, 1992; Walters *et al.*, 2005; Balešević-Tubić *et al.*, 2005; Alencar *et al.*, 2010; . A number of previous studies have drawn relationships between seed quality and longevity and concludes that storage duration is fundamental (S. Balešević-Tubić *et al.*, 2005; Jamro *et al.*, 2005; Yaja *et al.*, 2005; Vieira *et al.*, 2007; Alencar *et al.*, 2010; Khaliliaqdam *et al.*, 2012; Kandil *et al.*, 2013;). Elsewhere, other studies have shown interrelationship between seed longevity and cultivar (Vieira *et al.*, 1999; Panobianco & Vieira, 1996; Salinas *et al.*, 2010; Andric *et al.*, 2012;), initial seed moisture before storage (Vieira *et al.*, 2004), seed storage condition (Panobianco & Vieira, 2007) and seed health (Copeland & McDonald, 1995; Wain-Tassi *et al.*, 2012).

CHAPTER THREE

MATERIALS AND METHODS

3.0 Description of field experimental sites

Two experimental sites suitable for production of early and mid-maturing soybean cultivars were identified where the on-farm trials were conducted between the months of June to November 2015 in Uasin Gishu and Busia Counties.

In Uasin Gishu county, the experiment was carried out at the University of Eldoret farm located 10 Km North of Eldoret town between 0° 34’ North latitude and longitude 35° 18’ East, at an altitude of 2120 m above sea level. The county has an annual mean temperature of about 22° C and rainfall of between 900-1300 mm, varying soil types but mostly of igneous origin classified as orthic ferralsols according to USDA classification (CIDP-UG, 2013; Jaetzold *et al.*, 2006). The soils have low *p*H of between 4.5 – 5.0 accounting for the low soil fertility in these soil types (Kisinyo, 2011).

In Busia, the experiment was conducted in Busia Agricultural Training Centre (ATC) farm, located between 0° 25’ N latitude and 35°54’ E longitude. The site is on an altitude of 1130 m above sea level, and receives an annual rainfall range from 1270 mm to 1790 mm and mean temperature of range from 14° C to 18° C. The soils are generally well drained and predominantly Orthic ferralsols (Jaetzold & Schmidt, 1983)

The weather and soil characteristics for both sites (appendix I and II) shows that it is appropriate for production of early and mid-maturing cultivars of soybean. However, the problem of soil acidity due to Fe, Al and Mn oxides is widespread and further perpetuated with perennial use of acidifying fertilizers such as DAP and Urea, thus, low P and N levels (Mwangi *et al.*, 1999).

3.1 Description of experimental variables

3.1.1 Cultivars

Two soybean cultivars were selected for this study under the rationale of preference by farmers in Western Kenya, suitable to low and mid altitude agro-climate and seed nutritional composition. The represent the diverse characteristics of soybean cultivars based on protein and oil contents, two soybean cultivars were chosen, one with high protein content and another with high oil content. These cultivars were sourced from TSBF-CIAT in Maseno, Western Kenya that includes;

SB 133; It is locally referred to as saga. It has a high oil content of 24.37% and relatively lower protein content of 37.59% giving a protein: oil ratio of 1.5:1. It is large seeded variety with an estimated total number of 4, 808 seeds kg^{-1}. It is a medium maturing group that is tolerant to rust and does well in all altitude (TSBF-CIAT soybean data, unpublished).

SB 19; It has a high protein content of 42.29% and relatively lower oil content of 19.71%, giving a protein: oil ratio of 2.2:1. It is small seeded with an estimated number of seeds of 6,566 kg^{-1}. It is an early maturing group which does well in all agro-ecological zones but very susceptible to rust (TSBF-CIAT soybean data, unpublished).

3.1.2 Fertilizer and liming

Triple supper phosphate (TSP) fertilizer (0:46:0) was sourced from MEA limited, and applied at 0, 30 and 60 Kg P ha^{-1}. On the other hand, the liming material ($CaCo_3$) referred to as Physiolith® (granulated) was sourced from Timak-agro chemical company, Kenya. This was applied at the rates of 0 and 0.667 ton ha^{-1} of Physiolith® lime which is equivalent to 2 ton ha^{-1} of $CaCo_{3.}$

3.2 Experimental design and treatments

The experiment was a 2×3×2 factorial arrangement consisting of three main factors; cultivar, phosphorous and lime, laid out in a randomized complete block design (RCBD) and replicated thrice. The description of treatment as applied in the field and when harvested and the seeds treated independently for storage experiment is shown below in Table 1.

Table 1: Description of treatments for soybean cultivars, fertilizer and lime levels grown in Busia and Uasin Gishu counties in the year 2015.

Cultivar	+	Phosphorous	+	Lime
SB 19	+	0 kg P ha^{-1}	+	0 ton ha^{-1}
SB 19	+	30 kg P ha^{-1}	+	0 ton ha^{-1}
SB 19	+	60 kg P ha^{-1}	+	0 ton ha^{-1}
SB 19	+	0 kg P ha^{-1}	+	2 tons ha^{-1}
SB 19	+	30 kg P ha^{-1}	+	2 tons ha^{-1}
SB 19	+	60 kg P ha^{-1}	+	2 tons ha^{-1}
SB 133	+	0 kg P ha^{-1}	+	0 ton ha^{-1}
SB 133	+	30 kg P ha^{-1}	+	0 ton ha^{-1}
SB 133	+	60 kg P ha^{-1}	+	0 ton ha^{-1}
SB 133	+	0 kg P ha^{-1}	+	2 tons ha^{-1}
SB 133	+	30 kg P ha^{-1}	+	2 tons ha^{-1}
SB 133	+	60 kg P ha^{-1}	+	2 tons ha^{-1}

3.3 Field preparation and management

The cropping history of the field was sourced from the relevant authorities and established to have been used annually for production of vegetables, legumes and cereals interchangeably. Land was conventionally ploughed to a fine title a month before planting. Plots measuring 4 m by 3 m with 0.5 m walking paths between plots and 1 m separating the blocks then were demarcated. Granulated agricultural lime (Physiolith®) from Timak Agro Company and phosphorous fertilizer (TSP) were applied at different rates to the experimental units during planting. The seeds were planted on an inter row spacing of 50 cm and intra row spacing of 5 cm where, a guard row of 2 rows was planted around the field periphery. Watering was manually done using watering cans in all experimental sites in the first month after planting and later intermittently when necessary since the rain was unpredictable and unreliable. Adequate weed management was achieved by early proper land cultivation, harrowing and manually two times before flowering. Pests were controlled using ACTARA ® 25 WG (20 ml/ 20 L of water) a broad spectrum-systemic pesticides before flowering so as to minimize pest influence and ensure optimum crop development.

3.4 Data collection and analysis

Each plot was harvested individually at about 15% seed moisture content at a time when the crop had attained uniform harvest maturity characterized by leave fall and change of colour of the whole plant to brown or khaki. The seed from each treatment was separately sun dried, gently hand threshed, cleaned, weighed and further sun dried to a uniform moisture content of 13% for storage. The weights from each plot was used to calculate the treatment effect on seed yield per hectare (kg ha^{-1}). Ten replicates of 100 seed form each plot were counted to determine treatment effect on thousand seed weight.

3.5 Laboratory tests

3.5.1 Seed protein and oil content

The samples of seed from each treatment were each ground separately through a 40-mesh to a fineness that provided maximum homogeneity. In protein content determination, 3 grams of the sample was used Kjeldahl method to estimate the nitrogen content in seed. The total seed protein was later calculated by multiplying the nitrogen content in the seed by 6.25 (Williams *et al.*, 1998). Seed Oil content was determined using 1 gram of the sample in Soxhlet ether extraction method as described by AOSA, (1990).

3.5.2 Seed germination

Standard germination test was conducted where fifty seeds were drawn from each treatment combination and replicated thrice. The seeds were sown in clean sand media and germinated at 25 ± 2 °C and 70% relative humidity. Daily emergent seeds were counted and later evaluated on the 8th day to determine the number of normal and of abnormal seedlings, ungerminated (fresh and hard) and rotten seeds (ISTA, 2009). The final germination count was calculated as follows;

Equation 1

$$\text{Germination (\%)} = \frac{Number\ of\ seeds\ germinated}{Number\ of\ seeds\ tested} \times 100$$

3.5.3 Seed vigour test

Electrical conductivity test for the seeds was determined by soaking 50 seeds of known weights from each treatment, replicated three times in separate beakers containing 75 mL of deionised water that was stabilized overnight. The beakers were then covered with aluminium foil to prevent contamination and equilibrated in incubator at 25 °C for 24 hours alongside two control beakers with deionised water. The electrical conductivity of the seed leachates was then determined using conductivity meter (HI 991301 and probe meter HI 1288; Hanna instruments company, Romania, Europe).The vigour quality was evaluated based on the quality classification as; low (>100 and <120 μ S cm^{-1} g^{-1}), medium (81 - 100 μ S cm^{-1} g^{-1}) and high (< 80 μ S cm^{-1} g^{-1}) vigour (Vieira *et al.*, 1999; Vieira *et al.*, 2004). The EC was calculated according to (Hampton and TeKrony, 1995; ISTA, 2007) as expressed below as;

Equation 2

$$\text{Conductivity } (\mu\,\text{S cm}^{-1}\text{g}^{-1}) = \frac{Conductivity\ reading\ - Background\ reading}{Weight\ (g) of\ Replicates}$$

3.6 Storage experiment and laboratory tests

In the storage experiment, 200 grams of the harvested seeds from each experimental plot from each site were subjected to storage experiment at ambient condition of temperature range of 15 °C to 25 °C and in controlled (refrigerated) condition at 10 °C for a period of 6 months. The seeds were stored in sugar bags and stacked in carton box. Viability and vigour test as described in (section 3.6.2 and 3.6.3) above was done after the storage period was over.

3.7 Data analysis

The data collected for seed yield (kg ha^{-1}), thousand seed weight (TSW) (g), protein and oil content, germination percent and electrical conductivity (µ S cm^{-1} g^{-1}) were subjected to analysis of variance where significant differences among the treatments means were separated using Tukey's (HSD) test at $\alpha=0.05$. All the statistical analyses were handled using R® statistical software version 3.3.1 in R studio version 1.0.136.

CHAPTER FOUR

RESULTS

4.0 The influence of phosphorous and lime on soybean seed yield

This subsection will explain the results of seed yield and thousand seed weight of the soybean cultivars treated with P fertilizer and lime when produced in highly acidic soils in Eldoret and Busia (appendix II)

4.1.1 Seed yield

The seed yield was significantly by cultivar in Busia whereas no significant differences ($p < 0.05$) were observed when grown in Eldoret (Figure 1, appendices III (a) and (b)). Generally, high seed yield was recorded in SB 133 at both sites. The effect of phosphorous fertilizer on seed yield was significant ($p < 0.05$, appendices III (a) and (b)) at both sites.

