OPTIMIZATION OF SEED POTATO TUBER PRODUCTIVITY AND QUALITY THROUGH INTEGRATED WATER, NITROGEN AND PHOSPHORUS MANAGEMENT

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been previously presented for the award of a degree in any University.

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Recommendation

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DEDICATION

This work is dedicated to God who is my strength. Also to my wife Beatrice, our children Lucyann, Vincent and Veronicah, my dear mother Lucy Mugure, brothers Peter and Laban, Sisters Virginia and Margaret, and in memory of my dear father Gathungu Murungi and sister Hellen.

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ABSTRACT

Potato (*Solanum tuberosum* L.) is a major food crop and by far the most important vegetable crop in terms of quantities produced and consumed. Potato productivity and industry expansion have been constrained by the low quantity and quality seed tubers produced in the informal seed sector, partly due to improper fertilizer management practices and irregular rainfall patterns. A study was conducted in a Rainshelter (RTrial) at the Horticultural Research and Teaching Farm of Egerton University to determine the effect of integration of irrigation water, nitrogen (N) and phosphorus (P) application on seed potato growth, yield and yield components, tuber quality and sprouting characteristics. The treatments were arranged in a split-split plot layout in a completely randomised block design, consisting of three irrigation rates (40%, 65% and 100% field capacity), four N rates (0, 75, 112.5 and 150 kg N/ha) supplied as urea (46% N), and four P rates (0, 50.6, 75.9, 101.2 kg P/ha) supplied as triple superphosphate, replicated three times and repeated once. After harvest, seed potato tubers harvested from each treatment were stored for 90 days after which sprouting characteristics were determined in the postharvest Performance Evaluation Trial (PTrial). Data collected were subjected to analysis of variance and significantly different means were separated using Tukey's Studentized Range Test at $P \leq 0.05$. Subjecting potato to 100% compared to 65% and 40% irrigation rates significantly affected most of the parameters measured. High (100%) compared to 40% irrigation rate increased sprout emergence by 1.4% and 3.2%, stem number by 0.2, plant height at 108 DAP by 32.64 and 33.85 cm, stomatal conductance at 87 DAP by 32.82 and 31.99 $mmolm^{-2}s^{-1}$, leaf chlorophyll content index by 16.2 and 16.5, 19.8 and 19.6, and 15 and 20.3, when integrated with high compared with low N and P application rates at 59, 73 and 87 DAP, LAI by 1.54 and 0.61 at 51 DAP, and by 2.06 and 1.78 at 64 DAP, reduced the days to 50% flowering by 14.9 and 15.2, and WUE by 6.1 and 8.1 kg/m^3, increased NUE by 14.4 and 13.3 kg/kg, and PUE by 73.4 and 69.5 kg/kg, in RTrials I and II respectively. High (100%) compared to 65% irrigation rate reduced the number of tubers by 1.2 and 1.3 and seed potato yield by 2.3 and 3.1 t/ha, increased ware potato by 4.3 and 5.1 t/ha, reduced seed size II by 2.5 and 2.9 t/ha, seed size I by 1.6 and 2.1 t/ha, and chats by 0.7 and 0.8 t/ha, HI by 5.3% and 4.9%, tuber tissue P content to 0.18% and 0.22%, seed potato NEB by Ksh. 288,991 and 274,792, seed potato firmness at harvest by 1.2 and 1.3 kgf, TSS by 0.3% in RTrials I and II, respectively. The 100% compared to 65% irrigation rate reduced tuber yields by 2.33 and 3.08 t/ha, seed size II by 2.45 and 2.88 t/ha, seed size I by 1.62 and 2.1 t/ha, net economic benefit by Ksh 202,799 and 235,684, number of sprouts by 0.9 and 1.1, post-treatment evaluation stem number, density and height at 57 DAP by 1.3 and 1.1, 15.1 and 12.6, and 13.4 cm and 10.3 cm, and tuberization capacity in resultant plants by 5 and 8.7 tubers, in PTrials I and II, respectively. The N and P rates generally improved potato growth and development, yield and yield components in the RTrial, and also the number of sprouts, growth and tuberization capacity in the PTrial. Combined application of N and P at 112.5 kg N/ha and 75.9 kg P/ha, compared to 0 kg N/ha and 0 kg P/ha increased potato leaf chlorophyll content index at 73 DAP by 17.6, reduced days to 50% flowering by 4.7 and 4, potato physiological maturity by 18.6 and 19.7 days, increased total biomass production by 123.4 and 170.5 g, number of tubers by 1 and 1.4, seed potato yield by 19.1 and 25.1 ton/ha, seed potato HI by 8.5%, water use efficiency by 10 and 13 kg/m^3, N use efficiency by 41.89 and 53.31 kg/kg, P use efficiency by 140.7 and 186.6 kg/kg, seed firmness after storage by 1.3 and 3 kgf, seed potato tubers TSS by 1.4% and 1.6%, and NEB by Ksh. 490,210 and 619,591, in RTrials I and II, respectively. Application of N at 0 to 150 kg N/ha increased number of sprouts from 3.8 and 4.6 to 4.8 and 5.5, and sprouting from 54.8% and 66.3% to 68.7% and 78.6%, while P application at 0 to 101.2 kg P/ha increased sprouts from 3.8 and 4.5 to 4.8 and 5.7, and sprouting from 53.6% and 64.7% to 67.9% and 81.4%. Integration of N at 0 to 112.5 kg N/ha with 65% irrigation rate increased number of tubers produced by the resultant plants by 3.4 and 5.4, while high P rate at 75.9 kg P/ha increased tuberization by 8.4 and 10.7, in RTrials I and II, respectively. Integration of 65% irrigation rate, 112.5 kg N/ha and 75.9 kg P/ha rates optimised potato growth, seed yield, seed size distribution, water and mineral nutrient use efficiencies, seed potato tuber sprouting, net economic benefit, and vigour of resulting potato plants. It is therefore recommended to apply intermediate irrigation (65% field capacity), N (112.5) and P (75.9 kg P/ha) rates to optimise growth, development, yield, yield components and quality characteristics of potato destined for seed use.

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LIST OF ACRONYMS

ADC	Agricultural Development Corporation
AIC	Agricultural Information Centre
ANOVA	Analysis of Variance
CCI	Chlorophyll content index
CIMMYT	International Maize and Wheat Improvement Centre
CIP	International Potato Centre
CV	Coefficient of Variation
DAP	Days After Planting
DAS	Days After Storage
DM	Dry Matter
DPI	Department of Primary Industries
FAO	Food and Agriculture Organisation
FC	Field Capacity
FUE	Fertiliser Use Efficiency
GOK	Government of Kenya
HI	Harvest index
ICIPE	International Centre for Insect Physiology and Ecology
IPNI	International Plant Nutrition Institute
KARI	Kenya Agricultural Research Institute
LAI	Leaf area index
MD	Man days
MOA	Ministry of Agriculture
MSD	Minimum significant difference
MSD (N)	Minimum significant difference, nitrogen rate
MSD (P)	Minimum significant difference, phosphorus rate
MSD (W)	Minimum significant difference, irrigation water rate
N	Nitrogen
NEB	Net Economic Benefit
NUE	Nitrogen Use Efficiency
P	Phosphorus
P	Probability level
PAR	Photosynthetically Active Radiation
PTrial	Performance Evaluation Trial

PUE	Phosphorus Use Efficiency
RTrial	Rainshelter Trial
RUE	Radiation Use Efficiency
SM	Soil moisture
SS	Sum of squares
TDR	Time Domain Reflectometry
TSP	Triple Super phosphate
TSS	Total Soluble Solids
USA	United States of America
USAID	United States Agency for International Development
VWC	Volumetric Water Content
WAP	Weeks After Planting
WI	Wageningen International
WPC	Western Potato Council
WUE	Water use efficiency

CHAPTER ONE

INTRODUCTION

1.1. Background Information

Potato (*Solanum tuberosum* L.) is a major food crop and by far the most important vegetable crop in terms of quantities produced and consumed worldwide (FAO, 2005). Potato is the world's fourth important food crop after wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), and maize (*Zea mays* L.) because of its great yield potential and high nutritive value (FAO, 2009; Kumar, 2013). Potato is a staple component of the diet in many human cultures, a source of many essential nutrients and is available all year round (Arvanitoyannis *et al.*, 2012). It has significantly more nutritional value than major cereal crops (Thompson *et al.*, 2007). Potato is grown for many uses such as food, income and raw materials for processing. In all cases, a reliable supply of good quality seed is crucial to the development of the potato sector (WI, 2007). Potato is consumed as a staple food in many parts of the world (Butt, 2006) and by over one billion people, half of whom live in developing countries. It gives an exceptionally high yield and also produces more edible energy and protein per unit area and time than many other crops (Naik and Karihaloo, 2007).

Potato is used to postpone the consumption of cereals and is grown as a security crop against crop failures (Kamadi, 2011; Muthoni *et al.*, 2013). Its tubers constitute a highly nutritious food and supplies at least 12 essential vitamins, minerals, proteins, carbohydrates and iron (Thornt and Sieczka, 1980). It is consumed in many forms such as vegetable, chips and powder (Walingo *et al.*, 1997; FAO, 2009; Kibar, 2012). Potato provides subsistence to people from the high Andes to the plains of East Africa, and because it can be stored to provide food during food scarcity times, it is part of both commercial and subsistence agriculture (Secor and Rivera-Varas, 2004).

Potato is of socio-economic importance and benefits both commercial and resource-poor smallholder farmers. Many farmers prefer growing the crop because it has a short maturity period and can be grown throughout the year (Kabira, 2002). It has overtime generated special importance in most parts of Kenya as a means of strengthening food security and increasing revenues for farmers. Out of the four major food crops (rice, wheat, potato and maize), the potato has the best potential for yield increases (Wang, 2008).There is, therefore, increased need to boost output and improve cropping systems to increase profits.

Potato produces high yield, more edible energy and protein per unit area and time than many other crops, fits well into multiple-cropping systems, its cultivation is profitable and it provides employment hence it cultivation is expanding rapidly in developing countries

(Singh, 2008). Currently due to its short growth cycle and the convenience with which it fits into cropping systems as a rotation crop with maize, rice, soyabeans, cabbages and peas, lettuce, wheat, onions, potato has become a very important crop (Theisen, 2006; FAO, 2009; TOF, 2010). Potato plays an important role in the Kenyan economy and is one of the most important food and cash crops in the highlands. Due to its increased consumption and use in family diets, potato production rates have been increasing in Kenya. Potato matures in 3 to 4 months and its average yields range from 20 to 40 t/ha (Abdelgadir *et al.*, 2003), although most farmers realize less than 10 t/ha due to poor agronomic practices, low farm input use, clean seed tuber shortage, and poor pest control (Kabira *et al.*, 2006). While in some African countries potato is considered a "poor person's food", in Kenya it is considered a high quality and prestigious food item (FAO, 2009). Potato is grown by some 500,000 farmers on about 128,000 ha with average yields of 7.7 tonnes per ha and most potato growers are small-scale farmers (Janssens et al., 2013)

Potato production bears high income potential for farmers, but owing to various constraints such as limited supply of pest-free planting materials, low quality in terms of content and size, lack of sufficient irrigation, fertilization, low technical and postharvest handling know-how among farmers, local production rarely meets the market demand. Quality of produce is sometimes poor, consumer prices seem often higher than production costs and demand often outstrips supply, meaning that the sector is still under-exploited (Ayieko *et al.*, 2005). Potato productivity and industry expansion have been constrained by the poor quality seed tubers produced in the informal seed sector (Sayagie, 2009). Poor seed arise from inadequate supply of initial planting materials, improper fertilizer management practices and irregular rainfall patterns. One of the main constraints is the cost of producing seed tubers since this can account for between 30% and 50% of the total production costs, depending on the country or region (Correa *et al.*, 2009).

Kenya needs 300,000 tonnes of certified potato seed per year (MOA, 2009), but only 2,640 tonnes (TOF, 2012) are available from research institutions and certified seed producers and therefore 96% of the farmers use their own harvest for replanting (ICIPE, 2010). It is therefore very difficult for farmers in most parts of the country to get good quality seed potato for planting. What farmers are forced to do in most cases is that at the time of planting, they use the available potatoes in their seed store, regardless of whether they are well-sprouted or not and such poor potatoes only produce one or two stems, which lead to poor yields (TOF, 2012).To meet the increasing demand of seed tubers, production efficiency must be improved. The seed potato tubers must also present good physiological characteristics such as minimal weight loss in storage, firmness, total soluble solids content, and sproutability, which are crucial in improving production at the farm level. Small-scale potato farmers rely on farm-saved seed potato tubers, as well as seeds purchased from neighbours. Formal potato production sector's high-quality and more productive seed potato tubers are expensive and remain largely unavailable to smallholder farmers in sub-Saharan Africa. Only elite farmers can afford the expensive certified seed tubers. The balance of the seed requirement is supplied by the informal sector managed by traders, seed tuber and ware potato producers. The informal system, which includes unlicensed potato growers and suppliers mainly in immediate localities, entails farmer-to-farmer distribution that supplies 99% of the estimated 300,000 tonnes of seed potato tubers required annually (MOA, 2009). Compared to the formal seed sector which involves a long certification process according to the Seed and Plant Varieties Act Cap 326 the informal seed production system needs much less time to avail the seed to the farmers and therefore should be supported as it is the only sustainable method to alleviate the problem of seed shortage (TOF, 2013).

Quality seed is one of the most important elements in successful potato cultivation. Potato seed is usually the most expensive single input to potato cultivation accounting for 40 to 50% of production cost and shortage of good quality seed is recognized as the most important factor inhibiting potato production (Singh, 2008). Availability of quality potato planting materials in adequate quantities is a major issue and although efforts to strengthen the formal seed system are critical, there is need to consider effective integration with the informal seed system to close the availability gap. However, many informal seed potato farmers in Kenya still use ware potato production technology for producing seed tubers. Consequently, seed tubers available through the informal system are of poor quality. Though potato yields are affected by several factors, seed quality is the basic factor. Most potato growers do not apply integrated management practices during seed tuber production. Potato growth depends on a supply of plant nutrients, such as nitrogen (N), phosphorus (P) and potassium (K), each with a specific function for plant growth and lack of them results in retarded growth processes and reduced yields (van der Zaag, 1981).

In Kenya, low application of N and P under continuous cultivation is a major constraint that leads to poor potato growth and productivity. Informal seed tuber growers continuously grow potatoes for income generation purposes, resulting in depletion of the major nutrients in potato farms. For increased productivity inorganic N fertilizers have become extremely important in correcting declining soil fertility, seed tuber yields and quality. For high yields, potato requires both organic and inorganic mineral fertilization

(Plaza *et al.*, 2004). Farmers apply phosphatic or compound fertilizers such as diammonium phosphate at planting and do not or rarely do topdress the potatoes later in the growth season. However, use of these fertilizers has not been effective due to isolated application practices. Technical Centre for Agricultural and Rural Cooperation (2003) indicated that soil fertility depletion is the fundamental cause of low per capita food production in Africa. Fertilisers are expensive and their availability to most small-scale farmers in the informal sector is limited by cost, which then calls for integrated use to increase productivity per unit area of application. When applied nutrients are not taken up by the crop, fertilization efficiency decreases and unused N and P can be lost through leaching or runoff in groundwater or surface water (Obreza and Sartain, 2010).

Another factor that has limited seed potato production in many parts of Kenya is unreliable rainfall. Potato is sensitive to soil water deficit (Bowen, 2003; Kiziloglu *et al.*, 2006). Water deficit is a common stress in potato production, which leads to decrease in tuber quality and yield (Hassanpanah, 2009). Hot, dry conditions reduce availability of good-quality tubers and this demonstrates how proper soil moisture supply could have major impacts on the economics of potato production. During hot and sunny days even well-irrigated potato plants undergo temporary water stress (Jefferies, 1995). However, the severity of water stress effects depends on stress timing, duration and intensity. Irrigation has been increasingly employed to curtail effects of drought (Thompson *et al.*, 2007) in other countries, but in Kenya potato farmers rarely use this practice due to cost and lack of knowledge, among other factors. Knowledge on performance of potato under different irrigation regimes will help predict the expected seed tuber yield in environments characterized by varied rainfall amounts. Information on potato crop water use and soil water depletion will help determine the water required for optimal production, especially under rainfed conditions.

Recent potato yield increases are mainly due to improvements in cultural practices, particularly the increased use of irrigation, although new cultivars may also have played a major role. It is reported that 50% of the four-fold yield increase from 1930 to 1980 was due to genetic improvement (Bamberg and Rio, 2005). There is need to develop strategies to provide potato growers with good quality seed tubers at affordable price. Study of tolerance of potato to varying irrigation water and mineral nutrient supply rates will assist farmers in the informal seed potato sector in predicting seed potato tuber yields to expect under their prevailing agro-ecological conditions.

1.2. Statement of the Problem

Selection of the right potato planting material is one of the most challenging tasks a farmer undertakes to obtain good yields. Small-scale potato farmers are constrained by limited seed potato tuber quantity and quality. Although there exists potential of increasing potato productivity through increased informal seed potato tuber production there is limited knowledge on the effects of integrated irrigation water, N and P rates management on seed potato tuber yield, quality, and subsequent sprouting and growth vigour. Currently, informal seed sector farmers rely on ware potato fertiliser and irrigation rates, which are not economical or appropriate agronomically. Furthermore, efforts to study integrated N, P and irrigation water management effects on post-harvest sprouting qualities of seed potato tubers have been limited in scope, inconsistent in effort, or never been attempted. It is imperative to develop specific integrated N, P and irrigation water management packages that will result in high yield and quality of seed potato tubers. If value is added to seed potato production, through better irrigation water and fertilizer nutrient management, this will not only meet seed quality needs, but will enable have a highly profitable cash crop that can drive economic development and sustain livelihoods in areas where potato is grown. This will maximize profitability in the informal potato production sector.

1.3. Objectives

1.3.1. General objective

To increase seed potato tuber productivity and quality through integration of irrigation water, N and P fertilizer application rates and management.

1.3.2. Specific objectives

(1) To determine the effect of irrigation water, N and P rates on growth, yield and quality of seed potato tubers.

(2) To evaluate sprouting and tuberization capacity of seed potato tubers produced using different irrigation water, N and P rates.

(3) To establish the net economic benefit, WUE and FUE of seed potato tubers produced using different irrigation water, N and P rates.

(4) To determine interaction effects of irrigation water, N and P rates on growth, development, yield, quality, sprouting and tuberization capacity of seed potato tubers.

1.4. Hypotheses

The hypotheses tested were:

1.4.1. Irrigation water, N and P rates have no significant effects on growth, yield and quality of seed potato tubers.

1.4.2. Irrigation water, N and P rates have no effects on sprouting and tuberization capacity of seed potato tubers

1.4.3. The net economic benefit, WUE and FUE of seed potato tubers produced using different irrigation water, N and P rates are not significantly different.

1.4.4. Interaction of irrigation water, N and P rates on growth, yield, quality, sprouting and tuberization capacity of seed potato tubers are not significantly different.

1.5. Justification of the Research

Informal potato seed production system is characterized by buyer-seller arrangements that are disorganized and lack regulatory controls. On the contrary, the strategy of the informal seed potato sector should be to increase seed potato production and ensure that resource-poor farmers have access to healthy and improved seed potato tubers. Furthermore, there is lack of uniformity in description of seed potato size and farmers are not aware of the effects of different management practices on seed potato quantity and quality. Seed accounts for about 40% of the cost of production and quality seed is a prerequisite for profitable potato crop (Kang, 2008). For increased potato productivity, quantity and quality seed tubers should be accessible to farmers at affordable prices. Otherwise farmers in desperate situations will always turn to planting low quality seed potato. Knowledge of the effect of integrated water and nutrient management on quantity and quality of seed potato tubers will help to strengthen the informal seed potato production system.

Although potato is the most widely distributed crop in tropical and subtropical zones of the world (Burhan *et al.*, 2007), its productivity and quality are inadequate due to disjointed investigation of the many factors that hinder them. These factors include poor seed potato tuber quality, irrigation management, mineral fertilization, insect pest and disease forecasting, as well as poor planting dates and storage conditions (Walingo *et al.*, 2004). Farmers in the informal seed potato sector do not apply N and P fertilisers or they apply them using either high or low rates that result in production of large quantities of ware or chat potatoes, respectively. Large quantity of ware potatoes results in increased cost of seed tubers due to hefty quantities required to plant a unit area. Large quantity of chats, results in fewer tubers being required, but due to their small size they exhibit short shelf-life, poor growth and yield. While the big sized seed increase cost the seed that are too small can rot before emergence (Wang, 2008). It is therefore essential to control the conditions during production to optimize seed potato tuber quality.

The limited availability of certified seed potatoes to smallholders compounds the spread and perpetuation of diseases, as farmers have no option, but to obtain seed potatoes from unreliable sources, such as previous harvest, local markets or neighbours. This poor quality of seed then becomes a major constraint on yield increase. For this reason, supply of quality seed becomes a key issue for potato production. Poor crop husbandry practices lead to low yields, diseases, bruises, mixed and smaller tubers at harvest. There is need, therefore, to develop N and P management practices during potato growth, which will enhance desired quality of seed potato tubers in the informal sector. Increase in potato production will be achieved through the high quality seed potato tubers directing partitioning of the dry matter towards increased tuberization and average size. Currently, there are no recommendations for combined N, P and irrigation water rates for seed potato tuber producers in the informal sector to adopt, leaving the sector to rely on management practices for commercial or subsistence potato production. This discrepancy has resulted in production of under- or over-sized potato tubers that are not suitable for use as seed.

Water and N are important factors influencing tuber growth, development, quality and yield and their balanced management is important where rainfall is extremely low and soils have low organic matter content, since potato closes stomata under relatively low soil moisture deficit (Pereira and Shock, 2006). Plant needs for water and nutrients are interdependent, as a good water supply improves the nutritional status of crops, and adequate nutrient supply saves water (Roy *et al.*, 2006). Proper coordination of N, P and water management can increase potato productivity through their efficient use. Most work on seed potato tuber quality has focused on effect of diseases and little attention has been given to the effect of nutrient and water management in different genotypes. Despite the value of size of seed potato tubers to growers and the importance of N, P and water management, no work has been done on combined application of N, P and irrigation water. Farmers in the informal seed production sector are inconsistently and inappropriately applying N and P fertilisers due to lack of information on their combined effects on potato growth and development for high quantity and quality seed potato tuber production. In the long-term misapplication lowers yield and quality of seed potato tubers, as well as market and consumer values. Where fertilization is done, farmers do not supply irrigation water to the crop to enable it utilize the nutrients maximally during dry spells. There is poor understanding of tuberization requirements by growers in the informal seed potato production sector. As the need for food production increases with increasing population growth, it is important that strategies are developed to enhance the nutrient uptake and utilization efficiencies (Liu *et al.*, 2012). There is therefore need to evaluate, document and disseminate comprehensive management packages and knowledge on tuberization requirements. This can be achieved through combined investigation of N, P and irrigation water effects. Furthermore, in the face of increased fertilizer and irrigation water cost and stringent environmental regulation, there is a critical need to improve N, P and water use efficiency to ensure seed potato tuber production remains sustainable.

CHAPTER TWO
LITERATURE REVIEW

2.1. Overview of Potato

Enhanced productivity of potatoes can improve the livelihood of smallholder farmers, as well as meet the growing consumer demand (Gildemacher *et al.*, 2009). Potato tubers are a good source of energy and high quality proteins, vitamins and minerals (Burt, 1989). Development of potato plants can be divided into five growth stages, namely sprouting, vegetative, tuber initiation, bulking and maturation (Ewing and Struik, 1992; Agriculture, Food and Rural Development Department, 2005). Timing and duration of these growth stages depend upon environmental factors such as elevation, temperature, cultivar, soil moisture and nutrient status. Considerable work regarding individual fertilizer and water use management on potato growth and yield is available but the combined effects are scarcely documented. To produce quantity and quality seed potato tubers balanced N and P nutrient and water management must be enhanced during growth. In informal seed sector, intensification is crucial to tackling of the problem of potato self-insufficiency through production of more and quality seed tubers per unit area of land.

Potato production is practiced mainly by small-scale farmers in farms averaging between 0.5 ha and 2.0 ha. Production rates have not only been increasing, but they have exceeded those for many other major food crops (CIP, 1998). However, yield and quality of potato is affected by many factors, including poor seed, growing techniques, fertilization, disease control, storage facilities, marketing systems and varieties (Shamebo, 1997). The factors can be classified as genetic, environmental and cultural. Cultivar, physiology, cultivation practices, crop management, growth and storage conditions influence tuber quality (Burt, 1989; Struik and Wiersema, 1999). Potato tubers have high water content and are sensitive to environmental conditions during production. Thus, although high yielding potato varieties have been developed, their yield capacity and quality in the informal seed sector has over time been limited by poor farm-level crop husbandry practices. Potatoes are affected during the growing season by temperature extremes, nutrient excesses or deficiencies, water stress, physical damage, or other unfavorable growing conditions, may not respond to storage environments well (Kibar, 2012).