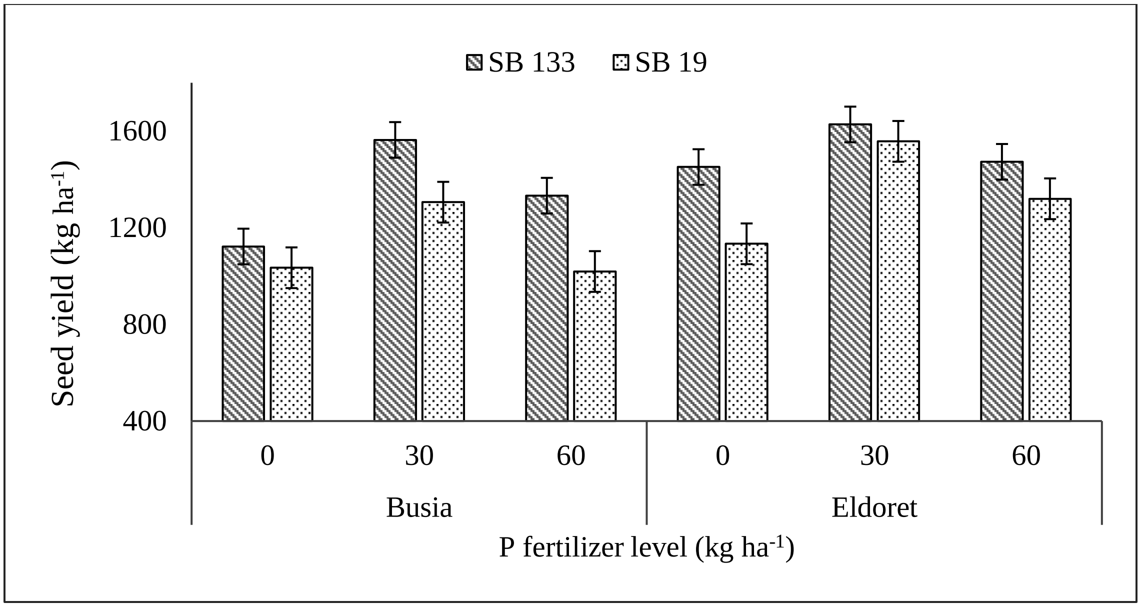

Figure 1: Seed yield (kg ha^{-1}) of soybean cultivars SB 19 and SB 133 produced in Busia and Eldoret under different rates of P fertilizer. Error bars represent the standard error, n = 6.

The soybean seed yield showed an increasing trend with increase in phosphorous fertilizer to a maximum at 30 kg P ha^{-1} where further increase resulted in a decline at both site. In this respect, SB 133 yielded 1563.48 kg ha^{-1} when produced in Busia and 1627.56 kg ha^{-1} in Eldoret accounting for a yield increase of 39 % and 12 % respectively from the control value. Similarly, high seed yield for SB 19 of 1305.80 kg ha^{-1} in Busia and 1557.6 kg ha^{-1} in Eldoret was recorded accounting for 26 % and 37 % respectively from the control value. Conversely, low seed yield in SB 133 was recorded when 0 kg P ha^{-1} was used in Busia and Eldoret (Figure 1). Similarly, low yields for SB 19 was recorded when 0 kg P ha^{-1} and 60 kg P ha^{-1} were used in Eldoret and Busia respectively.

There was no significant influence (p < 0.05) of lime on seed yield when the soybean cultivars were grown in Busia and Eldoret sites (figure 2, appendices III (a) and (b)).

Lime application at both sites resulted to an increase in seed yield though the increase was not statistically significant. Application of lime positively increase seed yield for SB 19 when produced in Busia from 986.53 kg ha^{-1} to 1253.04 kg ha^{-1} whereas slight increase in SB 133 accounting for a yield increase of 27 % and 2 % respectively (Figure 2, appendices III (a) and (b)). Conversely, a good response to lime was seen for SB 133 in Eldoret leading to a seed yield increase from 1430.05 kg ha^{-1} to 1604.48 kg ha^{-1} whereas slight increase was seen for SB 19, translating to a yield increase of 12 % and 4 % in that order.

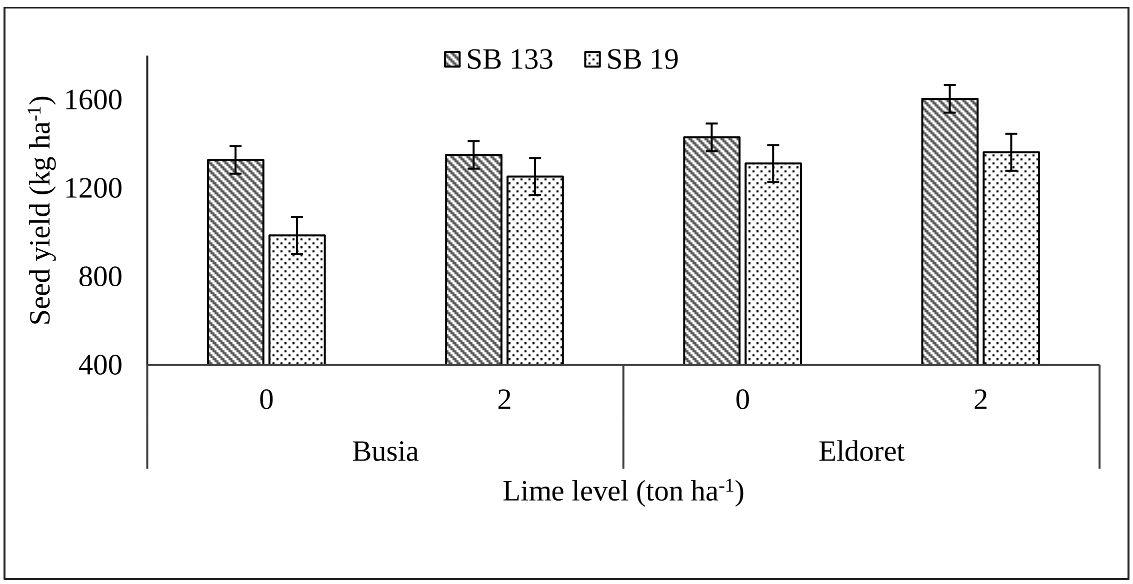

Figure 2: Seed yield (kg ha^{-1}) of soybean cultivars SB 19 and SB 133 as affected by lime in Busia and Eldoret. Error bars represent standard errors, n = 9.

4.1.2 Thousand Seed Weight

Thousand seed weight was significantly influenced by the cultivar differences ($p < 0.05$) when produced in Busia and Eldoret. Neither phosphorous fertilizer, liming nor their interactions had a significant influence on thousand seed weight of the soybean cultivars (Table 2, appendices IV (a) and (b)). The influence of P was observed to decrease TSW for both cultivars at the two sites. In this respect, P application at control (0 kg P ha^{-1}) recorded the highest value of 94.19 g in SB 19 and 133.31 g in SB 133 when produced in Busia. Similarly, in Eldoret site high TSW value of 184.00 g was recorded for SB 133 when produced in 0 kg P ha^{-1} and 111.21 g for SB 19 when produced in 30 kg P ha^{-1}. Generally, lower TSW for SB 133 and SB 19 were recorded when the soybean was produced in 60 kg P ha^{-1} at both sites.

On the other hand, lime application was effective in increasing yield for the soybean cultivars in Busia though the increase was not statistically significant (appendices IV (a) and (b)). Similar increase was recorded in Eldoret for SB 133 whereas SB 19 decreased with lime application (Table 2).

Table 2: Thousand seed weight of soybean cultivars SB 19 and SB 133 produced in Busia and Eldoret as influenced by phosphorous fertilizer and lime.

		Busia			Eldoret		
		Lime			Lime		
Cultivar	**Phosphorous**	**0 tons /Ha**	**2 tons /Ha**	**Mean**	**0 tons /Ha**	**2 tons /Ha**	**Mean**
SB 19	**0 Kg P Ha $^{-1}$**	93.68	94.70	94.19	108.56	105.72	107.14
	30 Kg P Ha $^{-1}$	95.43	92.46	93.94	117.09	105.32	111.21
	60 Kg P Ha $^{-1}$	87.44	92.44	89.94	110.09	109.69	109.89
	Mean	92.18	93.20	92.69	111.92	106.91	109.41
SB 133	**0 Kg P Ha $^{-1}$**	135.79	130.82	133.31	183.63	184.37	184.00
	30 Kg P Ha $^{-1}$	128.62	132.98	130.80	173.59	170.80	172.19
	60 Kg P Ha $^{-1}$	124.00	129.46	126.73	166.85	171.19	169.02
	Mean	129.47	131.09	130.28	174.69	175.45	175.07
	CV (%)		5.18			6.91	

4.2 Seed quality of soybean cultivars treated with phosphorous fertilizer and lime

This subsection will explain the results of the effect of P fertilizer and lime on seed crude oil, crude protein, initial seed viability (germination test) and initial seed vigour (electrical conductivity test) of soybean cultivar, SB 133 (oily) and SB 19 (proteinous).

4.2.1 Seed crude oil content

The crude oil content of soybean seeds was significantly influenced by the cultivar when produced in Busia and Eldoret (Figure 3). The effect of phosphorous fertilizer was significant for the soybean produced in Busia and not significant at Eldoret (appendices V (a) and (b)). In Busia, the seed oil content in SB 133 decreased at 30 kg P ha^{-1} but recorded high oil content at 60 kg P ha^{-1} of 21.92 %. In the same site, there was no significant difference on the level of seed oil for SB 19 at the different P fertilizer rates though high seed oil was recorded at 60 kg P ha^{-1} 19.71 %. In Eldoret site, there was no statistical difference between the P fertilizer rates in SB 133, though seed oil increased with P application. In the same site, SB 19 was not affected by P fertilizer rates.

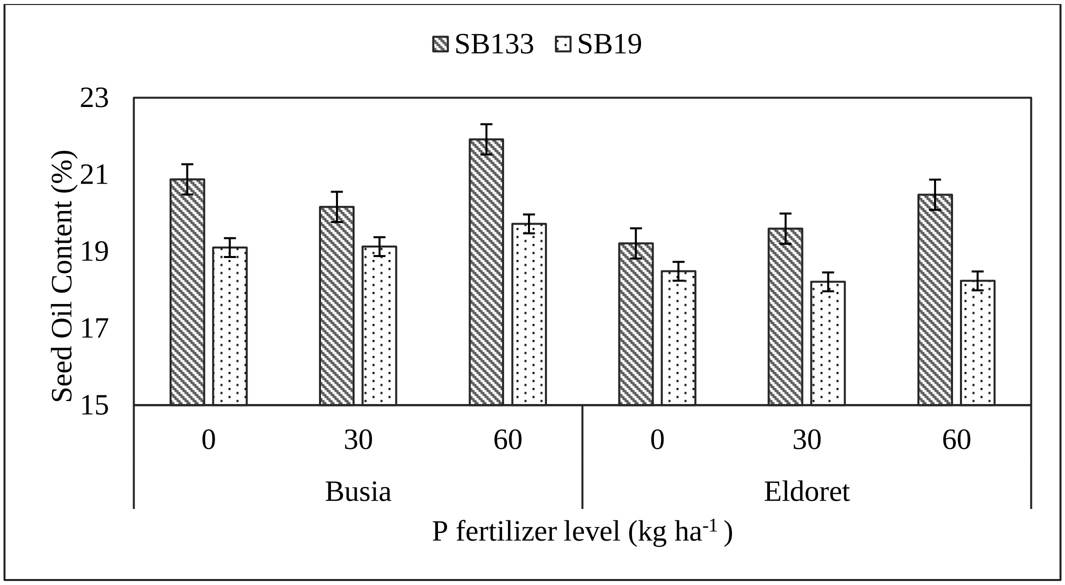

Figure 3: Seed oil content (%) of soybean cultivars SB 19 and SB 133 produced in Busia and Eldoret under different rates of P fertilizer. Error bars represent the standard error, n=6.

There was a significant effect of lime on seed oil content when the soybean cultivars were produced in Busia. Lime application resulted to a decline in seed oil content in both cultivars in Busia. No significant differences were observed when the varieties were grown in Eldoret. Lime in Eldoret increased seed oil content in SB 133 but decreased in SB 19 in Eldoret as shown in figure 4.

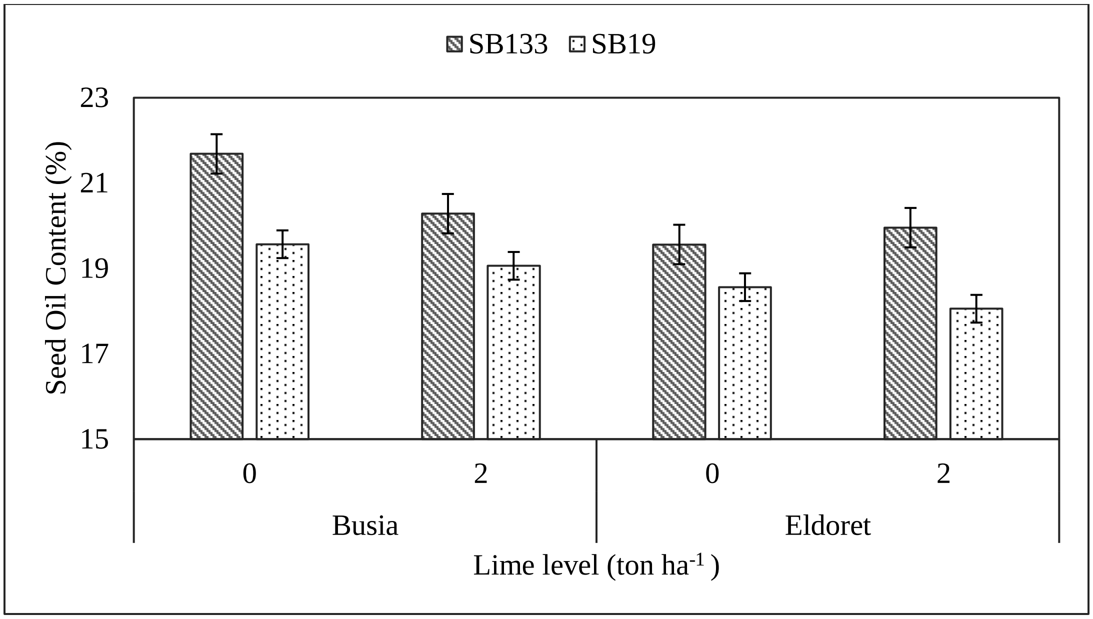

Figure 4: Seed oil content (%) of soybean cultivars SB 19 and SB 133 as affected by lime in Busia and Eldoret. Error bars represent standard errors, n = 9.

4.2.2 Seed protein content

Analyses of variance revealed significant differences in seed protein content between the soybeans cultivars produced in Eldoret whereas no significant differences were observed for soybean cultivars produced in Busia (appendices VI (a) and (b)). The influence of phosphorous fertilizer on seed crude protein was significant ($p < 0.05$) when soybean cultivars were produced in Eldoret whereas no significant differences was observed in Busia (Figure 5, appendices VI (a) and (b)). In this respect, seed protein content was observed to increase with increase in P fertilizer application in SB 19 at both experimental sites to a high value of 39.56 % and 40.40 % in Busia and Eldoret respectively. However, SB 133 in Busia increased to a maximum level at 30 kg P ha^{-1} of 38.83 % after which it declined as P fertilizer level increased. Conversely, in Eldoret site, protein declined to a lower value at 30 kg P ha^{-1} and later increased commensurate to P fertilizer application to 39.64 % (Figure 5).

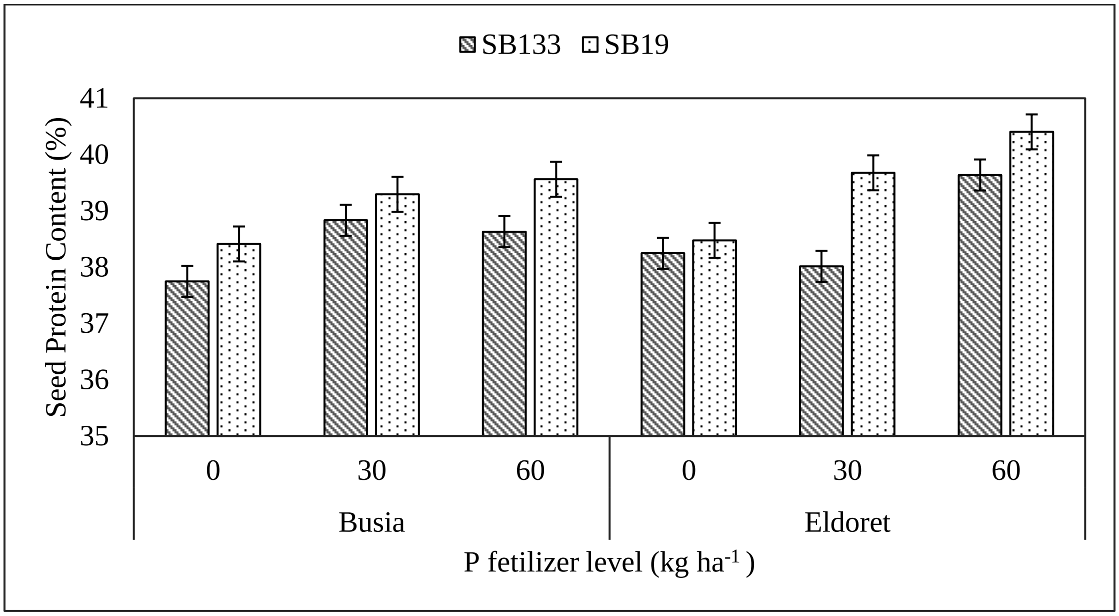

Figure 5: Seed protein content (%) of soybean cultivars SB 19 and SB 133 produced in Busia and Eldoret under different rates P fertilizer. Error bars represent the standard error, n=6.

The influence of lime on seed crude protein of soybean cultivars was significant ($p < 0.05$) when applied in Busia and Eldoret (Figure 6, appendices VI (a) and (b)). Lime application increased the seed protein content of both cultivars at the two experimental sites. SB 19 had a high seed protein content of 39.82 % in Busia and 40.26 % in Eldoret when lime was applied. Similarly, high protein content in SB 133 of 38.83 % and 39.00 % was recorded for Busia and Eldoret respectively when lime was applied.

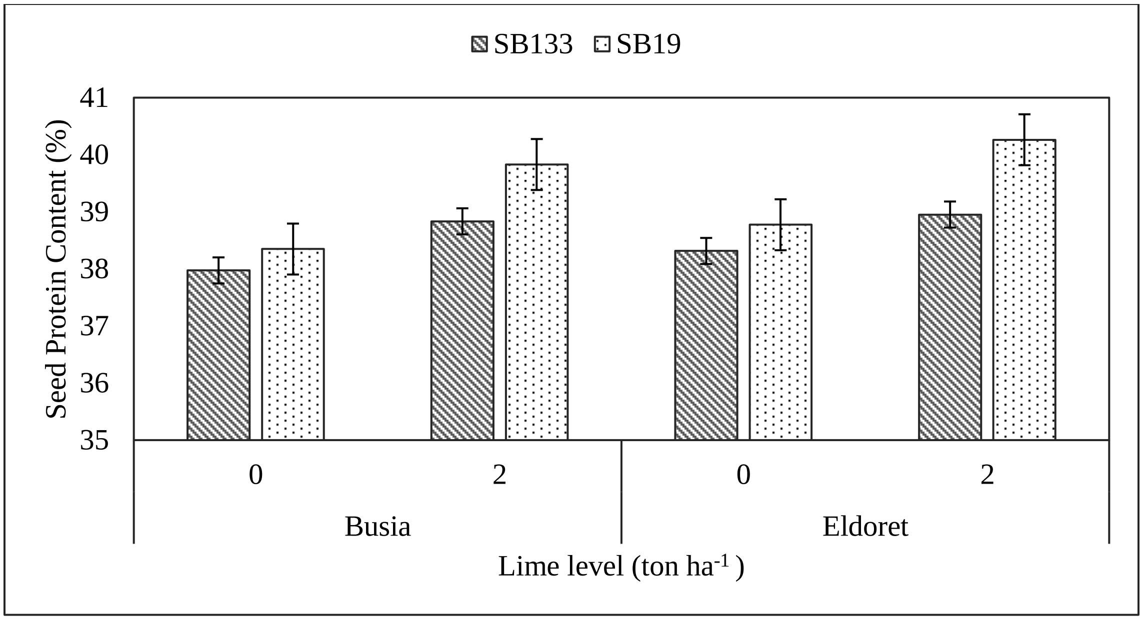

Figure 6: Seed protein content (%) of soybean cultivars SB 19 and SB 133 as affected by lime in Busia and Eldoret. Error bars represent standard errors, n = 9.

4.2.3 Initial seed electrical conductivity before storage

The initial seed electrical conductivity of soybean produced in Busia and Eldoret were significantly influenced by cultivar differences (Figure 7). High EC value of 107.93 µ S cm^{-1} g^{-1} in SB 19 and 120.75 µ S cm^{-1} g^{-1} in SB 133 was recorded for the seed produced in Busia and Eldoret respectively when produced under 60 kg P ha^{-1}.

Phosphorous fertilizer was observed to significantly influence initial EC for the soybean produced in Busia and not significant in Eldoret (Figure 7, appendices VII (a) and (b)). The P fertilizer effect was observed to increase the seed EC as the level of fertilization increased from 0 kg P ha^{-1} to 60 kg P ha^{-1}. It was observed that the soybean produced in Busia, SB 133 at all P levels and SB 19 at 0 kg ha^{-1} are of high quality (< 80 µS cm^{-1} g^{-1}), whereas, medium quality was recorded for SB 19 at 30 kg P ha^{-1} and low quality was reported for SB 19 at 60 kg P ha^{-1}. On the other hand, soybean produced in Eldoret site showed that SB 19 at all P levels produced medium quality whereas SB 133 at 0 kg P ha^{-1} yielded medium and at 30 kg P ha^{-1} and 60 kg P ha^{-1} produced seeds of low quality. There was significant interaction between phosphorous and lime at both sites.

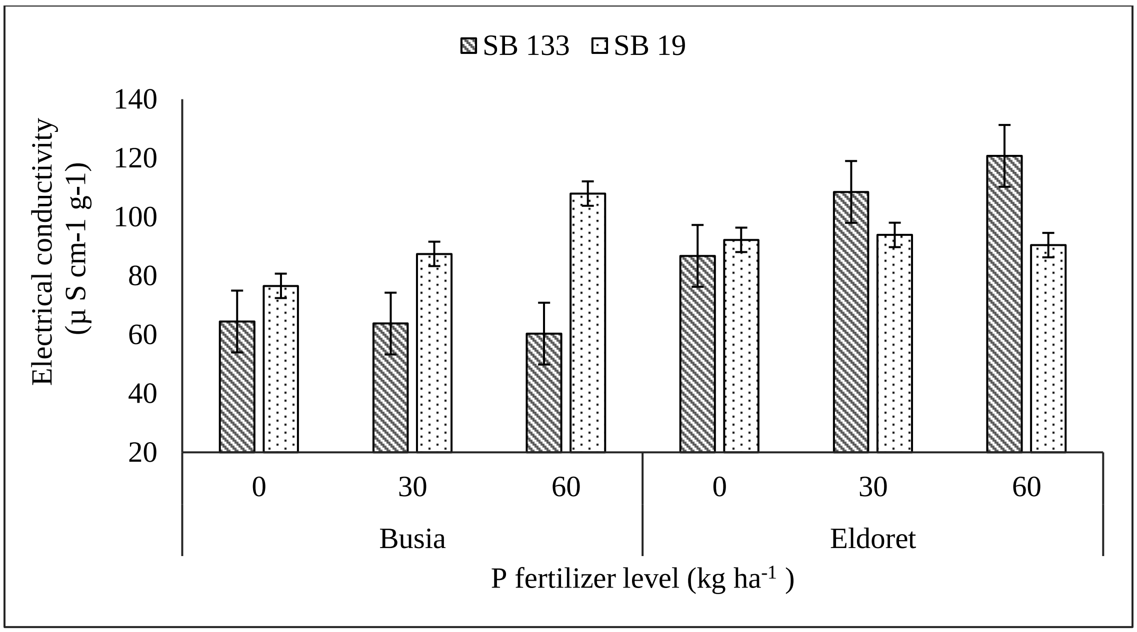

Figure 7: Seed electrical conductivity of soybean cultivars SB 19 and SB 133 produced in Busia and Eldoret treated with different rates of P fertilizer. Error bars represent the standard error, n=6.