2.2. Seed Potato Tuber Quality

Potato yield is strongly influenced by seed quality characteristics mainly seed tuber size, physical characteristics such as shape and presence of wounds, physiological age and seed tuber health (Struik, 2006). Other seed tuber quality attributes that may influence potato growth includes mineral nutrient composition, specific density, starch and dry matter content. Starch is the main component of the harvested parts of many crops, including cereals, peas and beans, potatoes and cassava and is the main form in which plants store carbon (Smith, 2010). Advances in seed potato multiplication technology and management present numerous options for improving local seed supply systems, both in terms of quality and quantity. The physiological status of seed potato has a great impact on sprouting, number of stems per plant, number of tubers per stem, tuber-size distribution, and tuber yield (Van der Zaag and Van Loon, 1987). Control of seed tuber quality is an essential element in the sustainability of the seed industry as it is the basis of increased yield at the farm level.

Tuber size affects yield per stem, and if small results in less foliage per stem and hence less radiation use and photosynthetic efficiency. Tuber size influences performance of potato attributes such as sprouting, vigour, growth and final yield (Allen and Scoot, 1980). Furthermore, tuber size influences bud and stem number per seed piece, which in turn influence tuber set and eventual yield of potato cultivars. Wiersema *et al.* (1987) reported that tubers weighing over 100 g developed more sprouts with longer length, steady ground cover and yield than small tubers (2.5 g). However, the benefit of large tubers diminishes as size increases further (Iritani and Thornt, 1984). The higher sprouting, growth, and yield potential associated with large-sized tubers is attributed to high stored food reserves and biochemical composition. During the early stages of growth, developing sprouts rely heavily on tuber carbohydrate reserves.

Young tubers produce strong sprouts, whereas tubers of advanced physiological age produce sprouts with reduced vigour (Mikitzel and Knowles, 1989). Van Ittersum (1992) reported that small tubers had longer dormancy due to young physiological age. This, however, depends on cultivar, growing conditions, fertilizer and irrigation management, since tubers of the same size may have a different number of buds (Struik and Wiersema, 1999). Furthermore, uneven growth of the potato plant and hence tubers can result in abnormalities in tuber shape. Fluctuating temperature, moisture and N, especially in the formative stage cause malformed tubers. Although the demand for seed tubers is high in most potato growing regions, it is rarely met and the most viable solution is farmers to grow their own farm saved seed tubers. However, lack of knowledge on the benefit of well-sprouted seed on potato productivity has led to poor potato yields on many farms.

2.3. Factors Affecting Potato Growth, Yield and Quality

Potato growth and development is affected by temperature, water, mineral nutrients, genotype, irradiance and photoperiodism (O'Brien *et al.*, 1993). However, length of growing season, air and soil temperatures, light intensity and duration, humidity and wind are uncontrollable, whereas genotype, size of mother tubers, tuber-piece cutting and type, cut-tuber size, plant stand, stem population, moisture, nutrition, pests, planting and harvest dates can be controlled by growers (WPC, 2003).

Initiation of tubers leads to preferential partitioning of assimilates to the tubers (Ewing and Struik, 1992) and the final tuber yield of a potato crop is the result of many physiological and developmental processes in which accumulation and partitioning plays a major role (Fonseka *et al.*, 1996). Tuber initiation is a key developmental stage in potato crop's life with profound implications to subsequent growth and development (O'Brien *et al.*, 1993). Potato quality is an important factor influencing success in the market (Mayer *et al.*, 2008). An increase in the proportion of misshaped tubers, with pointed ends, knobs and dumb bells indicates that the plants were stressed. During stress, the low availability of starch and/or nutrients may temporarily stop tuber growth. When growth resumes, it occurs at the site of most active cell growth. The end result is malformed tubers that decrease the quality of seed tuber size and shape.

Potato is a cool-season crop and cool night temperatures are important in accumulation of carbohydrates and dry matter, essential in enhancing starch storage in tubers. The number of tubers set per plant is high at lower temperatures, whereas higher temperatures favour development of foliage and large tubers, but retard tuberization. Potato is best adapted to cool climates with mean daily temperatures ranging from 15°C to 18°C (Haverkort, 1990). High yields are obtained when average daytime temperatures are about 21°C (WPC, 2003; Wicks, 2004). Extremely cool and high temperatures reduce net assimilation to tubers, while high temperatures may prevent tuber initiation (Worthingt and Hutchinson, 2005). Furthermore increase in temperature reduces dry matter partitioning and negatively impacts on the onset of growth and absolute growth rates (Kooman *et al.*, 1996). In potato 18-25 °C is the ideal temperature for germination, 20-25°C is the best temperature for photosynthesis and development of stems, leaves and flowering and 16-18 °C in the soil is the best for tuber formation (USAID, 2011)

Over 90% of potato tuber dry weight is a direct result of photosynthesis, but as temperature increases, the rate of respiration rises dramatically, resulting in less starch availability to drive plant and tuber growth (Thornton, 2002). Tuber growth begins at the time of flower anthesis and is affected by temperature, moisture supply, photoperiod and carbohydrate reserves. Potato tuberization involves enlargement of the tip of the rhizome, arising from underground sprouts. High temperatures reduce specific gravity by reducing the total amount of starch available for transport from leaves to tubers and the rate of incorporation of that starch into tuber tissues.

Changing climates within and between years caused by changes in precipitation and temperature dispersion have resulted in varied water stress conditions. The currently observed trend in global warming of between 0.6 ±0.2 °C since 1900 will continue and the average global temperature will increase by between 1.4 and 5.8°C over the period 1900 to 2100 (Hought *et al.*, 2001). With time increase in global average temperature of between 1.2 and 1.8 °C in the 2010-39 and 2.1 and 3.2 in 2040-69 is expected to occur (Hijmans, 2003). These climatic changes influence plant phenology and the rate of dry matter accululation (Battilani *et al.*, 2008). This climate change is no exception under the Kenyan condition and will definitely lead to a major decrease in potato productivity among others crops.

Water deficit decreases the number of leaves, plant water potential (Frensch, 1997), leaf area, stem height, ground cover, canopy radiation interception, harvest index, tuber number, growth, yield and dry matter concentration (Schittenhelma *et al.*, 2006). Water stress also causes tuber cracking and malformation, surface abrasion, hollow heart, brown centre, internal brown spot, vascular discolouration, reduced sugar content in stems, degradation of starch in the tuber stem-end and total glycoalkaloids concentration (Papathanasiou *et al.*, 1999). The amount of water needed for good tuber production varies with soil type, temperature, humidity, air movement, plant and stem populations, variety, nutrient supply, and cultural practices (Wicks, 2004). After tuber set the number of tubers that achieve maturity varies depending on cultivar, available moisture and nutrition.

Optimum moisture and nutrient levels early in the growing season are critical to maintenance and development of tubers. During tuber initiation small tubers form at the end of stolons and adequate moisture at this stage is necessary to encourage a large number of tubers to set. During bulking, tubers enlarge and leaf area attains a maximum level, resulting in maximum evapo-transpiration or water use (Achtymichuk, 2008). Growth and water use decrease towards the end of the bulking period. Too little moisture results in small, misshaped and reduced tubers, whereas too much moisture leads to erosion, increased disease susceptibility and leaching of fertilizer. Uneven moisture results in tubers with many knobs or hollow centres due to uneven growth. Proper potato development requires a continuous supply of soil water (WPC, 2003; Pereira and Shock, 2006). King and Stark (1997) identified five physiological development growth stages of potato namely planting to emergence (0 to 30 DAP), early vegetative development from emergence to tuber initiation (30-45 DAP), tuber initiation or "tuberization" where tubers form at the tips of the stolons (45-55 DAP), tuber enlargement or "bulking" (55-105 DAP), and finally when the growth rate of the canopy begins to decline and plants begin to die consequently losing leaves (105-140 DAP).

Yields are greatest when soil moisture is maintained above 65% of the available soil water capacity (Shock, 2003). Tuber set is particularly sensitive to moisture stress, and generally fewer tubers are set when available soil moisture is low (Hassanpanah, 2009). Low or fluctuating moisture levels contribute to common scab, early dying, hollow heart, knobby tubers, low dry matter, set and yield, whereas excessive soil moisture causes tuber rot and low yields (Shock *et al.*, 2006; Nasseri and Bahramloo, 2009).

2.4. Effect of Water Stress on Potato Growth, Tuber Production and Quality

Potato is particularly sensitive to soil water stress (Thompson *et al.*, 2007), which affects physiology, bulking, grade, specific gravity, processing quality and yield of tubers (Shock *et al.*, 2006). Potato tuber response to soil moisture conditions begins before tuber set. MacKerron and Jefferies (1986) showed increased water stress duration before tuber initiation reduces tubers set per stem. A visible shift from rainfed to irrigation-fed seed production could unlock the perennial potato seed shortage and guarantee food security through increased productivity.

Thornton (2002) and Shock (2004) found that all growth stages of potato, but particularly tuber formation, are very sensitive to water deficit stress. One of the first physiological responses affected by plant water deficits is the expansion of leaves, stems, and tubers (King and Stark, 1997). However, some stress can be tolerated during early vegetative growth and late tuber bulking stages (Wright and Stark, 1990). Furthermore, Hassan *et al.* (2002) reported that stolonization and tuberization are more sensitive than bulking and tuber enlargement to water stress conditions. Thus the critical period for water deficit in potato is during tuber development and achieving better yields requires adequate water supply from its beginning until ripening (CIP, 2007). There is dramatic decrease of water resources due to prolonged drought periods in many potato growing areas. Therefore proper water utilization is a constant concern to increase on the water use efficiency for improved seed potato production in the informal sector. Farmers in informal seed production sector generally lack knowledge on aspects of soil water management that increase water use efficiency, productivity and quality of potato. Currently, there is no irrigation rates recommendation for optimal seed potato production in Kenya.

Shock *et al.* (1992) reported that tuber market grade and stem-end fry colour is improved by moderate soil moisture stress before tuber initiation. Excess watering may lead to water-logging, loss of valuable nutrients from the root zone and salination. Rainfall patterns within seasons have changed to situations where drought occurs at critical crop growth stages and heavy rainfall occurs at crop maturity when water is least required. Global warming resulting from climate change is likely to lead to changes in time of planting, use of later maturing cultivars, including shifts in location of potato production (Hijmans, 2003). Often, the short rains are unreliable such that farmers rarely utilize it to grow a potato crop. Sometimes water demands may not be met by rainfall inputs because of the rising temperatures. Consequently water deficits are experienced and water supply through supplemental irrigation for increased yield and quality of seed potato is inevitable.

Water is a vital component of crop production and its adequate supply is essential to maximize both quality and crop yield (Birkenshaw and Bailey, 2012). Potato is considered to be a high water use crop. Its yield and grade is reduced by both over- and under-irrigation, and a mere 10% deviation from optimum water application throughout the growing season decreases yield (Pereira and Shock, 2006). Yield reductions due to over-irrigation are mediated through poor soil aeration, increased disease incidences and leaching of N from the shallow root zone. Deficient soil moisture conditions results in soils with clods that lower stem density due to poor tuber sprouting (Wiersema, 1987). Stem density is important in determining size, number and multiplication rate of potato tubers, which in turn determine tuber yield. Efficient irrigation management can maximize marketable seed yield and reduce production costs by conserving water, energy and nitrogen fertilizer. Water use efficiency (WUE) refers to the units of a crop produced per unit of available water and the more crop yield that is produced per unit of water, the greater is the WUE (Stewart, 2001). In potato, WUE is defined as the tuber yield obtained per unit of water consumed through evapotranspiration (Doorenbos and Pruitt, 1977).

With decreasing water supply resource the challenge to farmers is how to increase food production using less water or how to use available water resources optimally. With the decreasing water resources, irrigation water use efficiency is becoming more and more important and alternative water application methods, such as drip and sprinkler irrigation, can considerably contribute to the improvement of the water applications for agricultural purposes and irrigation efficiency (Sezen, 2005). An increase in WUE is needed to cope with the declining quantity of water available for agriculture while maintaining yield (Liu *et al.*, 2006; Battilani *et al.*, 2008). Crop WUE is an especially important consideration where irrigation water resources are limited or diminishing and where rainfall is scarce. In potato optimum yield is obtained when the utilizable water in soil is not over 30-50% and the crop is considerably affected by water deficiency during germination, tuber formation and tuber bulking periods and it is less sensitive to water during ripening and early vegetative periods (Ayas and Korukcu, 2010). Water productivity and management depend on crop genetic potential, water management practices and nutrient supply (Stewart, 2001). A balanced fertility programme helps produce a crop with roots that explore more soil volume for water and nutrients in less time, resulting in a healthier crop. Excess water can be a cause of nutrient losses, and insufficient water at a critical stage can limit growth and yield, and timing of water application influences nutrient use efficiency (Roy *et al.*, 2006). Therefore, water management and/or rainfall are among the most important factors determining yield and quality of potatoes (DAFF, 2013). However, limited information is available concerning combined effects of irrigation, N and P nutrient supply rates on potato seed tuber production and quality in many regions.