On the other hand, the effect of liming on seed EC was not significant at both sites (appendices VII (a) and (b)). However, it was noted that lime application resulted in lower EC value, implying that there is an improvement in seed quality (Figure 8).

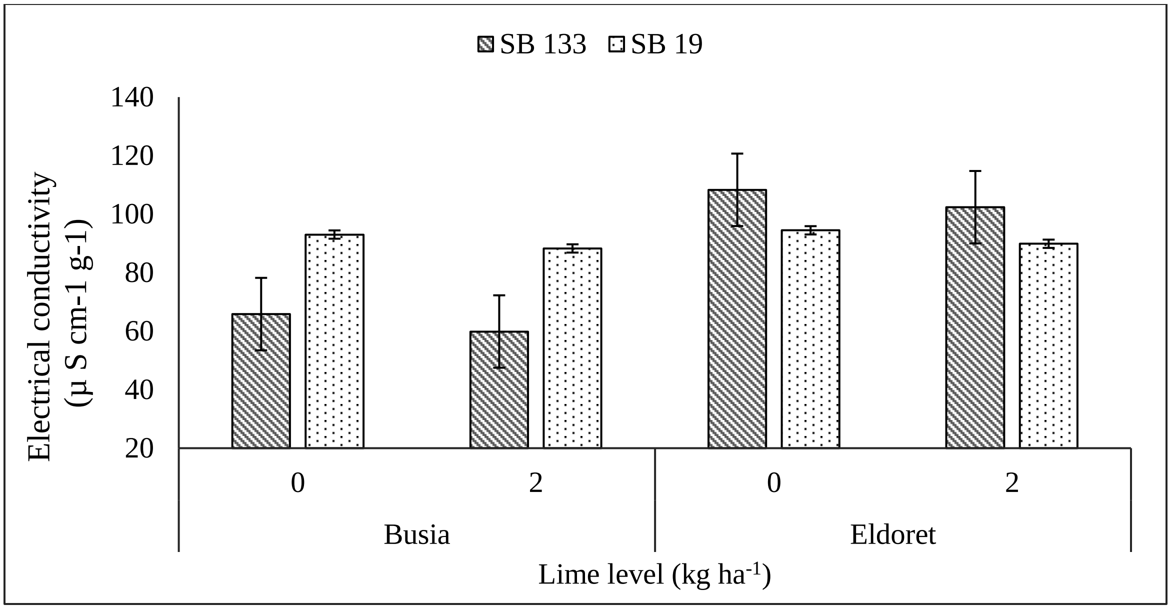

Figure 8: Seed electrical conductivity of soybean cultivars as affected by lime in Busia and Eldoret. Error bars represent standard errors, n = 9.

4.2.4 Seed germination percent before storage

The influence of cultivar on initial seed germination before storage was significant for the soybean seeds produced in Busia, whereas, no significant differences were observed on cultivars produced in Eldoret (Table 3, appendices VIII (a) and (b)). It was noted that the highest germination percent was recorded in SB 19 where lime was not applied of 94.67 % and 94.89 % in Busia and Eldoret respectively.

The influence of phosphorous fertilizer on initial seed germination of the soybean cultivars was not significant when the soybean were produced in Busia and Eldoret (appendices VIII (a) and (b)). High germination percent for the soybean produced in Busia was recorded when P was applied at 60 kg ha^{-1} in SB 19 and at 30 kg ha^{-1} in SB 133. On the other hand, in Eldoret, high germination for SB 19 and SB 133 were recorded at 60 kg P ha^{-1} and 0 kg P ha^{-1} respectively (Table 3). At both sites, all the phosphorous levels produced germination percentage above the market acceptable value of ≥ 80.0 % except P level at 0 kg P ha^{-1} and 60 kg P ha^{-1} when used to produce SB 133 in Busia (Table 3).

The influence of lime on initial seed germination of soybean produced in Busia and Eldoret was not significant ($p < 0.05$, appendices VIII (a) and (b)). In this respect, it was observed that the mean germination percentage of the soybean seeds from the limed plots were lower than those that were not limed.

Table 3: Germination (%) of soybean cultivars (B 19 and SB 133 grown in Busia and Eldoret in the year 2015 as affected by P fertilizer and lime application

		Busia			Eldoret		
		Lime			Lime		
Cultivar	**Phosphorous**	**0 tons /Ha**	**2 tons /Ha**	**Mean**	**0 tons /Ha**	**2 tons /Ha**	**Mean**
SB 19	**0 Kg P Ha $^{-1}$**	94.67	88.67	91.67	93.33	94.67	94.00
	30 Kg P Ha $^{-1}$	92.67	95.33	94.00	96.67	92.67	94.67
	60 Kg P Ha $^{-1}$	96.67	95.33	96.00	94.67	95.33	95.00
	Mean	94.67	93.11	93.89	94.89	94.22	94.56
SB 133	**0 Kg P Ha $^{-1}$**	76.00	80.00	78.00	95.33	95.33	95.33
	30 Kg P Ha $^{-1}$	84.67	81.33	83.00	92.67	90.00	91.33
	60 Kg P Ha $^{-1}$	76.67	74.00	75.33	92.00	92.67	92.33
	Mean	79.11	78.44	78.78	93.33	92.67	93.00
	CV (%)		6.53			3.97	

4.3 Seed quality of soybean cultivars after storage

This subsection explains the results of the effects of storage condition and duration on seed viability (germination test) and vigour (electrical conductivity test) of soybean cultivars produced in Busia and Eldoret after six months of storage respectively.

4.3.1 Seed germination of the soybean cultivars as influenced by storage duration

There was significant effect of the cultivar on seed germination percent for the soybean produced in Busia and Eldoret ($p < 0.05$, appendices IX and 10). It was observed that SB 19 maintained a high germination percentage (≥ 80) compared to the oily seeds SB 133 before and after storage (Table 4). The effect of storage duration on seed germination percent was significant ($p < 0.05$) at the 6th month after storage for the seeds produced in Eldoret and Busia respectively. It was observed that regardless of the storage condition, the seed germination declined as the storage period increased. Similarly, there were significant interactions between the cultivars produced in Eldoret and the storage duration (appendix X) and between storage condition and storage duration for the seeds produced in Busia (appendix IX).

Low germination at the end of the storage period was recorded for the seeds with high oil content produced from both sites. In this regard, low germination count in SB 133 and SB 19 produced in Eldoret was recorded from the seeds treated with 60 kg P ha^{-1} and 2 ton ha^{-1} in the field though it was not statistically different from the seeds that received different P fertilizer and lime level. Similarly, low seed germination was observed on seeds produced from 60 kg P ha^{-1} and 2-ton ha^{-1} in SB 133 and 60 kg P ha^{-1} and 0-ton ha^{-1} in SB 19 (Table 4). Generally, high germination count was observed in the proteinous seeds, SB 19 after storage period was over. The highest germination percent was observed in SB 19 from 30 kg P ha^{-1} + 2-ton ha^{-1} for soybean produced in Eldoret and 30 kg P ha^{-1} + 0-ton ha^{-1} in Busia (Table 4).

Table 4: Seed germination percent of soybean cultivars SB 133 and SB 19 after 6 months of storage in ambient and controlled condition.

			Eldoret			Busia		
Treatment			**Before Storage**	**After Storage**		**Before Storage**	**After Storage**	
Cultivar	**Lime**	**Phosphorous**		**Ambient**	**Controlled**		**Ambient**	**Controlled**
SB 19	0 ton ha^{-1}	0 kg P ha^{-1}	93.33	86.00	89.33	94.67	84.67	86.00
		30 kg P ha^{-1}	96.67	84.00	88.00	92.67	84.67	85.33
		60 kg P ha^{-1}	94.67	80.00	89.33	96.67	76.67	82.00
	2 tons ha^{-1}	0 kg P ha^{-1}	94.67	86.67	90.67	88.67	74.00	87.33
		30 kg P ha^{-1}	92.67	82.67	92.00	95.33	85.33	84.67
		60 kg P ha^{-1}	95.33	73.33	85.33	95.33	81.33	84.00
SB 133	0 ton ha^{-1}	0 kg P ha^{-1}	95.33	76.00	84.00	76.00	66.67	72.00
		30 kg P ha^{-1}	92.67	74.00	64.67	84.67	56.67	68.67
		60 kg P ha^{-1}	92.00	66.00	75.33	76.67	58.00	67.33
	2 tons ha^{-1}	0 kg P ha^{-1}	95.33	83.33	86.67	80.00	58.67	70.00
		30 kg P ha^{-1}	90.00	80.67	77.33	81.33	70.00	75.33
		60 kg P ha^{-1}	92.67	67.33	68.00	74.00	56.00	66.67
		CV (%)	3.97	12.62		6.34	11.62	
		Tukey's (*p* ≤0.05)	ns	ns		16.12	17.01	

4.3.2 Seed germination of the soybean cultivars as influenced by storage condition.

There were significant differences in seed germination for the cultivars produced at both sites as reported in 4.3.1 above after storage. Similarly, significant difference was observed on the effect of storage condition on seed germination for the cultivars produced in Busia (Table 4). On the contrary, the effect of storage condition was not significant on soybean cultivars produced in Eldoret after storage (Table 4, appendices IX and X). Equally, significant interactive effects were reported between storage duration and condition for the soybean produced in Busia, whereas no significance were observed for soybean produced in Eldoret. However, it was observed that seed germination percent declined rapidly for the cultivars stored in the ambient condition to values below the marketable threshold value of ≥ 80.00% than in controlled condition as seen in Table 4 above.

At the end of the storage period, high germination percentage was recorded for the seeds stored under controlled condition, compared to the seeds stored under ambient condition. In both conditions, SB 19 maintained a high germination percent than the SB 133. For instance, for the cultivars produced in Busia, high germination percent was recorded in SB 19 produced under 30 kg P ha^{-1} + 2 ton ha^{-1} lime under ambient and 0 kg P ha^{-1} + 2 ton ha^{-1} lime under controlled conditions. On the contrary, low germination was observed in SB 133 produced under 60 kg P ha^{-1} + 2 ton ha^{-1} lime for both conditions (Table 4).

For the cultivars produced in Eldoret, high seed germination was recorded for SB 19 produced at 0 kg P ha^{-1} + 2 ton ha^{-1} lime under ambient condition and 30 kg P ha^{-1} + 2 ton ha^{-1} lime under controlled conditions (Table 4). On the other hand, the low germination percentage was recorded in SB 133 seeds produced under 60 kg P ha^{-1} + 2 ton ha^{-1} lime in ambient and 30 kg P ha^{-1} + 0 ton ha^{-1} (Table 4).

4.3.3 Electrical conductivity of the cultivars as influenced by storage duration

The analysis of variance revealed significant effect of cultivar on electrical conductivity at the 6th month after storage for seeds produced in Eldoret and Busia respectively (appendices XI and XII). It was observed that in Busia, high EC values were recorded in SB 19 as compared to SB 133 (Figure 9). In the same site, it was observed that EC responded to P level, where, high EC value was recorded at 60 kg P ha^{-1}. The effect of lime was not significant but showed that its application reduced EC in both SB 133 and SB 19. These values were observed to be the inverse of the annotations made for the cultivars produced in Eldoret where SB 133 cultivars recorded a high EC values than SB 19 (Figure 10). Electrical conductivity increased with P application in SB 133 whereas there was no significant difference in SB 19. Lime application was significant in reducing the EC for SB 133 whereas no differences were observed in SB 19.

There was significant effect of storage duration on seed electrical conductivity (appendices XI and XII) where, as the storage period increases, seed electrical conductivity also increases considerably. Additionally, there were significant interaction between storage duration and condition affecting the seed electrical conductivity as shown in appendices XI and XII.

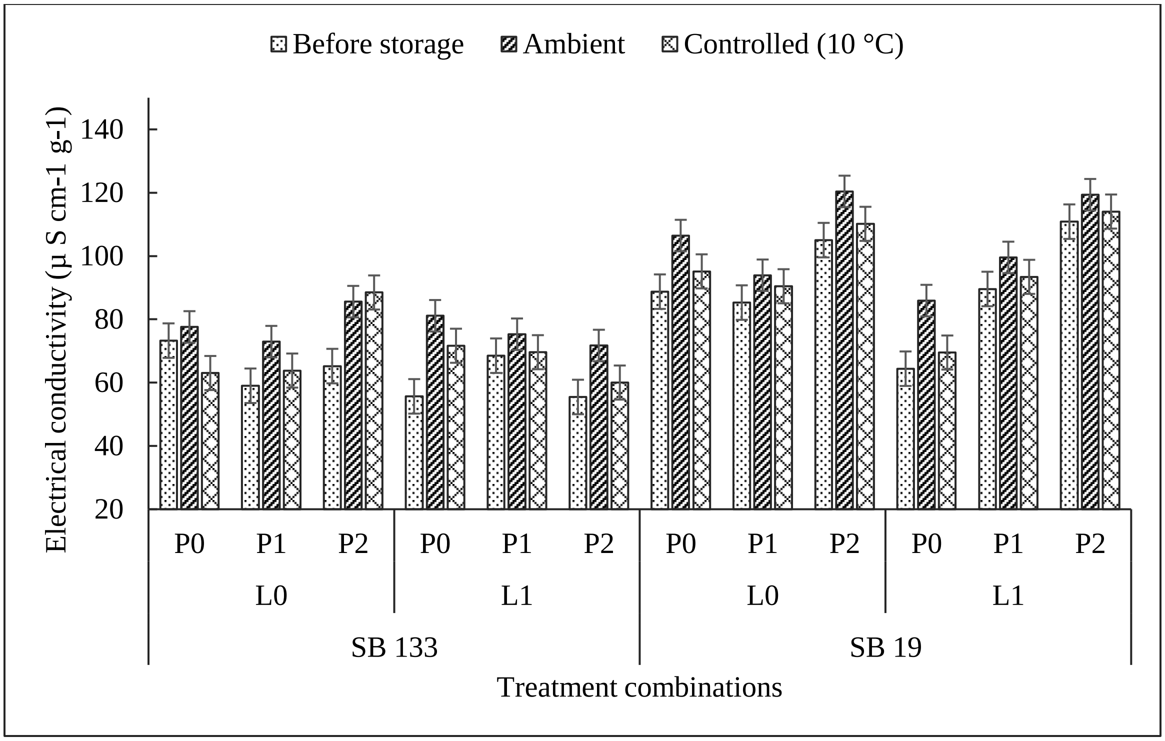

Figure 9: Electrical conductivity of the soybean cultivars produced in Busia when stored for six months under ambient and controlled condition. The error bars indicate the standard error of means, n=3.

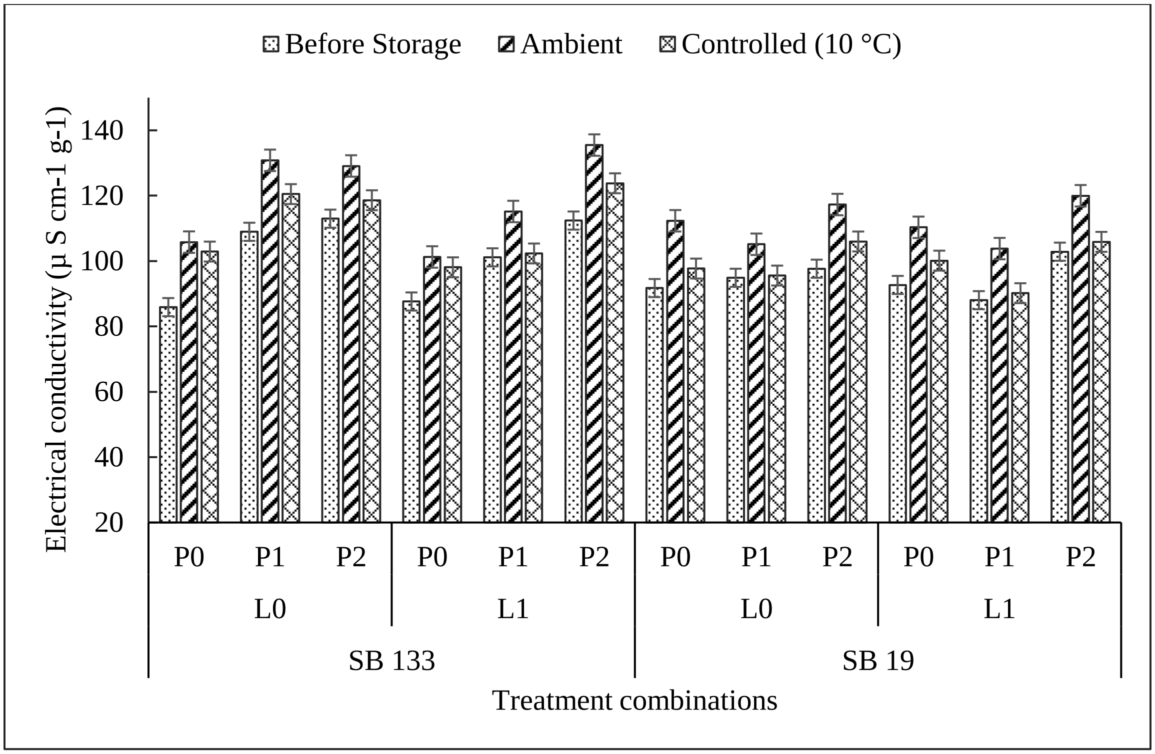

Figure 10: Electrical conductivity of the soybean cultivars produced in Eldoret when stored for six months under ambient and controlled condition. The error bars indicate the standard error of means, n=3.

4.3.4 Electrical conductivity of the cultivars as influenced by storage condition.

There was significant effect of the cultivars on electrical conductivity as described above in 4.3.3. Significant effect of the storage condition on electrical conductivity was observed for the cultivars produced in both sites at the end of storage period (appendices XI and XII). It was noted that storage under ambient condition generally registered high EC values than those stored under controlled condition. High EC values were recorded for SB 133 produced in Eldoret (Figure 10) and SB 19 produced in Busia (Figure 9). In this respect, the use of 60 kg P ha^{-1} + 2 ton ha^{-1} lime in seed production yielded the highest EC for the seeds stored in the ambient condition of 135.5 µ S cm^{-1} g^{-1} for SB 133 and 137.8 µ S cm^{-1} g^{-1} for proteinous cultivars when produced in Eldoret and Busia respectively. Similarly, in the controlled condition, high EC values of 123 µ S cm^{-1} g^{-1} for SB 133 seeds were reported when 60 kg P ha^{-1} and 2 ton ha^{-1} lime was used in Eldoret and 120.4 µ S cm^{-1} g^{-1} in SB 19 when 60 kg P ha^{-1} + 0 ton ha^{-1} lime was used in Busia (figure 9 and 10).

Generally, high EC values were associated with high P levels except in SB 133 produced in Busia (figure 9 and 10). Contrariwise, lower EC values were recorded under controlled condition of 103.81 µ S cm^{-1} g^{-1} in SB 19 produced in Eldoret under 30 kg P ha^{-1} + 2 ton ha^{-1} lime and 60.02 µ S cm^{-1} g^{-1} in SB 133 produced in Busia under 60 kg P ha^{-1} + 2 ton ha^{-1} lime. On the other hand, lower EC values under ambient condition were recorded in SB 133 (98.08 µ S cm^{-1} g^{-1}) produced under 0 kg P ha^{-1} + 2 ton ha^{-1} lime in Eldoret and 71.72 µ S cm^{-1} g^{-1} in SB 19 produced in Busia under 60 kg P ha^{-1} + 2 ton ha^{-1} (figure 9 and 10).

CHAPTER FIVE

DISCUSSION

5.0 The yield of soybean cultivars as influenced by phosphorous fertilizer and lime

This subsection discusses the effect of P fertilizer on and lime on seed yield and thousand seed weight of soybean cultivars produced in Eldoret and Busia.

5.1.1 Seed yield

The significant influence of phosphorous at both sites can be attributed positive response due to low available P in the soil as shown in the soil test summary in appendix II. In this regard, it is apparent that application of fertilizer increases the pool of available P necessary for crop uptake and early root growth which translate to improved crop growth and yield (Gangasuresh *et al.*, 2010). Recording comparable yields from the control experiment as observed in Eldoret site indicates the importance of residual P as suggested by Mallarino & Rueben, (2005). In other studies, scholars have suggested threshold values above which application of P fertilizer would not result to significant soybean yield such as 12 ppm P-Bray-1 (Ferguson *et al.,* 2006) and 6-7 mg P/kg P-Olsen (Ryan *et al.,* 2008).

Phosphorous fertilizer increased the seed yield to maximum point after which a further increase lead to yield decline. The increase in seed yield as a result of P application had been reported before by Borges and Mallarino, (2000, 2003) and Haq and Mallarino, (2005). Similarly, results were observed by (Mahamood *et al.*, 2009) while working in acidic soils in Nigeria and recently by (Suryantini & Kuntyastuti, 2015) in Indonesia. Equally, the influence of P on seed yield had been demonstrated before in the study of

Ryan *et al.* (2008) that reported increased yields of legume when 15-60 kg of P_2O_5 fertilizer ha^{-1} $year^{-1}$ was applied. Additionally, other studies have reported positive influence of application of P fertilizers on soils with low P test (Kaleem *et al.*, 2009; Kamara *et al.*, 2008).

The trend of decline in yield when the P application exceed certain threshold as seen in this work had been reported elsewhere. For instance, (Verde *et al.*, 2013) in a recent study reported significant reduction of yield when 60 kg P ha^{-1} was applied thus supporting the results obtained in this work. However, Mabapa *et al.* (2010) in an experiment in South Africa reported increased soybean seed yield with increasing P fertilizer up to 60 kg P ha^{-1}.

The cultivar differences were significant with SB 133 outperforming SB 19 in seed yield at both sites. These differences can be attributed to the genetic variation where SB 133 produces large seeds that are plumpy and heavier than SB 19 (TSBF-CIAT soybean data, unpublished). It can also be suggested that SB 133 is adaptive, with better root system that are efficient in P acquisition and utilization as ascribed by other scholars Gahoonia and Nielsen, (2004) and Mahamood *et al.* (2009) while studying the performance (yields) of different soybean cultivars under low P levels.

Lime application at both sites was effective resulting to an increase in seed yield.This positive effect of liming on seed yield had been reported in a recent studies by (Bekere, 2013) in Ethiopia while studying liming, nitrogen and bradyrhizobia bacteria in soybean. Similarly, Verde et al, (2013) in an experiment investigating lime use in Central Kenya also found significant effect on grain yield. In other studies elsewhere, positive response of soybean and on other legumes has been reported due to lime application either alone or in combination with P fertilizer (Kassel *et al.*, 2000; Caires *et al.*, 2006; Andric *et al.*, 2012). These findings are also consistent with the work of Nekesa *et al.* (2011) in Western Kenya that found significant soybean grain yield increase when TSP fertilizer or Di-ammonium phosphate (DAP) was combined with lime. This increase in seed yield following lime application might be as a result of lime reacting with water in the soil to produce OH^- ions and Ca^{2+} ions which displaced H^+ and Al^{3+} ions from soil adsorption sites causing an increase in soil pH and availing P for plant uptake (Chimdi *et al.*, 2012; Kisinyo *et al.*, 2005).