2.5. Effects of Nutrient Supply on Potato Growth, Yield and Quality

Average yield of potato seed tubers has not been increased by genetic potential, and this yield gap is caused by a number of factors, including poor soil nutrient status and irregular rainfall patterns. Since fertilizer is an expensive and precious input, determination of its economical and appropriate application procedures to enhance productivity and profit to farmers in the informal seed sector is of major importance. Misapplication of fertilizer nutrients affects both yield and quality to a remarkable extent and hence proper management is of immense value (Manzoor *et al.*, 2006). Soil fertility maintenance is the most important constraint to sustaining yields under short fallows or continuous cropping systems although significant problems with pest control and erosion arise (Smith *et al.*, 1997). Mineral nutrients are essential for healthy plant growth and optimum yield. Therefore, it is important to maintain high soil fertility through balanced nutrient supply (ICIPE, 2006). Optimum use of mineral fertilisers by crops is essential for sustainable agriculture and nutrient use efficiency comprises both uptake efficiency and utilisation efficiency (Hawkesford, 2012).

The aim of fertiliser application is to feed the soil, which in return feeds the plant. However, plant nutrition involves providing to the plant the right nutrient, in the right amount, in the right place and at the right time (Onwueme and Sinha, 1991). Furthermore, efficiency of nutrient use might be affected by other growth factors such as water (Ojala *et al.*, 1990). Currently, prolonged drought is persisting and rainfall has become erratic in many parts of the world, thereby confounding fertiliser use. Nutrient uptake by potato is nearly complete when majority of tuber growth ends and little additional uptake occurs during maturation stage (Westermann, 1993). Despite the several studies conducted on fertilizer use in potato, gaps remaining include integrated N, P and irrigation water application to maximize seed tuber quality.

2.5.1. Effects of nitrogen

Nitrogen (N) is an essential element for the growth and development of all living organisms, as it is a constituent of DNA, RNA, ATP and protein and in plants, it is also an essential component of chlorophyll, auxin, cytokinins, alkaloids and glucosinolates (Andrews and Lea, 2013). It is the most important constituent of plant proteins and is required throughout crop growth cycle (Madan and Munjal, 2009). Nitrogen is an important component of many structural, genetic and metabolic compounds in plants (Tisdale and Nelson, 1975; Hassan *et al.*, 2005). However, despite the importance of N in metabolism, low soil N availability is often the major nutrient factor limiting the growth and yield of crops. Stresses that involve deficiencies of N and water will adversely affect the amount of chlorophyll plants produce as well as cell turgidity (Schlemmer *et al.*, 2005). Nitrogen application in potato encourages vigorous growth that enhances control of diseases such as early blight (*Alternaria solani*) (CIP, 1996). Nitrogen fertilizers are too expensive for many farmers, who then apply suboptimal rates (GOK, 1994). Informal sector farmers incur great costs due to lack of synchronization of rate, timing and method of application of the various sources of N (De Datta *et al.*, 1983). Nitrogen fertilizer, in conjunction with irrigation and genotype, affect tuber characteristics such as size, specific gravity, and N concentration (Gregory and Simmonds, 1992; Harris, 1992; Storey and Davies, 1992). Adequate N strengthens stems to prevent lodging, increases yield, improves quality, enables tubers to adapt to environmental stress, and promotes tolerance of insect infection and resistance of fungal diseases.

Although the potato crop requires a heavy input of N for high yields (Harris, 1992), total assimilate partitioned to tubers tends to decrease as N fertilization is increased. Under in intensive agricultural production systems, as much as 50% of the N applied to the field is not used by the crop plant (Cameron *et al.*, 2013). It is therefore important to develop N fertilizer management strategies that optimize crop productivity and N use efficiency (NUE), but decrease N losses. NUE will involve either N uptake efficiency, N utilisation efficiency, and the ability of the plant to transfer N to the yield part (Andrews and Lea, 2013). To optimize N beneficial role in potato production and minimize its negative effects on human health and the environment it's important to focus attention on improving fertilizer N efficiency at a global scale. This will involve increasing in uptake per unit nutrient added (recovery efficiency) and crop yield per unit nutrient added (agronomic efficiency). Although timing and method of N application may be important, applying the correct amount is perhaps the most important factor in seed potato tuber production systems (Westermann, 1993). Intensive fertilizer management is necessary to ensure proper nutrient supplies to growing crops and N management is one of the most important aspects for potato production (Reiter *et al.*, 2012). Areas of opportunity for improvement in fertilizer N efficiency has been identified as continued improvement in cropping system management, use of site-specific precision agricultural technologies, better prediction of soil N mineralization, improved timing of N application, improved manure management and crediting, improved fertilizers and biotechnology (Dibb *et al.*, 2003).

Nitrogen is critical in potato production and is applied to achieve maximum economic benefits by insuring against loss of tuber yield and quality. Its efficiency may be substantially improved if it is applied as close as possible to actual plant growth needs (Westermann *et al.*, 1988). Nitrate leaching may be reduced by improving irrigation management or reducing N fertilization rates, although the latter may have the undesirable effect of reducing seed potato tuber yields. It is therefore imperative that comprehensive information is availed to facilitate development of nutrient limits that avoid both potato yield and quality losses.

Guidelines on N fertilizer requirements for potato have been developed to ensure maximum yields without consideration of their effects on seed size quality. Nitrogen and water supply have important interactive effects on N and WUE and loss, as well as tuber yield and quality (Pereira and Shock, 2006). Nitrogen uptake by potato can be considerably less than the fertilizer application rates guide, due to variation in soil moisture regimes and genotypes used (Feibert *et al.*, 1998). Nitrogen rate and timing are critical elements of management as is the method of application. Applying too little N to potato may result in poor quality, low yields and profits. When too much N is applied, more ware potato result. Consequently, high seed potato quantities are required per unit area, thereby increasing the cost of the seed tubers. Applying too late in the season delays maturity and reduces quality of tubers (Westermann, 1993). These intricate consequences suggest the importance of determining the optimal N rate to maximize productivity, minimize nitrate loss to the environment through leaching and cost of application, and to increase profitability to the farmer through production of proper-sized seed potato tubers. More efficient use of nitrogen fertilizer is essential for improving the economic output of the farm and reducing the risk of environmental pollution (Ailincai *et al.*, 2013).

2.5.2. Effects of phosphorus

After N, P is the 2nd most deficient plant nutrient that is applied to plants as fertilizer (Waraich *et al.*, 2011a). It is essential for normal plant growth and development as it promotes photosynthesis, respiration, energy storage, cell division and crop maturity (McKenzie and Middlet, 1997; Mathew and Hameed, 2002). Potato is highly responsive to soil-applied nutrients, especially to phosphorus (P), due to its short cycle and high yield potential (Fernandes and Soratto, 2012). Broadly, P is the primary storage of sunlight energy, provider of energy in many plant processes, and drives size, number and viability of seeds (IPNI, 2008). It is required for optimum plant growth and its deficiency very often increases days to maturity and incidences of disease, and reduces crop quality and proteins (Dowbenko, 2002). A good supply of P has been associated with increased root growth, which means that a plant can explore more soil for nutrients and moisture. The high ability for P binding to the soil through mechanisms of adsorption and precipitation reduces its availability to the plants (DoVale and Fritsche-Neto, 2013). Factors such as rate, method, chemical form, soil moisture and temperature can all affect phosphorus use efficiency (PUE).

Early growth of potato plants is characterized by limited root concentration and poor capacity to exploit soil nutrient reserves and the crop has traditionally been regarded as having a large requirement of P (Ali *et al.*, 2004). Potato has a relatively shallow, fibrous root system with the majority of the roots in the surface 30 cm (Lesczynski and Tanner, 1976; Tanner *et al.*, 1982). The root system develops rapidly during early growth and achieves maximum development by mid-season. Potato then may not be able to access enough nutrients from the soil due to the limited root system and therefore application of appropriate rates for quantity and quality seed production is of considerable importance.

Because many soils in the highlands of East and Central Africa are depleted of soil nutrients, particularly P (Jama *et al.*, 1997), phosphatic fertilizer application in potato production is a general recommendation. Potato plants establish poorly and grow very slowly where P fertilizer is not applied due to inadequate root growth. There is a general recommendation of 230 kg P_2O_5/ha (AIC, 1981) that should be applied during ware potato planting. The impact of this rate alone or in combination with N and irrigation water application to the different potato varieties in the informal sector on seed tuber yield and quality is not known. Adequate soil moisture enhances fertilizer dissolution and reaction in the soil and N supply might affect uptake and utilization of P applied (Tisdale and Nelson, 1975). Integrated N, P nutrient and irrigation water application has not been systematically done in the informal seed sector in many potato growing areas. However, as seed potato needs increase there seems a permanent and expanding role for fertilizers and irrigation water in their production and the effects of their integration should be determined.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Research Sites

The potatoes were grown in a Rainshelter at the Horticultural Research and Teaching Farm of Egerton University, Njoro between 19th August 2011 and 19th December 2011 in season I (RTrial I) and between 5th April and 6th August 2012 in season II (RTrial II). Beans were grown between December 2011 and March 2012 to separate the two potato growth periods. A post-treatment seed Performance Evaluation Trial was planted at the same location between 17th April and 13th June 2012 (PTrial I) and between 20th November 2012 and 16th January 2013 (PTrial II) using seed potatoes stored for 90 days after harvesting, RTrials I and II, respectively. The site has well-drained sandy loam-Vintric mollic andosol soils, normally receives 908 to 1012 mm rainfall per annum and 15.6°C to 23°C average temperature, lies at an altitude of 2238 m ASL, latitude 0°23' south, longitude 35°35' east, in agro-ecological zone Lower Highland 3 (Jaetzold and Schmidt, 1983).

Three soil samples were randomly collected from the top 0 - 15 cm and 15 - 30 cm of the soil profile using a soil auger and analyzed for total N and P before planting and after harvesting of tubers to determine nutrient dynamics. Total N was determined using the Kjeldahl method (Bremner and Mulvaney, 1982). Olsen and Sommers (1982) method was used to determine P content. Soil analysis was conducted at Kenya Agricultural Research Institute (KARI) Njoro Soil Analysis Laboratory. Meteorological data on rainfall, temperature, and relative humidity was obtained from weather stations at Egerton University, Njoro. In the rainshelter, maximum and minimum temperatures were recorded daily from three maximum-minimum thermometers hanged at one metre from ground in two extreme ends and the middle of the structure during the trial periods. The minimum temperature was recorded at 7 o'clock in the morning and the maximum at midday.

3.2. Seed Potato Tuber Production

3.2.1. Plant material and planting

Certified seed potato tubers of variety Tigoni was obtained twice from the Agricultural Development Corporation (ADC) at Molo for the two growth periods. Tigoni is one of the most popular potato cultivar due to its high productivity, disease resistance and diverse uses, including processing and home consumption. Pre-sprouted seed potato tubers was planted at a spacing of 0.3 m x 0.75 m within and between rows, respectively, giving a tuber population density of 44,444 per hectare or 28 per plot. Tubers were partially covered with a thin layer of soil at planting to facilitate location of rows and initial split N application immediately after planting.

3.2.2. Treatments, experimental layout and design

The treatments consisted of three irrigation water rates, four N rates, and four P rates. The three irrigation water rates [40% (W3), 65% (W2) and 100% (W1) field capacity (FC)] were applied throughout the potato growth period using drip irrigation tubes. Shock (2003) indicated that potato yields are greatest when soil moisture is maintained above 65% of the available soil water capacity. Before initiating treatments, all plants were uniformly irrigated to field capacity for two consecutive days to stimulate germination and root development. The amount of water used to reach field capacity was designated as 100%, and then the amounts used for 65% and 40% were derived from this 100% amount. A WaterScout (Model SM 100 Sensor) connected to 2475 Plant Growth Station (Watch Dog Model, Spectrum Technologies, Plainfield, IL 60585, USA) which is applicable between zero percent to saturation was used to indicate the need for irrigation. This is a Time Domain Reflectometery (TDR) method of analysis of soil water content by volume and offers the option of instantaneous readout or data logging. The TDR signal is determined by the dielectric constant of the surrounding soil, which can be related to the volumetric water content (VWC). When installed vertically, the probes give an average reading over the length of the probe and therefore it is relatively easy to take readings of soil moisture in the 0-15 cm zone. The Waterscout was inserted vertically into the soil along the drip line placed along a potato crop row and then the readings observed on the Plant Growth Station.

The soils in the study site are well-drained sandy loam-Vintric mollic andosol. These falls within the soils with medium soil water availability. Birkenshaw and Bailey (2012) referred soils with medium soil water availability to include, Loamy Sand; Loam; Silty clay loam; Clay, and have between 60 mm – 100 mm of water per 500 mm of depth. According to King and Stark (1997), at 65% available water, sandy loam to loam has soil water potential and volumetric water content ranges of -35 to -50 kPa and 19-22%, respectively. The need to irrigate was determined by periodically monitoring soil water content using the Waterscout. The field capacity and the permanent wilting point as indicated in Jensen *et al.* (1990) in Table 1 below in sandy loam ranges from 18-28% and 6-16% volumetric water content, respectively. These values though not absolute, served as a general guide for irrigation water treatment in the study.

Table 1: Soil water content on volumetric basis (%) for agricultural soils

	Field Capacity		Permanent Wilting Point		Available Water		Water Holding Capacity (in/ft)		Water Holding Capacity (cm)	
Texture Class	Average	Range	Average	Range	Average	Range	Average	Range	average	range
Sand	12	7-17	4	2-7	8	5-11	0.96	0.60-1.32	2.44	1.52-3.35
Loamy Sand	14	11-19	6	3-10	8	6-12	0.96	0.72-1.44	2.44	1.83-3.66
Sandy Loam	23	18-28	10	6-16	13	11-15	1.56	1.32-1.80	3.96	3.35-4.57
Loam	26	20-30	12	7-16	15	11-18	1.80	1.32-2.16	4.57	3.35-5.49
Silt Loam	30	22-36	15	9-21	15	11-19	1.80	1.32-2.28	4.57	3.35-5.79
Silt	32	29-35	15	12-18	17	12-20	2.04	1.44-2.40	5.18	3.66-6.1
Silty Clay Loam	34	30-37	19	17-24	15	12-18	1.80	1.44-2.16	4.57	3.66-5.49
Silty Clay	36	29-42	21	14-29	15	11-19	1.80	1.32-2.28	4.57	3.35-5.79
Clay	36	32-39	21	19-24	15	10-20	1.80	1.20-2.40	4.57	3.05-6.1

(Adopted from Jensen *et al.*, 1990). NB: Conversion: 1 inch = 2.54 cm

The Waterscout was only used to determine the need for irrigation but not the amount of water. When the percent volumetric water content equal or below 6% was observed on the 2475 Plant Growth Station after vertically inserting the Waterscout along the potato crop row, then this was the time for irrigation. The observations were only done on 100% field capacity which formed the basis of other irrigation water treatments.

To separate the irrigation from the rainfall effect, the experimental area was enclosed in a rainshelter using a clear polythene sheet, which was spread over the experimental plots to ensure no rain water infiltrated the plot area (Plate 1). The polythene was only spread on top at about 2 to 3 m height, supported by poles and rafters, and the sides of the area were left open to facilitate ventilation and air circulation. The clear polythene sheet ensured light penetration and because it was bulky it was not withdrawn at any time during the potato growth period. Fertiliser requirements of seed potato are usually lower than those of ware potato and 50% to 75% of ware potato's demand should be applied (Lung'aho *et al.*, 2007). The recommended N for the ware potato production is 150 kg N/ha (Sikka, 1994; Waddell *et al.*, 1999). In this study, N was supplied as urea (46% N) at four rates of 0 (N1), 75 (N2), 112.5 (N3) and 150 (N4) kg N/ha). Each rate was applied in two equal splits, with the first half at planting and the second at 5 weeks after planting (WAP). The N fertilizer was applied in a shallow drill about 3 cm above seed tubers in the furrow at planting time.

The recommended rate of phosphorus (P) for ware potato production is 230 kg/ha P_2O_5 (AIC, 1981) translates to 101.2 kg P/ha. Four rates of phosphorus: 0 (P_1), 115 (P_2), 172.5 (P_3) and 230 (P_4) kg/ha P_2O_5, which translated into 0, 50.6, 75.9, and 101.2 kg P/ha, were supplied at planting time as triple super phosphate (TSP) containing 46% P_2O_5. The TSP was broadcasted in furrows and covered with a thin layer of soil to avoid direct contact with seed potato tubers.

The RTrial was laid in a randomised complete block design with split-split plot arrangement, where irrigation water was assigned to main plots, N to subplots, and P to sub-subplots. The treatments were replicated three times and the RTrial repeated once. Each plot measured 1.8 m * 2.25 m. Paths between main plots and subplots were 1 m wide, while those between sub-subplots were 0.7 m wide. Each plot had 4 rows each with 7 tubers, giving a total of 28 tubers per treatment. The first and last rows including the first and last tubers per row formed the guard rows. Two guard rows encircled the entire experimental area.

Data was taken on the 10 middle plants. The total experimental area measured 92.7 m long by 14 m wide. Each block/replicate measured 29.9 m long by 14 m wide. The clear polythene rain shelter covered across all the blocks so that they were within one unit. A 60 cm deep furrow was made at the edges of the upper and the lower side of the rain shelter and a clear polythene paper buried upright protruding about 60 cm from the ground to prevent any possible entry of rain or runoff water that could have affected the applied water treatments (Plate 1). The experimental layout was as shown in Figure 1. All the W*N*P treatments in 100%, 65% and 40% irrigation water rates were planted together within their respective main plot as shown in Figure 1. The irrigation water was supplied from one-500-L capacity plastic tank (Model Kentank), which was connected to the drip lines through a 2.5 cm mainline (Plate 1). The irrigation water rates were supplied to the drip lines that were installed across main plots which contained the W*N*P treatments. The drip holes were perforated at a spacing of 15 cm, which facilitated uniform water supply within the potato row. The drip lines supplied equal water quantities along the row of the W*N*P treatments.

In both RTrials I and II irrigation water rates 100%, 65% and 40% field capacity were supplied in equal amounts distributed within the growth season for a total of 26 applications times (Appendix 1). Therefore, out of the 122 days the potato was grown the crop received water for 26 times. However, initially one metre cubic (1000 L) of water was supplied regardless of water treatment at 3 and 4 DAP to facilitate uniform starting point for all treatments. The remaining amount of irrigation water was supplied in equal quantities from the 4th day after the last application up to 91 DAP, which was towards the end of bulking period. Thereafter irrigation water was supplied every 5th day up to 106 DAP to allow the crop utilize soil water reserves in the root zone. At 106 DAP the potato was assumed to have completed bulking and harvesting could have been done any time.

A total of 18,080 L (18.08 m^3), 12,452 L (12.452 m^3) and 8,432 L (8.432 m^3) were supplied throughout the growth period in both RTrials I and II for 100%, 65% and 40% field capacity in each replicate, respectively (appendix 1). After supplying the initial 2000 L (2 m^3) at 3 and 4 DAP, the balance 16,080 L (16.08 m^3), 10,452 L (10.452 m^3) and 6,432 L (6.432 m^3) for 100%, 65% and 40% field capacity in each replicate, respectively, were supplied in equal quantities. The initial application of 1000 L (1 m^3) proved to be excess, which could have led to higher chances of wastage. This was reduced by $^1/_3$ to provide 670 L (0.67 m^3) as 100% field capacity. This was used to determine 65% and 40% rates, which translated to 435.5 L (~0.44 m^3) and 268 L (~0.27 m^3) for 65% and 40% irrigation water, respectively. These were pre-determined in the 500 L capacity plastic tank before application.


Potato planted in Rainshelter


Irrigation water rates


Polythene guard


Drip tube lines

Plate 1: Rainshelter, irrigation rates, polythene water guard and driptube lines in the experiment

9.3 metres

12 metres

Block 1

W2N1P2 1	W2N1P1 2	W2N3P2 3	W2N3P4 4	W3N3P3 5	W3N3P2 6	W3N1P1 7	W3N1P4 8	W1N2P2 9	W1N2P1 10	W1N3P4 11	W1N3P1 12
W2N1P4 24	W2N1P3 23	W2N3P1 22	W2N3P3 21	W3N3P1 20	W3N3P4 19	W3N1P3 18	W3N1P2 17	W1N2P4 16	W1N2P3 15	W1N3P2 14	W1N3P3 13
W2N2P3 25	W2N2P2 26	W2N4P1 27	W2N4P3 28	W3N4P2 29	W3N4P1 30	W3N2P4 31	W3N2P3 32	W1N1P2 33	W1N1P4 34	W1N4P1 35	W1N4P3 36
W2N2P1 48	W2N2P4 47	W2N4P2 46	W2N4P4 45	W3N4P3 44	W3N4P4 43	W3N2P1 42	W3N2P2 41	W1N1P1 40	W1N1P3 39	W1N4P4 38	W1N4P2 37

Block 2

W3N4P2 29	W3N4P4 43	W3N2P1 42	W3N2P4 31	W1N3P4 11	W1N3P3 13	W1N1P1 40	W1N1P3 39	W2N1P1 2	W2N1P2 1	W2N4P3 28	W2N4P1 27
W3N4P1 30	W3N4P3 44	W3N2P2 41	W3N2P3 32	W1N3P1 12	W1N3P2 14	W1N1P4 34	W1N1P2 33	W2N1P4 24	W2N1P3 23	W2N4P2 46	W2N4P4 45
W3N3P4 19	W3N3P1	W3N1P1 7	W3N1P4 8	W1N2P3 15	W1N2P2 9	W1N4P4 38	W1N4P3 36	W2N2P2 26	W2N2P3 25	W2N3P3 21	W2N3P2 3
W3N3P2 6	W3N3P3 5	W3N1P3 18	W3N1P2 17	W1N2P1 10	W1N2P4 16	W1N4P1 35	W1N4P2 37	W2N2P4 47	W2N2P1 48	W2N3P1 22	W2N3P4 4

Block 3

W1N2P2 9	W1N2P1 10	W1N4P1 35	W1N4P2 37	W2N2P2 26	W2N2P1 48	W2N3P4 4	W2N3P3 21	W3N3P3 5	W3N3P2 6	W3N2P1 42	W3N2P4 31
W1N2P3 15	W1N2P4 16	W1N4P4 38	W1N4P3 36	W2N2P4 47	W2N2P3 25	W2N3P2 3	W2N3P1 22	W3N3P1 20	W3N3P4 19	W3N2P3 32	W3N2P2 41
W1N1P2 33	W1N1P3 39	W1N3P1 12	W1N3P3 13	W2N1P2 1	W2N1P4 24	W2N4P1 27	W2N4P2 46	W3N4P4 43	W3N4P3 44	W3N1P2 17	W3N1P1 7
W1N1P1 40	W1N1P4 34	W1N3P4 11	W1N3P2 14	W2N1P1 2	W2N1P3 23	W2N4P3 28	W2N4P4 45	W3N4P1 30	W3N4P2 29	W3N1P4 8	W3N1P3 18

igure 1: Field layout: Split-split plots in randomized complete block design where: W1, W2, W3 are irrigation rates (main plots), N1, N2, N3, J4 are nitrogen rates (subplots), and P1, P2, P3, P4 are phosphorus rates (sub-subplots), numbers 1-48 in block 1 represents treatments 1 – 48. he plots with the same numbers as block 1 in blocks 2 and 3 represents similar treatments.

The initial 2 m^3 supplied immediately after planting was meant to induce sprouting. The 670, 435.5, and 268 L were supplied to the 16 W x N x P sub-subplots within an irrigation water treatment and therefore each of the plot W x N x P received about 41.88, 27.22 and 16.75 L for 100%, 65% and 40% irrigation water, respectively. After the initial application of the irrigation water rates at 11 DAP, volumetric water content (VWC) was determined after: two hours (VWC1), one (VWC2), two (VWC3) and three days (VWC4) after irrigation to determine whether the applied irrigation water was adequately supplying moisture as required by potato and for what duration of time to determine the irrigation frequency. This was done after three consecutive irrigations and the resulting average VWC was 19.6%, 13.1%, 9.1% and 6.2% in 100% irrigation water rate, 11.9%, 8.3%, 6.7% and 4.8% in 65% irrigation water rate, and 7.4%, 5.9%, 4.5% and 2.9% in 40% irrigation water rate for VWC1, VWC2, VWC3, and VWC4 after irrigation water application monitoring, respectively. Data on volumetric water content in four sampled days is shown in Appendix 2. Right after the irrigation events, there was a noticeable increase in soil moisture content and water had infiltrated up to 30-60 cm soil profile in 100% irrigation water rate. The degree to which the volumetric soil water content increased, however, depended upon volume of irrigation water supplied.

3.2.3. Crop maintenance in the field

Routine field maintenance practices such as weeding and spraying against diseases and insect pests using appropriate fungicides and insecticides was done when necessary. Weeding or physical uprooting of weeds was done any time weeds were visible. Recommended fungicides for control of early and late blight such as Ridomil® were used. Insect pests mainly aphids, thrips, and white flies were controlled using Metasystox® and mites using miticides. Earthing up was done during weeding. The haulm was not cut off before harvesting for purposes of shoot growth determination at harvest.

3.3. Data Collected

3.3.1. Potato growth and development measurements

Plant data was taken on agronomic characteristics (sprout emergence/germination percentage and time, number of stems, plant height, days to 50% flowering, physiological characteristics (stomatal conductance and chlorophyll concentration, leaf area,), and days to physiological maturity.