In both sites, the seed yield was below the averages earlier suggested by Chianu *et al.*, 2009 of 3000 kg ha^{-1}. The low yield can be attributed to a number of factors including late planting and poor rainfall pattern in the year. It is suspected that the prolonged dry spell experience in the area affected the soil moisture and subsequently dissolution of fertilizer and lime. Low soil moisture following low rainfall had been reported to cause significant grain yield loss of up to 74.05% (Kamara *et al.*, 2011). It is suspected also that decline in soil moisture negatively affected microbial activity, nutrients availability and its uptake which on severe cases suppressed normal growth and thus poor yields.

Generally, it can be deduced from this study that besides phosphorous fertilizer being an essential input for improving growth, development and yield of soybean (Kakar *et al.*, 2002; Mahamood *et al.*, 2009), rational decision over P fertilizer should be guided by soil P test. Additionally, phosphorous efficient genotypes have been reported to exist (Sanginga *et al.*, 2000) which could offer exploitation of environmentally safe and sustainable way to maximize production instead of increasing production cost in acquiring P fertilizers, thus further studies need to be pursued to find out this genotypes and maximize their potentials.

5.1.2 Thousand Seed Weight

Thousand seed weight (g) is an important yield contributing attribute that reflects the ultimate yield of the crop. There were significant differences between the TSW of the oily seeds (SB 133) and the proteinous seeds (SB 19). The cultivar differences were attributed to be caused by absolute variation in seed sizes and weight where the oily seeds were big, plumpy and heavier than the proteinous seeds.

The application of P fertilizer did not cause significant difference on the soybean TSW of the soybean cultivars, similar to the observations made in previous findings by Seguin and Zheng (2006) and Ojo *et al.* (2016). Application of P fertilizer was observed to decrease TSW. These findings are in agreement with the works of Suryantini and Kuntyastut (2015). However, other scholars have reported a significant increase in seed weight with increasing level of applied phosphate fertilizer (Mugendi *et al.*, 2010; Devi *et al.*, 2012; Mohsen *et al.*, 2014). Similarly, a recent study conducted in Mozambique revealed significant effect of P fertilizer on 100 seed weight where high seed weight was recorded from 60 kg P_2O_5 ha^{-1} application (Mateus *et al.*, 2014). The effect of reduced TSW as a result of P increase confirms the assertions that P levels above the soil critical threshold does not result in significant TSW response. On the other hand, lime effect on thousand seed weight was not significant and conforms to the work reported by Bekere (2013).

5.2 The seed quality of soybean cultivars treated with phosphorous fertilizer and lime

This section discusses the effect of P fertilizer and lime on seed crude oil, protein content, initial seed viability and vigour of soybean cultivar, SB 133 (oily) and SB 19 (proteinous).

5.2.1 Seed crude oil content

There was significant difference in seed crude oil between the two varieties in both sites. This is because of the outstanding cultivar differences where SB 133 is oilier and SB 19 proteinous (TSBF soybean data, unpublished). The effect of phosphorous fertilizer on seed oil content was significant for the seeds produced in Busia. This implies that the P fertilizer applied in Busia was effective, since P is an essential ingredient in lipid formation in seeds. Similar results have been reported before where application of P fertilizer increased seed oil (Tanwar & Shaktawat, 2003; Shah *et al.*, 2001; Devi *et al.*, 2012) which affirms the importance of phosphorous in the synthesis of phospholipids.

However, other scholars' did not find significant effect of P fertilizer on seed oil, similar to the findings observed in the seeds produced in Eldoret site. In this site, it was noted that seed crude oil in SB 19 declined with increased application of P. Comparable, results have been reported by Mokoena (2013) where high oil content was recorded at 0 kg P ha^{-1}. Similarly, Win *et al.* (2010) in Bangkok while using P levels at 0.5 mM, 1 mM and 2 m M, reported a decline in oil content when application exceeded 1 mM. Furthermore, other recent studies that did not report significant effect of P fertilizer include Goggi *et al.* (2013) and Macák & Candráková, (2013) in Slovakia. The poor response of seed oil as exhibited by SB 19 in Eldoret suggest that high levels of P have deleterious effects on seed quality as reported by Goggi *et al.* (2013).

There was a significant effect of liming on seed oil content when the soybean cultivars were produced in Busia. However, lime application at both sites was observed to cause decline in seed crude oil content. This indicates that lime was effective in releasing fixed P into the soil solution which explains why SB 19 in Eldoret had its oil content decline further with increased P level. Generally, from this experiment, it was not very clear on the influence of P fertilizer and lime application on seed oil since the response was small, inconsistent and failed to show a linear trend commensurate to increasing treatment application as previously observed by (Haq & Mallarino, 2005; Seguin & Zheng, 2006).

5.2.2 Seed protein content

Cultivar differences were significant with SB 19 being highly proteinous than SB 133. It was observed that the cultivar differences were clearly differentiated in Eldoret site than in Busia due to differences in climatic and soil conditions. The influence of P fertilizer on seed protein content was not significant in Busia as previously been reported elsewhere by Goggi *et al.* (2013), Macák & Candráková (2013) and Win *et al.* (2010). Nonetheless, it was noted in this site that protein content increased with P application up to a maximum level at 30 kg P ha^{-1} in SB 133 whereas SB 19 reached maximum protein at 30 kg P ha^{-1}. The positive trend of increase in protein increase as a result of P fertilizer illustrates the significant role P plays in seed protein synthesis. The phosphorous effect where it increases protein in one cultivar whereas causing a decline in another confirms the assertions of Kaviani and Kharabian (2008) in Iran that there lacks a straight relationship between increasing fertilization and enhanced total seed proteins.

Conversely, significant influence of P fertilizer on seed protein content was observed in Eldoret site. These findings are in agreement with previous work by Devi *et al.* (2012) in an experiment in India where it determined increase in protein with P application up to the highest value of 80 kg P_2O_5 ha^{-1}. Analogous results have also been described before (Shah *et al.*, 2001; Kaviani & Kharabian, 2008; Deliboran *et al.*, 2011; Kumar *et al.*, 2011). An increase in protein content following P fertilizer confirms the pertinent contribution of phosphorous in the crops physiological functions. In this respect, it has been implicated to be helpful in N utilization through improving the activities of *Bradyrhizobium japonicum* thus increasing N fixed and available for use by plant to synthesis proteins (Haru & Ethiopia, 2012; Tsvetkova & Georgiev, 2003). Increasing the amounts of P in the soil improves the relationship between the root bacteria and the leguminous plants and to a greater extent helps in supporting soybean plant's tolerance to stress conditions.

On the other hand, liming effect on seed protein was significant at both experimental sites. Lime in both sites resulted to an increase in protein content. Comparable results were observed by Tanaka *et al.*, (1991) that reported increased seed protein concentration when lime was incorporated in the study. These results indicate the multiple importance of liming in improving the soil condition, reducing soil acidity and enhancing release of P which is an essential energy source for nitrogen fixing bacteria besides supporting the plants physiological processes. Moreover, the liming material used in this study "Physiolith®", is a granulated lime known for being quick in neutralizing soil acidity. It is therefore possible that it might have dissociated to release its anions and cations that reacted with acidic cations such as Al^{3+} Mn^{2+} and Fe^{2+} thereby correcting the soil *p*H and availing P and molybdenum to the soil solution. Nonetheless, other studies did not find significant effect of lime on seed protein such as in the works of Caires *et al.* (2006) that was conducted in Brazil on oxisol (clay-kaolinite-rhodic soils) with *p*H 4.6

5.3 Seed physiological quality before storage

The influence of phosphorous fertilizer and lime on seed germination (%) and electrical conductivity was used to assess the treatment effect on soybean seed physiology before storage.

5.3.1 Initial seed electrical conductivity

The cultivar effect on initial seed electrical conductivity before storage was significant for the seeds produced at both sites. This could be attributed to genetic differences between the cultivars that regulates the cell wall plasticity and seed composition which indirectly determines the rate at which water is imbibed. This differences might also have been contributed to the production environment on seed quality as earlier reported by (Haq & Mallarino, 2005; Sun *et al.*, 2007). Though this study did not perform analysis on genotype-environment interaction, the profound difference between the oily and proteinous cultivars indicated crucial influence of genetic composition on seed quality as earlier reported by (Panobianco & Vieira, 1996; Vieira *et al.*, 1999).

The influence of P on seed electrical conductivity was significant in Busia and no statistical differences were seen in Eldoret. Nonetheless, the general trend indicated that as the amount of P increased, the EC also increased considerably. The same observation had been reported by Goggi *et al.* (2013), where non-treated plots (0 kg P ha^{-1}) produced a lower EC values than those treated with P fertilizer. The high electrolyte leachates from imbibed seeds had been associated with increased P fertilizer (Copeland & McDonald, 1995; Goggi *et al.*, 2013). The diminution of seed quality as the level of applied P increases in this study gives an impression that high levels of P fertilizer can negatively affect the seed quality and should be investigated to identify seed quality threshold and reduce associated cost of production for the resource poor farmers.

High seed EC had been associated with poor seed quality which at times may not be the case because it can be affected by a number of factors such as; cultivar (Panobianco & Vieira, 1996; Salinas *et al.*, 2010; Vieira *et al.*, 1999), initial seed moisture (Vieira *et al.*, 2004), seed storage condition (Panobianco & Vieira, 2007), imbibition injury (Bewley & Black, 1994), seed pathogens (Copeland & McDonald, 1995; Wain-Tassi *et al.*, 2012), and differences in lignin content of the seed tegument as reported by (Alvarez *et al.*, 1997; Panobianco, 1999).

The effect of lime in this study was not statistically significant at both sites. Nonetheless, it was noted that the influence of lime on EC was inversely proportional, such that, lime application resulted to lower EC value. This may imply that calcium present in the liming material might have been utilized by the plant in developing cell wall components thereby helping to enhance its integrity.

5.3.2 Seed germination percentage

Seed germination percentage was significantly influenced by cultivar differences for the soybean produced in Busia. In this regard, high seed germination was recorded in SB 19. These differences indicate the salient cultivar differences between the oily seeds and the proteinous.

Phosphorous application did not produce significant differences on the germination percent of the soybean cultivars. However, in both sites, the germination percentage was above the acceptable marketable percentage of ≥ 80.00 (Vieira *et al.*, 2004). Similar results on non-significance of P levels on seed germination in soybean had been reported by Goggi *et al.* (2013). Furthermore, the same author reported a negative response of germination to increased P levels in one site which affirms the results reported in Eldoret site for SB 133 (Table 3) where high germination was recorded at 0 kg P ha^{-1}. Similar results where high seed germination was recorded from seeds produced from 0 kg P ha^{-1} and declined as P level application increased (Krueger, 2011). This implied that an increase in P fertilizer application might have had depressing effect in seed quality development and might not have added any value to seed germination potential.

Other studies have suggested that low seed germination at high P level had been associated with excessive release of P in solutes during germination that encourages establishment of higher pathogen load (Copeland & McDonald, 1995; Goggi *et al.*, 2013; Lott *et al.*, 1995). It is likely that the level of P relates closely to the stability of the membrane integrity which supports the assertions in this study that seed physiological quality is affected by P fertilization.

Similarly, lime application did not have an effect on seed germination. However, lime application resulted to decline in seed germination. There are possibilities that the lime effect resulted in releasing of P held up in the soil which increased availability of P for plant uptake as emphasised by (Kisinyo *et al.*, 2005; Chimdi *et al.*, 2012) which might have affected germination percentage since a negative relationship between germination and P level has been identified in this study.

5.4 Influence of storage on seed physiological quality

This subsection discusses the effect of storage duration and condition on seed germination (%) and electrical conductivity of cultivars produced in Busia and Eldoret.

5.4.1 Seed germination of the cultivars as influenced by storage duration.

There was significant effect of the cultivars on seed germination percent for the soybean produced in Busia and Eldoret. In this regard, it was observed that SB 19 maintained a high germination percentage (≥ 80) as compared to SB 133 at the end of the storage period. Previous work have reported significant effect of seed composition and identifying oily seeds to deteriorate faster in storage than seeds with higher proportions of protein and starch (Priestley, 1986; Nagel & Borner, 2010). Similar cultivar differences have been reported by previous studies (Panobianco & Vieira, 1996; Vieira *et al.*, 1999). These differences between the cultivars could be as a result of genetic factors and seed chemical composition which might have contributed to the rate of deterioration and germinability at the end of the storage period. Similar assumptions has been made in the work of (Simic *et al.*, 2007) that established a strong negative relationship between absolute seed longevity and seed oil percentage. This can explain the reason why the cultivars SB 133 (oily) generally had a lower germination after storage. Previous studies have suggested that the rapid loss of germination potential of seeds had been attributed to lipid peroxidation over time, resulting in the formation of various hydroperoxides products that affects membranes' permeability (Harrington, 1972; Balešević-Tubić *et al.*, 2005; Walters *et al.*, 2005). However, the findings in this study contradicts to the work of Le Van *et al.* (2008) that affirmed that seeds with high oil content have higher germination within the first year due to minimal levels of imbibition injury.

The impact of storage duration on seed germination was significant. It was noted that as the storage duration increases, the seed germination decreased considerably.

Storage period had been cited as a factor accelerating biochemical changes as the seed ages thereby directly affecting the quality and longevity (Balešević-Tubić *et al.*, 2010; Sharma *et al.*, 2006). Similar trend of seed quality deterioration with increasing storage duration have been reported in the works of Panobianco and Vieira (2007) where significant decrease in germination percentage was observed after the 3rd to 18th month regardless of the storage temperature at 10, 20, 25, 20/10 and 25/10º C. Comparable inferences have been made in another study in Bangladesh by (Saha & Sultana, 2008) where, the same trend of decrease in seed germination and field emergence of soybean were observed when stored for a period of 20 months. Likewise, Alencar *et al.* (2011) in an experiment unveiled existence of triple interdependent relationship between storage duration, moisture content and temperature that affects the seed germination. It was worth noting that the results from this experiment are in agreement with previous work that investigated relationships of storage duration and seed deterioration (Balešević-Tubić *et al.*, 2005; Yaja *et al.*, 2005; Vieira *et al.*, 2007; Alencar *et al.*, 2010; Khaliliaqdam *et al.*, 2012; Kandil *et al.*, 2013).

5.4.2 Seed germination of the soybean cultivars as influenced by storage condition.

The result from this experiment identified significant effect of storage condition on seed germination for the cultivars produced in Busia after 6 months of storage. It was observed that seed germination percent declined rapidly for the cultivars stored under ambient condition to values below the marketable threshold value of ≥ 80.00% than in controlled condition. The effect of storage temperature on seed germination had been documented before to having a negative relationship such that an increase in storage temperature produces a decrease in seed germination (Yaja *et al.*, 2005; Sharma *et al.*, 2006; Simic *et al.*, 2007). Similarly, Alencar *et al.* (2011) had demonstrated that high storage temperature of 30 and 40 ºC led to rapid deterioration of seeds regardless of the initial seed moisture content. This low germination could be as a result of imbibition injury during germination due to rapid water absorption after storage as reported by Bewley & Black, (1994). Higher germination percent was recorded in SB 19 as compared to the oily cultivars. The sensitivity of the oily seeds to storage temperature had been reported before to be caused by the hydrolysis of lipids by lipases leading to rapid loss of seed physiological quality, storability (Smith & Berjak, 1995; Sharma *et al.*, 2006; Balešević-Tubić *et al.*, 2010) and seed health status as reported by (Copeland & McDonald, 1995; Kausar *et al.*, 2009).

5.4.3 Electrical conductivity of the soybean cultivars as influenced by storage duration

The analysis of variance revealed significant effect of cultivar on electrical conductivity where high EC value were reported on the SB 133 and SB 19 cultivars produced from Busia and Eldoret respectively. These differences can be attributed to the variances in the production site which might have influenced the process of seed quality development. These results may imply that SB 133 can best be produced in Busia whereas SB 19 in Eldoret as suggested by their EC values. This inference is supported by the assumptions made before in other studies suggesting that the genetic composition, production environment and storage are crucial in influencing quality (Haq & Mallarino, 2005; Sun *et al.*, 2007). Similarly, the effect of storage duration was tested to be significant. In this respect, the study found notable effect of storage duration augmenting increase in EC values. This implied loss in seed vigour as reported by Vieira *et al.* (2008). Additionally, Kandil *et al.* (2013) in a recent study observed that as the storage period increased from 3, 6, 9 and 12 months, the seed electrical conductivity increased consistently by 7.28, 11.57, 13.96 and 18.0%, respectively from the initial EC value. Similar effects of storage duration on seed vigour supporting the results of this study have been reported (Yaja *et al.*, 2005; Sharma *et al.*, 2007; Saha & Sultana, 2008; Vijay & Dadlani, 2009; Khaliliaqdam *et al.*, 2012). The high EC recorded in SB 133 might be as a result of their vulnerability to deterioration due to lipid oxidation that increases the contents of free fatty acids during storage as seed ages thereby lowering the seed vigour as reported by (Harrington, 1972; Balešević-Tubić *et al.*, 2005; Walters *et al.*, 2005; Alencar *et al.*, 2010).

5.4.4 Electrical conductivity of the soybean cultivars as influenced by storage condition

There was significant effect of the storage condition on seed electrical conductivity of the cultivars produced in both sites. High EC values were produced from the seeds stored under ambient condition than those under controlled. Related results have been described in the recent study by Kandil *et al.* (2013) in an experiment in Egypt, where significantly higher EC values were reported when seeds were stored in ambient than controlled conditions. Associated results have also been reported in an experiment by Vieira *et al.* (2007) where an increase in lixiviates loss was linked to higher storage temperature treatments of 20 and 25º C over time. Additionally, Tanya *et al.*, (2014) in an experiment in Thailand observed less seed deterioration occurring in controlled condition on accelerating aging test, while severe deterioration occurred when seeds were stored in ambient conditions. Other studies that found similar results also identified moisture content alongside temperature as critical and concluded that there is increased rate of seed deterioration when either seed moisture content or storage temperature or both increases (Ellis *et al.*, 1992; Yaja *et al.*, 2005). Similarly, Alencar *et al.* (2011) in an experiment studying initial seed moisture contents at 11.2, 12.8 and 14.8%, and storage temperatures at 20, 30 and 40 °C for 180 days, concluded significant effect on seed vigour (EC) as the level of moisture content, temperature or storage duration increases. Furthermore, the high EC values recorded in the ambient may be as a result of the contribution of relative humidity, which plays an important role in seed rehydration which affects seed moisture content thus accelerating seed deterioration. Other studies have pointed out the influence of storage relative humidity as affecting seed absolute longevity (Barton, 1943; Vieira *et al.*, 2001; Goggi *et al.*, 2013). Finally, other scholars have reported concomitant findings to this study on the effect of storage condition on seed vigour (Jamro *et al.*, 2005; Panobianco & Vieira, 2007; Balešević-Tubić *et al.*, 2010; Alencar *et al.*, 2010; Khaliliaqdam *et al.*, 2012).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

i. Soybean seed yield increased with phosphorous fertilizer application up to maximum at 30 kg P ha^{-1}.

ii. Thousand seed weight of soybean is not affected by phosphorous fertilizer and liming.

iii. Soybean seed oil content was influenced by P fertilizer and lime in Busia

iv. Soybean seed protein content responded positively to P fertilizer and lime application.

v. Initial seed vigour was influenced by phosphorous fertilizer and lime whereas there was no influence on seed viability.

vi. The seed vigour and viability of soybean after storage was influenced by cultivar, storage duration and storage condition.

6.2 Recommendation

i. Phosphorous fertilizer should be applied at levels not exceeding 30 kg P ha^{-1} for optimum soybean seed yield and quality.

ii. Eldoret site is relatively high-altitude area and from this study it was shown to favour production of oily cultivars whereas Busia (low altitude) was better for proteinous cultivars.

6.3 Further work

i. There is need to carry out further studies on different phosphorous and lime levels at different environments to determine recommendation levels for different soil types so as to maximize on seed yield and seed qualities.

ii. There is need to study the effect of calcium in the liming material on seed quality aspects.

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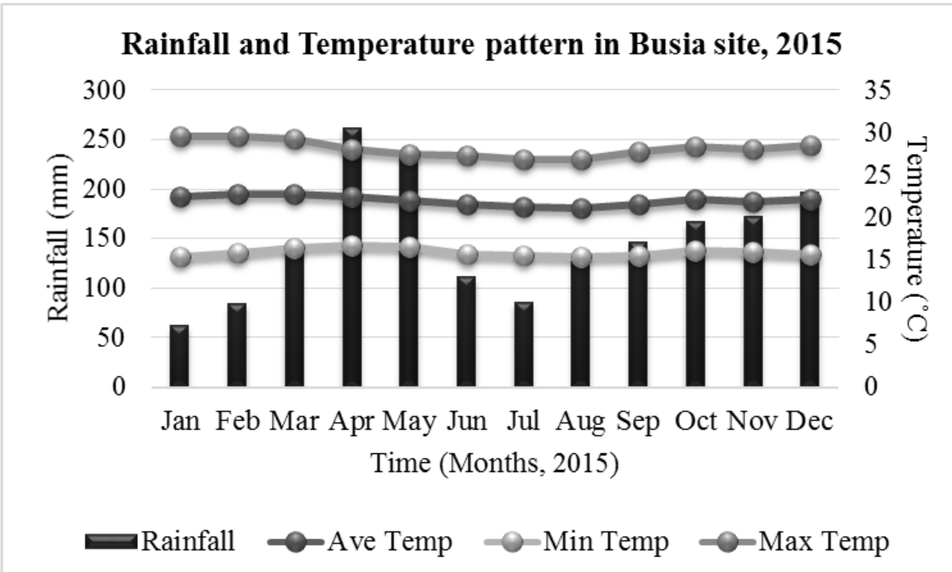
APPENDICES

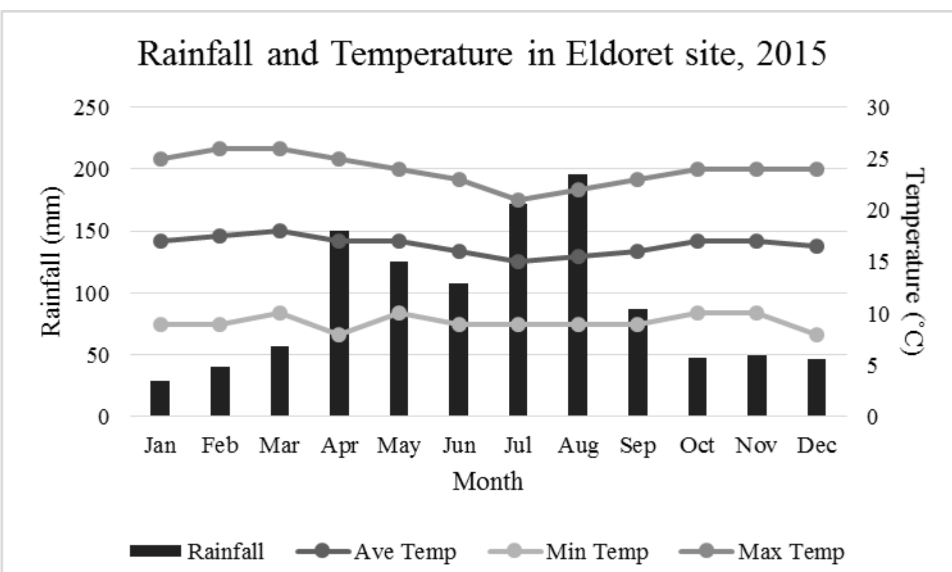
APPENDIX I: Climate data on rainfall (mm) and temperature (˚C) during the production season of 2015

a. **Busia**



Source: Climate data.org

b. **Eldoret**



Source: climatemps.com

APPENDIX II: Selected soil analysis results of the experimental sites

		Site	
		Busia	Eldoret
Parameter	Unit	Value	
***p*H**	(H2O, 1:2.5)	5.41	4.96
P	ppm	5.00	9.11
K	ppm	146.00	1070.00
Ca	ppm	1131.00	1470.00
Mg	ppm	234.00	336.00
Mn	ppm	189.00	120.00