3.3.1.1. Sprout emergence percentage

The number of sprouted plants per plot was counted at 14 days after emergence (about 28 DAP) and the sprout emergence percentage calculated by dividing the number of emerging sprouts per plot by the number of tubers planted and multiplying by 100. Emergence time was determined by counting days from planting to tip emergence.

3.3.1.2. Number of stems

Number of stems was determined on three randomly selected plants of each treatment at 45 DAP by counting the number of main stems within an individual plant. Only stems arising from the mother tuber were considered as main stems.

3.3.1.3. Plant height

Stem elongation was determined beginning 45, 59, 73, 94, and 108 DAP in both RTrials I and II. Three mature plants were randomly selected from each treatment for height measurement using a metre rule. Height was measured from the ground level to the tip of each plant.

3.3.1.4. Leaf stomatal conductance

The stomatal conductance was measured on fresh tissues of one randomly selected leaf of medium growth on three middle randomly pegged plants per treatment at 59, 73 and 87 days after planting (DAP) in both RTrials I and II using a leaf porometer (SC-1; Decagon Devices, Pullman, WA). Stomatal regulation of gas exchange by leaves is of great importance to photosynthesis and stomatal movements can be affected by various environmental factors, including plant water status, CO_2 concentration and light (Raschke, 1975; Kim *et al.*, 2004).

3.3.1.5. Leaf chlorophyll content index

Leaf chlorophyll content was measured at 59, 73 and 87 DAP using chlorophyll content meter (CCM-200 plus; Opti-Sciences, Tyngsboro, MA) on fresh tissues of lower, middle and uppermost fully expanded leaves on the three randomly pegged plants per plot. The measurements were taken halfway from the leaf base to the tip and halfway from the midrib to the leaf margin. Chlorophyll content meter assists in rapid, non-destructive, determination of chlorophyll content in intact leaf samples. A non-destructive estimation of leaf Chlorophyll and Chlorophyll Concentration Index (CCI) value that is proportional to the amount of chlorophyll in the sample is the units of measurements. Leaf chlorophyll content provides valuable information about physiological status of plants (Gitelson *et al.*, 2003).

3.3.1.6. Leaf area index (LAI)

Three plants per treatment were pegged and the leaf area measured using the graphical method in both RTrials I and II. The total leaf area per plant was estimated using a graph paper whereby leaves within a plant were randomly selected and divided into four growth categories namely smallest, small, medium and large. The leaves within these categories were removed from a potato plant and placed on a graph paper and their approximate area determined by counting the number of 1 cm^2 grids on the graph paper occupied by the individual leaf. The individual leaf area for the smallest, small, medium and large was 7 cm^2, 18 cm^2, 34 cm^2, and 42.5 cm^2, respectively. When the individual leaf area of these four categories of leaves within the potato was determined, leaves within the plant similar to the smallest, small, medium and large were counted separately. The total leaf area per category was obtained by multiplying the number of leaves counted per category by the respective individual leaf area i.e. multiplying the leaf area per active haulm by the number of active haulms per plant. The total leaf area of the plant was obtained by adding the total leaf area of smallest, small, medium and large leaf categories. The total leaf area was determined at 51 and 64 DAP a period characterised by tuber set and initiation of tuber bulking within the potato plant. The resulting total leaf area was used to calculate LAI using the formula: LAI = Total leaf area (cm^2)/ground area (cm^2) (Beedle, 1987).

3.3.1.7. Days to 50% flowering

Days to 50% of the plant population flowering was recorded at flowering stage. 50% flowering was determined by counting the number of plants with flowers including one flower within a treatment plot. A treatment plot was considered to have attained 50% flowering when at least half of the plants within the plot had flowered.

3.3.1.8. Days to physiological maturity

Days to physiological maturity were recorded when the leaves of 70% of the plants in the plots turned yellow.

3.3.1.9. Potato total biomass (biological yield)

Total biomass per plant was calculated by adding both the tuber and shoot dry mass. Dry matter of shoots and tubers per plant was determined at harvesting stage using three randomly selected plants from the middle rows in each treatment plot. The shoots were cut, placed in "Mafuco® khaki" papers, and weighed using a pan electronic balance when wet and later taken to the laboratory and dried at 80°C for 72 h in an oven (Model number TV80UL 508032, Memmert, Germany). Similarly tubers from each of the three plants were weighed when wet and then separately sliced into smaller pieces, and placed in "Mafuco® khaki" papers and dried in the oven at 105°C for 72 h. After weighing, the shoot and tubers dry mass per plant were summed together and the total biomass per plant calculated.

3.3.2. Seed potato tuber yield and yield components

Depending on variety, potato takes between 90 and 140 days from planting to tuber maturity and harvesting was done at the intermediate timing of 122 DAP. Tubers were hoe-harvested from 10 middle plants per treatment to facilitate determination of various tuber characteristics including the yield, grades, tuber numbers, harvest index, and quality characteristics (tuber specific density, dry matter and starch content).

3.3.2.1. Number of tubers per plant

The harvested 10 plants per treatment were placed separately on the ground to facilitate determination of number of tubers per individual plant within the treatment. Swollen tubers produced per plant were counted and recorded to determine treatment effects.

3.3.2.2. Tuber yield

After counting of the tuber numbers per plant, all the tubers from the 10 middle plants per treatment were combined together and placed in one "PIL®" polythene paper bag and weighed with a spring balance to determine the yield per treatment plot. This was later converted to yield in t/ha.

3.3.2.3. Tuber grading

After yield determination the tubers per treatment were graded into small sized (25-35 mm), seed size I (35-45 mm) and seed size II (45-60 mm) (Kabira *et al.*, 2006) using grading scales (graders) obtained from KARI, Tigoni Marindas Sub Centre. Each grade was weighed separately using a spring balance to determine its weight per treatment plot which was later converted to yield per grade in t/ha. Tubers less than 35 mm in diameter were regarded as chats and those greater than 60 mm as ware potato, and terminated. Grading was done to facilitate determination of the economic benefit of different treatments and only seed size I and II were considered.

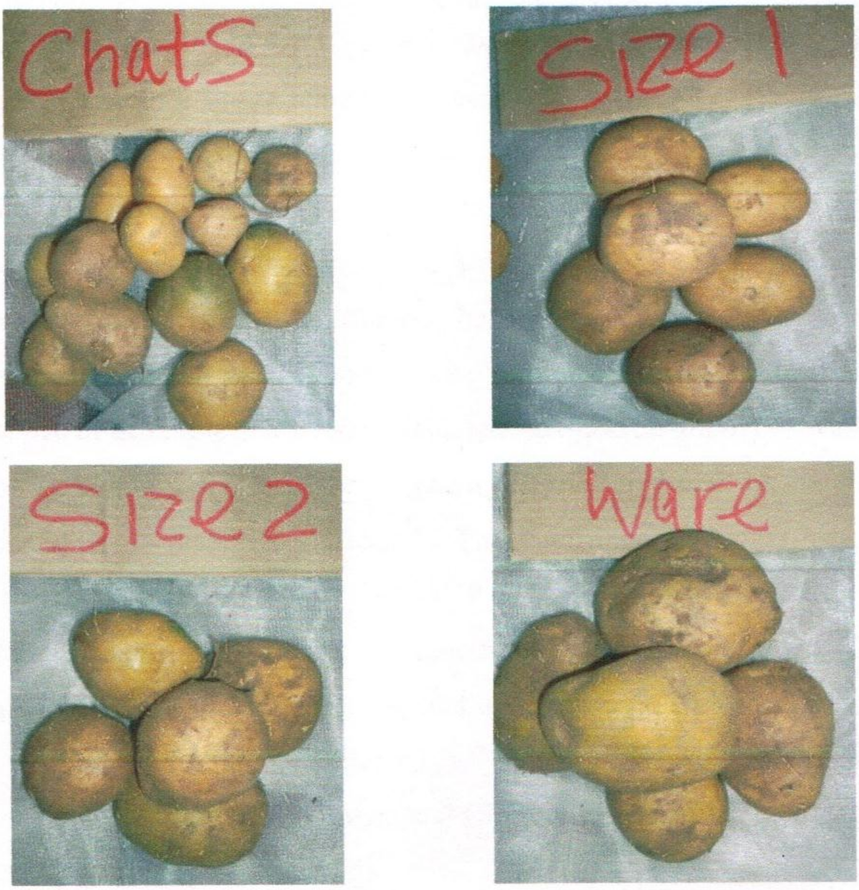


Plate 2: Seed potato size distribution

3.3.2.4. Harvest index (HI)

Harvest index, which is the weight of a harvested produce divide by the total plant weight (Mackerron and Heilbronn, 1985; Tadesse *et al.*, 2001), was calculated. Total fresh tuber yield per plot was obtained by dividing the yield obtained per 10 plants harvested by 10 and multiplying by the total number of plants per plot (28 plants). The total fresh aboveground biomass per plot was obtained by adding the fresh weight of the shoots of the three harvested plants for biomass analysis and dividing this weight by three and multiplying by the total number of plants per plot (28 plants). The fresh aboveground biomass per plot was recorded in grams and was converted into kilograms by dividing with 1000 before calculating the harvest index. Total fresh tuber yield and aboveground biomass were added to obtain the total plant weight per plot. Harvest index was calculated by dividing total fresh tuber yield by total plant weight and multiplying by 100 to express HI as percentage (%).

3.3.2.5. Specific density, Starch, and dry matter (DM) contents

Starch content and DM of a 5 kg sample of tubers per treatment were determined at harvest on the principle of a linear relationship between specific gravity with starch and/or DM. Specific gravity is a measurement of density and in tubers it is the weight of the tuber compared to the weight of the same volume of water. It was computed by weighing five (5) kg tuber sample in a sturdy wire basket both in air (Wa) and in water (Ww) using a spring balance. The weight measured is the difference between the weight of the sample, and the weight of an equal volume of water. The two weights were then applied to the equation and the specific gravity of different treatments calculated as: Specific gravity = Wa/(Wa-Ww). A high correlation occurs between the specific gravity of the tuber and the starch content and also the percentage of dry matter or total solids. This contributes to higher recovery rate and better quality of the processed product (DPI, 2010). Starch content = 112.1x - 106.4, while percentage DM = 158.3x - 142; where x = specific gravity (Kawano *et al.*, 1987). Starch content indicates accumulated food reserves that are later used by tubers in initial growth after planting. The sample of potato selected per treatment was free of any dirt. Specific density is dimensionless while starch content and DM are expressed as percentage.

3.3.2.6. Tissue N and P contents

Total tuber tissue N content was determined by micro-Kjeldahl method (Bremner and Mulvaney, 1982) while Olsen and Sommers (1982) method was used to determine P content using a sample of ground tuber tissue. The tubers per plant were sliced into smaller pieces, placed in the "Mafuco® khaki" papers and dried in the oven (Model number TV80UL 508032, Memmert, Germany) at 105°C for 72 hours. After oven drying the dry sliced tubers were ground into powder using a Ramtons® blender model No. RM/161, serial No. 02899/12338, China. The powder was then sieved using a laboratory test sieve, BS410, 1986, serial No. 537947, aperture 600µm, Endecotts Ltd, London, England and packed in "Mafuco® khaki" paper bags No. ¼ ready for laboratory analysis.

3.3.2.7. Water and nutrient use efficiencies

Water-use efficiency (WUE) is a quantitative measurement of how much biomass or yield is produced over a growing season, normalised with the amount of water used up in the process. WUE is an important determinant of yield under stress and even as a component of crop drought resistance and has been used to imply that rainfed plant production can be increased per unit water used, resulting in "more crop per drop" (Blum, 2009). Nitrogen uptake efficiency (NUE) is a measure of the capacity of the plant to recover applied N (Errebhi, *et al.,* 1999). This applies also to water and phosphorus. Water use efficiency (WUE) and nitrogen use efficiency (NUE) and phosphorus use efficiency (PUE) were calculated as proposed by Tayel *et al.* (2006) and Roy *et al.* (2006).

3.3.2.7.1. Water use efficiency

Water use efficiency = Yield (kg)/water consumptive used (m^3). Water Consumptive was calculated by adding the amount of water applied per treatment plot in the whole growth period. Total water consumptive was 18.08, 12.45, and 8.43 m^3 for W1, W2 and W3 irrigation water treatments respectively, which after dividing with the 16 WxNxP translated to 1.13, 0.78 and 0.53 per treatment plot in 100, 65 and 40% irrigation water rates, respectively. This was equal in both RTrials I and II. Yield per plot was divided by the consumptive water used in the same plot to obtain the WUE (kg/m^3).