APPENDIX III: ANOVA on the influence of phosphorous fertilizer and lime on seed yield of soybean cultivars when produced in Busia and Eldoret.

a. Busia

```
               Df  Sum Sq Mean Sq F value Pr(>F)
Rep             2   26580   13290   0.148 0.8635
Var             1  434703  434703   4.834 0.0387 *
Phosp           2  813101  406551   4.521 0.0227 *
Lime            1  188113  188113   2.092 0.1622
Var:Phosp       2   82999   41499   0.462 0.6363
Var:Lime        1  133810  133810   1.488 0.2354
Phosp:Lime      2  396037  198018   2.202 0.1343
Var:Phosp:Lime  2  178424   89212   0.992 0.3868
Residuals      22 1978249   89920
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

b. Eldoret

```
               Df  Sum Sq Mean Sq F value Pr(>F)
Rep             2  334874  167437   2.406 0.1135
Var             1  292205  292205   4.199 0.0526 .
Phosp           2  557340  278670   4.005 0.0329 *
Lime            1  114569  114569   1.646 0.2128
Var:Phosp       2   95393   47697   0.685 0.5143
Var:Lime        1   34151   34151   0.491 0.4909
Phosp:Lime      2  128419   64210   0.923 0.4123
Var:Phosp:Lime  2  182374   91187   1.310 0.2899
```

```
Residuals      22 1530874   69585
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

APPENDIX IV. ANOVA on the influence of phosphorous fertilizer and lime on thousand seed weight of soybean cultivars when produced in Busia and Eldoret.

a. Busia

```
               Df Sum Sq Mean Sq F value   Pr(>F)

Rep             2     53      26   0.790   0.4662
Var             1  12716   12716 381.122 2.21e-15 ***
Phosp           2    190      95   2.846   0.0796 .
Lime            1     16      16   0.468   0.5012
Var:Phosp       2     11       5   0.157   0.8553
Var:Lime        1      1       1   0.024   0.8781
Phosp:Lime      2     80      40   1.194   0.3220
Var:Phosp:Lime  2     67      33   0.998   0.3847
Residuals      22    734      33
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

b. Eldoret

```
               Df Sum Sq Mean Sq F value   Pr(>F)
Rep             2    407     203   2.106   0.1456
Var             1  38798   38798 401.673 1.28e-15 ***
Phosp           2    230     115   1.188   0.3236
Lime            1     40      40   0.419   0.5242
Var:Phosp       2    570     285   2.950   0.0733 .
Var:Lime        1     75      75   0.775   0.3881
Phosp:Lime      2    133      67   0.691   0.5118
Var:Phosp:Lime  2     12       6   0.063   0.9393
Residuals      22   2125      97
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

APPENDIX V. ANOVA on the influence of phosphorous fertilizer and lime on seed oil content of soybean cultivars when produced in Busia and Eldoret.

a. Busia

```
                          Df Sum Sq Mean Sq F value   Pr(>F)    
Rep                        2  5.488   2.744   2.163 0.138837    
Cultivar                   1 25.083  25.083  19.771 0.000203 ***
Phosphorous                2  8.751   4.375   3.449 0.049790 *  
Lime                       1  8.170   8.170   6.440 0.018754 *  
Cultivar:Phosphorous       2  2.092   1.046   0.824 0.451591    
Cultivar:Lime              1  1.800   1.800   1.419 0.246283    
Phosphorous:Lime           2  0.038   0.019   0.015 0.984962    
Cultivar:Phosphorous:Lime  2  1.044   0.522   0.412 0.667602    
Residuals                 22 27.911   1.269                     
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

b. Eldoret

```
                          Df Sum Sq Mean Sq F value   Pr(>F)    
Rep                        2  0.001   0.001   0.001 0.999438    
Cultivar                   1 18.923  18.923  17.014 0.000445 ***
Phosphorous                2  1.870   0.935   0.841 0.444717    
Lime                       1  0.028   0.028   0.025 0.875866    
Cultivar:Phosphorous       2  3.470   1.735   1.560 0.232456    
Cultivar:Lime              1  1.822   1.822   1.639 0.213834    
Phosphorous:Lime           2  2.144   1.072   0.964 0.396882    
Cultivar:Phosphorous:Lime  2  2.479   1.239   1.114 0.345937    
Residuals                 22 24.467   1.112                     
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

APPENDIX VI. ANOVA on the influence of phosphorous fertilizer and lime on seed protein content of soybean cultivars when produced in Busia and Eldoret.

a. Busia

```
                           Df Sum Sq Mean Sq F value Pr(>F)  
Rep                         2  11.24   5.620   2.492 0.1058  
Cultivar                    1   4.22   4.224   1.873 0.1850  
Phosphorous                 2   7.99   3.994   1.771 0.1936  
Lime                        1  12.32  12.324   5.463 0.0289 *
Cultivar:Phosphorous        2   0.34   0.168   0.075 0.9283  
Cultivar:Lime               1   0.87   0.868   0.385 0.5413  
Phosphorous:Lime            2   0.15   0.074   0.033 0.9676  
Cultivar:Phosphorous:Lime   2   0.97   0.486   0.215 0.8078  
Residuals                  22  49.63   2.256                 
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

b. Eldoret

```
                           Df Sum Sq Mean Sq F value  Pr(>F)   
Rep                         2  5.639   2.819   2.476 0.10716   
Cultivar                    1  7.050   7.050   6.193 0.02089 * 
Phosphorous                 2 17.474   8.737   7.674 0.00296 **
Lime                        1 10.185  10.185   8.946 0.00673 **
Cultivar:Phosphorous        2  3.130   1.565   1.375 0.27381   
Cultivar:Lime               1  1.630   1.630   1.431 0.24428   
Phosphorous:Lime            2  0.392   0.196   0.172 0.84282   
Cultivar:Phosphorous:Lime   2  0.913   0.456   0.401 0.67459   
Residuals                  22 25.047   1.139                   
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

APPENDIX VII. ANOVA on the influence of phosphorous fertilizer and lime on initial electrical conductivity of soybean cultivars when produced in Busia and Eldoret.

a. Busia

```
                           Df Sum Sq Mean Sq F value   Pr(>F)    
Rep                         2   2250    1125   8.628 0.00171 ** 
Cultivar                    1   6951    6951  53.297 2.6e-07 ***
Phosphorous                 2   1137     568   4.359 0.02543 *  
Lime                        1    258     258   1.975 0.17391    
Cultivar:Phosphorous        2   1965     983   7.534 0.00322 ** 
Cultivar:Lime               1      3       3   0.026 0.87443    
Phosphorous:Lime            2   1217     608   4.664 0.02048 *  
Cultivar:Phosphorous:Lime   2    233     117   0.895 0.42312    
Residuals                  22   2869     130                    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

b. Eldoret

```
                           Df Sum Sq Mean Sq F value   Pr(>F)    
Rep                         2   1473     736   2.516 0.103785    
Cultivar                    1   4549    4549  15.542 0.000694 ***
Phosphorous                 2     68      34   0.116 0.890656    
Lime                        1    416     416   1.420 0.246057    
Cultivar:Phosphorous        2    265     133   0.453 0.641721    
Cultivar:Lime               1      8       8   0.027 0.870164    
Phosphorous:Lime            2   2049    1024   3.500 0.047900 *  
Cultivar:Phosphorous:Lime   2    238     119   0.407 0.670512    
Residuals                  22   6440     293                     
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

APPENDIX VIII. ANOVA on the influence of phosphorous fertilizer and lime on initial seed germination percent of soybean cultivars when produced in Busia and Eldoret.

a. Busia

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Rep	2	12.7	6.3	0.183	0.834	
Var	1	2146.8	2146.8	61.872	7.81e-08	***
Phosp	2	98.7	49.3	1.422	0.263	
Lime	1	5.4	5.4	0.157	0.696	
Var:Phosp	2	184.9	92.4	2.664	0.092	.
Var:Lime	1	5.4	5.4	0.157	0.696	
Phosp:Lime	2	0.9	0.4	0.013	0.987	
Var:Phosp:Lime	2	96.9	48.4	1.396	0.269	
Residuals	22	763.3	34.7			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

b. Eldoret

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Rep	2	10.9	5.44	0.294	0.748
Var	1	0.1	0.11	0.006	0.939
Phosp	2	1.6	0.78	0.042	0.959
Lime	1	5.4	5.44	0.294	0.593
Var:Phosp	2	76.2	38.11	2.056	0.152
Var:Lime	1	1.0	1.00	0.054	0.818
Phosp:Lime	2	20.2	10.11	0.546	0.587
Var:Phosp:Lime	2	24.7	12.33	0.665	0.524
Residuals	22	407.8	18.54		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

APPENDIX IX. ANOVA on the effect of storage on seed germination percent of soybean cultivars produced in Busia

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cultivar	11	10443	949	19.409	< 2e-16	***
StorageDur	1	5256	5256	107.453	< 2e-16	***
StorageCond	1	367	367	7.510	0.00732	**
Cultivar:StorageDur	11	693	63	1.287	0.24338	
Cultivar:StorageCond	11	192	17	0.357	0.96900	
StorageDur:StorageCond	1	367	367	7.510	0.00732	**
Cultivar:StorageDur:StorageCond	11	192	17	0.357	0.96900	
Residuals	96	4696	49			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

APPENDIX X. ANOVA on the effect of storage on seed germination percent of soybean cultivars produced in Eldoret

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cultivar	11	2405	219	3.762	0.000172	***
Storage.Cond	1	160	160	2.761	0.099851	.
Storage.Dur	1	6400	6400	110.134	< 2e-16	***
Cultivar:Storage.Cond	11	306	28	0.479	0.912107	
Cultivar:Storage.Dur	11	1561	142	2.443	0.009867	**
Storage.Cond:Storage.Dur	1	160	160	2.761	0.099851	.
Cultivar:Storage.Cond:Storage.Dur	11	306	28	0.479	0.912107	
Residuals	96	5579	58			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

APPENDIX XI. ANOVA on the effect of storage on seed electrical conductivity of soybean cultivars produced in Busia

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cultivar	11	39035	3549	13.842	1.65e-15	***
StorageDur	1	2128	2128	8.299	0.00489	**
StorageCond	1	1015	1015	3.960	0.04945	*
Cultivar:StorageDur	11	2532	230	0.898	0.54534	
Cultivar:StorageCond	11	508	46	0.180	0.99831	
StorageDur:StorageCond	1	1015	1015	3.960	0.04945	*
Cultivar:StorageDur:StorageCond	11	508	46	0.180	0.99831	
Residuals	96	24612	256			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

APPENDIX XII. ANOVA on the effect of storage on seed electrical conductivity of soybean cultivars produced in Eldoret

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cultivar	11	13277	1207	16.595	< 2e-16	***
Storage.Cond	1	975	975	13.399	0.000412	***
Storage.Dur	1	5422	5422	74.552	1.27e-13	***
Cultivar:Storage.Cond	11	120	11	0.150	0.999283	
Cultivar:Storage.Dur	11	517	47	0.646	0.784926	
Storage.Cond:Storage.Dur	1	975	975	13.399	0.000412	***
Cultivar:Storage.Cond:Storage.Dur	11	120	11	0.150	0.999283	
Residuals	96	6982	73			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1