3.3.2.7. 2. Nitrogen and phosphorus use efficiency

Nitrogen or phosphorus use efficiency = (Tubers in kg of fertilised plot – of control plots)/nitrogen or phosphorus fertiliser used in kg. The amount of nitrogen applied per treatment plot was 0, 75.7, 113.5 and 151.4 grams for N1, N2, N3 and N4, respectively. Phosphorus applied was 0, 20.5, 30.74, and 40.91 grams per treatment plot P1, P2, P3 and P4, respectively. Before analysis these figures were transformed into kilos. NUE or PUE was expressed in kg/kg

3.3.2.8. Economic analysis

Economic analysis {net economic benefit (NEB)} of seed production was performed after harvest. It was calculated by deducting the gross production cost from the gross field benefit (CIMMYT, 1988) per treatment. The gross tuber output (benefit) was determined by multiplying the weight of tubers by the prevailing seed market price with ADC. The minimum seed price of 50 kg bag at ADC is KSh. 1,400 and 1,800 of seed size II and I respectively. This translated to KSh. 28 and 36 per kg of seed size II and I respectively. These prices were adopted for economic analysis. The gross benefit is the gross income derived from sale of the seed tubers. The gross production cost of fertilizer and irrigation per unit area was recorded and subtracted from the gross benefit to obtain the net benefit. The cost of irrigation was calculated using the water rates of Nakuru Rural Water and Sanitation Company, of KSh. 500 per 6 m^3 consumption. The cost of a bag of TSP was KSh. 4,000 and that of urea KSh. 3,600. The net benefit/plot was translated to net benefit per hectare. Labour costs in man days (MD) was uniform between the treatments per hectare and included planting (25), weeding (25), spraying (2), earthing up (25), harvesting (75), and grading (40) a total of 192 MD each costing KSh. 205. Water, fertiliser and labour were considered as the major seed potato investment costs.

3.3.3. Postharvest physiological characteristics of seed potato tubers and their resultant growth

After harvest endodormancy was determined by transferring 15 seed tubers per treatment to diffuse-light sprouting conditions. Wiersema (1987) stated that storage conditions that favour apical dominance limit the number of sprouts, and pre-sprouting in diffuse light allows sprouts to become well developed and firm. The tubers were kept in diffuse light conditions in paper punch perforated and stapled at the top "Mafuco® khaki" paper bags of size No. 16 for 90 days after harvesting. Perforation was done to allow free air movement. After withdrawal from storage, relative weight loss, firmness, total soluble solids, sprout numbers and length (sprouting characteristics) were determined. Three potato tubers were later selected per treatment and planted to study the growth vigour (number of stems, plant height) and tuberization capacity under the prevailing farmer conditions. A similar layout as for the rain shelter Trial (RTrial) as shown in figure 1 was adopted and each treatment plot was represented by a treatment tuber.

3.3.3.1. Seed potato tuber relative weight loss

The fifteen (15) seed tubers of seed size I were weighed at the beginning and at the end of the 90 days storage period to determine the absolute tuber weight loss. Relative weight loss (%) of seed potato after storage was determined by dividing the difference between the initial and final tuber weight after storage by initial weight before storage and multiplying by 100 in both seasons.

3.3.3.2. Seed tuber firmness

Seed potato firmness or softness was determined before and after 90 days storage using a manually operated fruit pressure tester (penetrometer, Bishop FT 327, Italy) of a probe diameter of 0.5 cm (size 10). This was assessed on three randomly selected tubers per treatment by slowly pushing the penetrometer down into the centre of the tuber and the penetrometer reading observed. The penetrometer measured the firmness as the resistance to compression or kilogram-force (kgf). Three puncture tests per treatment were taken (Kitinoja and Kader, 2003). The penetrometer scale reading ranged from 0-13 kgf. Percentage change in firmness was determined by dividing the difference between the firmness before and after 90 days storage by the firmness before storage and multiplying by 100.

3.3.3.3. Seed tuber total soluble solids concentration (TSS)

Seed potato total soluble concentration was determined before and after 90 days storage using a refractometer. The TSS was determined as per procedure in (Harrill, 1998; Kitinoja and Kader, 2003). Seed tuber was pierced and a drop of the juice squeezed and placed on the refractometer and the light refracted through a prism and measured the total dissolved solids (which is mainly sugar, but also does include minerals) in the plant sap. The refractometer measurement was from zero to 30% Brix (Model 1974). Seed potato tubers have refractive index of crop juices calibrated in % sucrose or degree Brix of between three-eight units (Harrill, 1998). The refractometer was cleaned and standardized between each reading with distilled water to read 0% soluble solids content.

3.3.3.4. Seed potato tuber sprouting characteristics

After 90 days storage, the number of sprouts and length of longest sprout in three randomly selected tubers per treatment was determined by counting the sprouts and measuring with a 30-cm ruler, respectively. The criterion for broken dormancy or sprout development was a stem structure of at least 2 mm (Van Ittersum, 1992). Sprouting capacity was expressed as the number of developed sprouts as a percentage of total sprouts per tuber.

To be able to determine the percent sprouting per treatment six samples of seed potato size I each containing three tubers part of those obtained from ADC Molo were randomly selected every season before planting the seed and the number of eyes counted. During the first season the samples included samples A (10, 8,9), B (5, 7, 6), C (8, 6, 6), D (5, 7, 9), E (6, 5, 6), F (6, 6, 6) whereas season two samples had A1 (7, 5, 6), B1 (6, 9, 9), C1 (7, 7, 8), D1 (8, 7, 8), E1 (6, 8, 8), F2 (7, 7, 9) in set being the number of eyes. The data was summed up and used to obtain the average number of eyes. A total of 252 eyes were recorded in the 36 tuber samples.

The average number of eyes in the potato used in the Trial was obtained by dividing the total eyes recorded in both seasons by the number of tubers. This resulted to an average of seven (7) eyes per tuber and was used to determine the percent sprout per treatment. The percent sprout was calculated by dividing the sprouts recorded by seven (7) and multiplying by 100. The vigour was also classified in two categories, according to their length, <1 cm (weak) and >1 cm (strong) (Van Ittersum, 1992).

3.3.3.5. Seed potato tuber field performance evaluation

Three of the sprouted tubers per treatment were planted under prevailing (outdoor) farmer conditions to determine the treatments with the highest vigour and tuberization. The emerging plants were allowed to grow for a period of 8 weeks in both PTrials I and II.

3.3.3.5.1. Number of stems and plant height

Data on growth vigour of the emerging plants was determined by counting the number of main stems and measuring the height from the tip to the base of the plant. These parameters helped to characterize the sprouting capacity of the seed tubers and the vigour of resulting plants following initial treatment.

The number of stems was recorded 22 DAP and used to calculate stem density as the number of main stems or aboveground stems per plant. A main potato stem was considered as the one that originates from the tuber. The number of main stems/m^2 was calculated using the formula: Stem density = total stem number/[total row length * row spacing] (Wiersema, 1987). Total stems/m^2 were determined by multiplying the number of stems by the number of plants per equivalent area which is equal to eight. The total row length and width in a m^2 is 0.9 by 0.75m respectively. Stem density assists determine expected yield of seed tubers obtained from various treatments. Plant height was determined at 22, 36, 50 to 57 DAP.

3.3.3.5. 2. Tuberization

The three plants per treatment were uprooted after 8 weeks of growth of potato in the field (58 DAP). The harvested plants per treatment were placed separately on the ground to facilitate determination of tuber numbers per individual plant within the treatment. All the visible tubers per plant were counted and recorded to determine the post treatment effects.

3.4. Data Analysis

Data collected was subjected to analysis of variance using the SAS system for windows V8 1999-2001 by SAS Institute Inc., Cary, NC, USA and significantly different means separated using Tukey's Studentized Range Test at $P \leq 0.05$. The data on stem numbers and that of relationships such as nitrogen and phosphorus use efficiencies was transformed using the square-root transformation before analysis using the formula: transformed data=square root (collected data+1) to enable normal distribution and the homogeneity of variances). The data for the two seasons were analysed separately. The model fitted was:

$Y_{ijkl} = \mu + R_i + W_j + (RW)_{ij} + N_k + WN_{jk} + (RWN)_{ijk} + P_l + WP_{jl} + NP_{kl} + WNP_{jkl} + (RWNP)_{ijkl} + \varepsilon_{ijkl}$ (adopted from Gomez and Gomez, 1984; Montgomery, 2012)

Where: i=1, 2, 3; j=1, 2, 3; k = 1, 2, 3, 4; l = 1, 2, 3, 4.

μ = overall mean

R_i = i^{th} block effect

W_j = j^{th} water effect

$(RW)_{ij}$ = main plot error (a)

N_k = k^{th} nitrogen effect

WN_{jk} = interaction effect of the j^{th} water level and the k^{th} nitrogen level

$(RWN)_{ijk}$ = subplot error (b)

P_l = l^{th} phosphorus effect

WP_{jl} = interaction effect of the j^{th} water level and the l^{th} phosphorus level

NP_{kl} = interaction effect of the k^{th} nitrogen level and the l^{th} phosphorus level

WNP_{jkl} = interaction effect of j^{th} water, the k^{th} nitrogen level and l^{th} phosphorus level

$(RWNP)_{ijkl}$ = sub-subplot error (c)

ε_{ijkl} = random error component

CHAPTER FOUR

RESULTS

4.1. Soil Analysis and Climatic Data

After analysis the soil at the site was found to have a pH of 5.46, total N of 0.12%, available P of 0.19%, exchangeable K of 0.10% and organic carbon of 3.51% in the upper 1-15 cm, and a pH of 5.6, total N of 0.02%, available P of 0.11%, exchangeable K of 0.08% and organic carbon of 3.02% in the lower 15-30 cm. A total of 601.6 mm and 942.3 mm of rain was received in the site during the first (Aug-Dec 2011) and the second (Apr-Aug 2012) Rainshelter trials (RTrial), respectively. A total of 635 and 221.7 mm was received during PTrials I (Apr-June 2012) and II (Nov 2012-Jan 2013), respectively. Mean temperatures were 19.0°C and 18.9°C during the Rainshelter Trials and 19.5°C and 19.9°C during the post-treatment performance evaluation in PTrials I and II (Table 2). In the Rainshelter the mean temperatures were 20.7°C and 20.5°C in RTrials I and II, respectively (Table 3).

4.2. Effect of Irrigation Water, N and P Integration on Potato Growth and Development

4.2.1. Sprout emergence (germination) percentage

The number of emerging sprouts in potato differed significantly with irrigation water, N and P rates. There were no interactive effects of either irrigation water, N and/or P combined (Appendix 3). Higher sprout emergence rates were observed with high application rates of irrigation water. The highest sprout emergence percent was observed with 100% irrigation water followed by 65%, while 40% had the lowest sprout emergence. High compared with low irrigation water rate increased the percent sprout emergence by 1.4% and 3.2% in RTrials I and II, respectively (Figure 2). Furthermore, sprout emergence percent significantly increased with high N and P application rates. High compared with low P application increased the sprout emergence percentage by 10.2% and 14.4% while it increased by 4.2% and 5.9% with high N application in RTrials I and II, respectively. Overall higher sprout emergence percent was observed in RTrial II than I (Table 4). The results showed that the emergence percent is a function of individual effect of irrigation water, N and P application rates. However, there were no interactive effects on potato emergence between N and P application in both RTrials ($P \leq 0.05$).

Table 2: Weather data from January 2011 to March 2013 at Egerton University Meteorological Station (9035092)

	Year								
	2011			2012			2013		
Month	R (mm)	T	RH (%)	R (mm)	T (°C)	RH (%)	R (mm)	T (°C)	RH (%)
Jan	3.3	21.2	53	0	21.1	40	42.7	20.6	53
Feb	9.6	22.3	42	16.3	21.3	45	2.5	21.9	42
Mar	182.3	21.4	53	31.6	22.5	42	85.4	21.3	52
Apr	20.9	21.0	53	287.0	20.0	70			
May	116	20.5	66	181.8	19.7	71			
June	216.5	19.3	74	166.2	18.7	74			
July	130.1	19.1	74	87.2	17.6	78			
Aug	130	18.2	74	220.3	18.7	69			
Sep	149.3	18.6	70	192.4	19.4	65			
Oct	89.2	19.8	65	94.3	20.0	62			
Nov	146.7	19.0	75	26.6	19.7	66			
Dec	86.4	19.3	61	152.1	19.3	65			
Total	1280.3			1455.8					

R = Rainfall, T= Temperature, RH = Relative humidity

Table 3: Mean monthly temperature data in the Rainshelter for 2011 (Aug-Dec) and 2012 (Apr-Aug) seasons

	2011			2012		
Month	Maximum	Minimum	Mean (°C)	Maximum	Minimum	Mean
Apr	-	-	-	23.1	16.2	19.7
May	-	-	-	23.6	16.9	20.3
June	-	-	-	24.2	17.4	20.8
July	-	-	-	23.7	18	20.9
Aug	22.6	16.2	21.4	23.6	17.9	20.8
Sep	23.1	16.9	21.1	-	-	-
Oct	24.9	16.5	20.7	-	-	-
Nov	24.1	16.3	20.2	-	-	-
Dec	23.9	16.1	20.0	-	-	-
Mean	**23.7**	**16.4**	**20.7**	**23.6**	**17.3**	**20.5**

(Appendix 4). Higher irrigation water rates improved the number of stems compared to where low irrigation water was supplied. High compared to low irrigation water rate increased the stem numbers by 0.2 both in RTrials I and II, respectively (Figure 3). High rates of either N or P also increased the number of stems per plant. High N rate above 75 kg N/ha and 112.5 kg N/ha did not significantly affect the number of stems per plant. High compared to low P application increased the number of stems by 0.8 and 1.0 while high N application increased the same by 0.4 and 0.5 in RTrials I and II, respectively. Significant differences were observed between the P rates in RTrial I, but there was no significant difference between 75.9 kg P/ha and 101.2 kg P/ha in RTrial II (Table 5). Generally, higher increases in stem numbers were observed by P followed by N and the least increase was observed with irrigation water application rate.

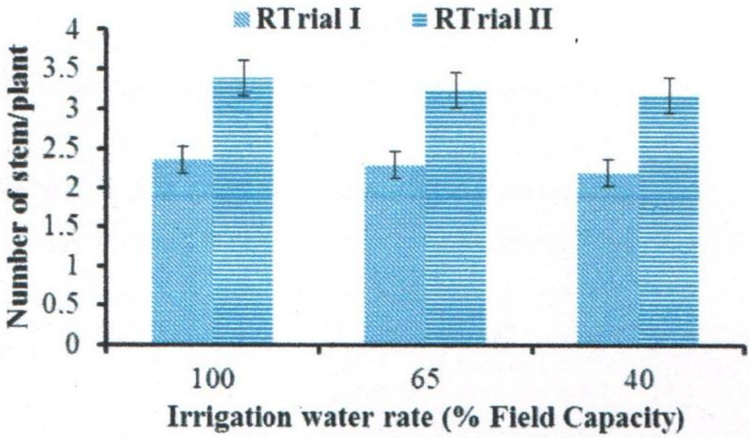


Figure 3: Effect of irrigation water rate on stem numbers per plant

4.2.3. Plant height

Plant height differed significantly among the irrigation water, N and P application rates at 45, 59 and 73 DAP (Appendices 5, 6 and 7). Integration of irrigation water, N and P rates in different combinations also significantly affected plant height late in the growth season, at 94 and 108 DAP (Appendices 8 and 9).

Taller stems were observed in potatoes that received high irrigation water, N and P application rates both in RTrials I and II. Plant height progressively increased from 45 to 73 DAP. This increase was significantly dependent on irrigation water, N and P application rates. High irrigation water rate at 100% resulted in taller plants which attained a height of 98.3 and 103.3 cm compared to 76.2 and 80.4cm recorded with 40% irrigation water rate, 73 DAP while 65% had intermediate height in both RTrials I and II, respectively.

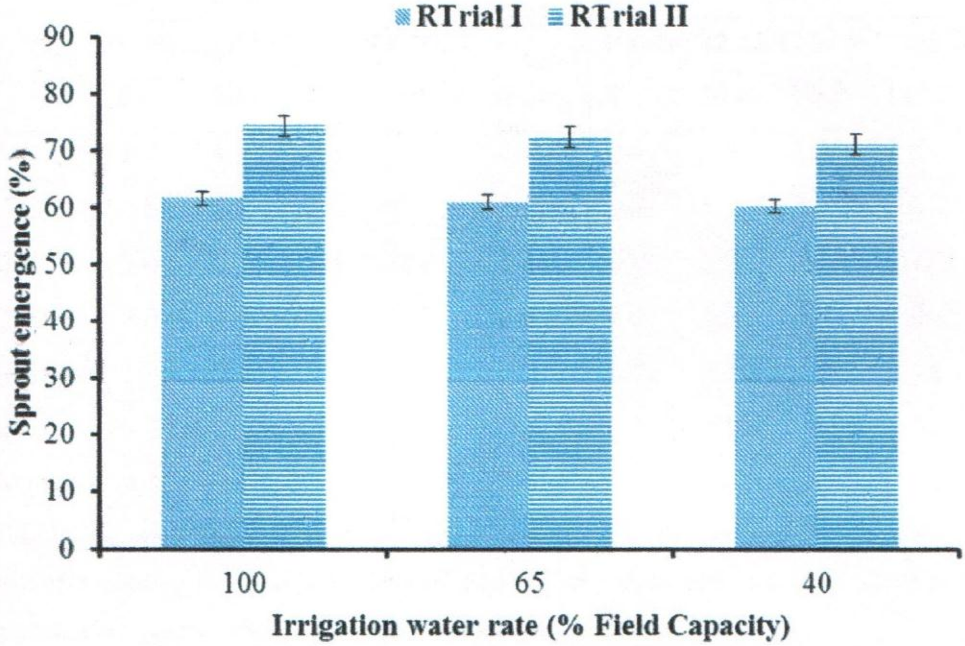


Figure 2: Effect of irrigation water rates on potato sprout emergence

Table 4: Effect of N and P rates on potato sprout emergence percentage

		P rate (kg P/ha) in **RTrial I**					P rate (kg P/ha) in **RTrial II**				
		0	50.6	75.9	101.2	Mean	0	50.6	75.9	101.2	Mean
N rate (kg N/ha)	0	53.9	55.9	60.3	64.3	58.6c*	63.5	67.5	71.8	76.2	69.7c*
	75	55.2	58.7	61.9	67.1	60.7b	65.1	69.8	75.4	77.8	72.0b
	112.5	57.5	60.7	62.3	66.3	61.7ab	65.9	71.4	76.2	80.9	73.6ba
	150	58.3	61.5	63.1	68.3	62.8a	67.1	73.0	78.6	84.1	75.7a
	Mean	56.3d*	59.2c	61.9b	66.5a		65.4d*	70.4c	75.5b	79.8a	
	MSD	1.6 (N, P)					2.3 (N, P)				
	CV (%)	4.1					5.0				

*Means followed by the same letter (s) along the row for P and the column for N are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. Interactions were not significant. MSD = Minimum Significant Difference. Mean separation was done within each season.

4.2.2. Number of stems

Irrigation water, N and P rates significantly affected the number of stems per plant. Integration of irrigation water with either N or P, and that of N and P, or the combined application of the three factors did not significantly affect the number of stems per plant.

Table 5: Effect of N and P rates on potato stem number

		P rate (kg P/ha) in **RTrial I**					P rate (kg P/ha) in **RTrial II**				
		0	50.6	75.9	101.2	Mean	0	50.6	75.9	101.2	Mean
N rate (kg N/ha)	0	1.7	1.9	2.2	2.6	2.1b*	2.4	2.8	3.3	3.6	3.0b*
	75	1.8	2.1	2.4	2.7	2.2ab	2.6	3.1	3.5	3.6	3.2b
	112.5	2.0	2.2	2.5	2.7	2.4a	2.9	3.2	3.5	3.7	3.3ab
	150	2.0	2.4	2.6	2.7	2.4a	3.0	3.3	3.7	4.0	3.5a
	Mean	1.9d	2.2c	2.4b	2.7a		2.7c	3.1b	3.5a	3.8a	
	MSD	0.2 (N, P)					0.3 (N, P)				
	CV (%)	9.4					9.4				

*Means followed by the same letter (s) along the column for N rate and the row for P rate are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. Interactions were not significant. MSD = Minimum Significant Difference. Mean separation was done within each season.

Similarly a strong relationship was observed to exist between plant height and both N and P application. High N and P application rates resulted in significantly high plant height between 45 and 73 DAP and vice versa regardless of irrigation water rate (Table 6).

From 94 to 108 DAP integration of irrigation water, N and P significantly increased the plant height. At 94 DAP plant height increased to 132 and 141 cm with combined application of high irrigation water, N and P rates compared to 72.6 and 76.8 cm observed with integrated application of low irrigation water, N and P application rate in both RTrials I and II, respectively. At 108 DAP average plant height was 148.9 and 151.9 cm with 100% irrigation water, high N and P application rates compared to 70.4 and 71.9 cm recorded with integration of 40% irrigation water rate together with low N and P rates in both RTrials I and II, respectively. Therefore, higher height was observed with high irrigation water when any rate of either N or P was supplied. Application of N and P irrespective of the irrigation water rate increased the plant height from 0 kg N/ha by 0 kg P/ha to 150 kg N/ha by 101.2 kg P/ha both at 94 and 108 DAP (Table 7).

Overall plant height increased from 45 to 94 DAP and a decline was observed in treatments that received low irrigation water, N and P rates at 108 DAP. However, significant differences in the plant height were observed among the treatments throughout the growth period in both RTrials I and II ($P \leq 0.05$).

Table 6: Effect of irrigation water, N and P rates on potato height from 45 to 73 DAP

	Plant height (DAP) in **RTrial I**			Plant height (DAP) in **RTrial II**		
Irrigation water rate (% FC)	45	59	73	45	59	73
100	43.4a*	71.6a	98.3a	45.7a*	75.3a	103.3a
65	39.5b	64.7b	87.8b	41.6b	68.0b	91.9b
40	34.3c	56.6c	76.2c	36.6c	59.4c	80.4c
MSD (W)	1.9	1.9	2.1	2.0	2.0	2.2
N rate (kg N/ha)						
0	33.9d	56.9d	79.7c	36.2c	59.8d	83.9c
75	38.1c	63.5c	87.3b	40.4b	66.7c	91.7b
112.5	40.7b	67b	91.2a	42.8b	70.5b	95.2a
150	43.6a	69.7a	91.6a	45.9a	73.3a	96.7a
MSD (N)	2.5	2.5	2.7	2.5	2.6	2.8
P rate (kg P/ha)						
0	33.2d	57.6d	79.4d	35.2d	60.6d	83.4d
50.6	37.6c	62.2c	84.6c	39.8c	65.4c	88.9c
75.9	41.4b	66.1b	90.6b	43.4b	69.3b	95b
101.2	44a	71.3a	95.2a	46.8a	74.9a	100.2a
MSD (P)	2.5	2.5	2.7	2.5	2.6	2.8
CV (%)	18.3	10.9	8.6	17.5	10.9	8.6

*Means followed by the same letter (s) along the column for irrigation water, N and P application rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

4.2.4. Leaf stomatal conductance ($mmolm^{-2}s^{-1}$)

Leaf stomatal conductance was significantly affected by all the treatments at the various stages of potato growth. Integration of irrigation water, N and P application rates did not affect leaf stomatal conductance. However, effects of integration of N and P on leaf stomatal conductance were observed at all growth stages (Appendices 10, 11 and 12). Leaf stomatal conductance increased with irrigation water, N and P application rates. While high irrigation water rate increased the leaf stomatal conductance, low irrigation water rate reduced the leaf stomatal conductance (Table 8).

Table 7: Effect of irrigation water, N and P rates on potato plant height at 94 and 108 DAP

Trial I		Height at 94 DAP				Height at 108 DAP			
		P rate (kg P/ha)				P rate (kg P/ha)			
Irrigation water rate (% FC)	N rate (kg N/ha)	0	50.6	75.9	101.2	0	50.6	75.9	101.2
100	0	95.1b*	98.4c	106.7c	108.8c	95.9a	98.3d	101.6d	112.2c
	75	99.9a	106.2b	113.3b	118.3b	97.1a	108.2c	111.1c	121.7b
	112.5	98.9a	107.4b	124.4a	132.2a	98.3a	113.1b	144.8a	145.6a
	150	97.2a	112.1a	124.9a	132a	98.9a	120.6a	137.6b	148.9a
65	0	83.8c	88.2c	93.2b	96.7d	82.1c	88.3b	97.8c	101.7d
	75	91b	93.4b	95.8b	106.4c	84.2c	91.7b	102b	106c
	112.5	91.2ab	95.9b	110.6a	110b	91.1b	99.1a	108.3a	110.4b
	150	94.1a	100.8a	109.3a	113.9a	95.4a	101.2a	111.1a	116.2a
40	0	72.6c	75.3b	83.3c	87.8d	70.4c	73.4c	80.6b	83.2c
	75	77.7b	81.9a	87.2b	91.7c	75.1b	80.3b	81.3b	84.8c
	112.5	81.3a	84.7a	90.6a	95.7b	76.8b	82.9ab	89.8a	94.8b
	150	80.6a	83.2a	90.6a	102.8a	81.7a	84.7a	88.4a	103.3a
	MSD	3.2 (N)	3.2 (P)	2.5 (W)		3.9 (P)	3.9 (N)	2.6 (W)	
	CV (%)	9.2				11.4			
Trial II									
100	0	97.8b	103.3c	111.3d	114.9d	97.8	100.7d	103.3d	114.8c
	75	99.7b	112.1b	118.9c	124.3c	99.5	110.5c	113.3c	124.1b
	112.5	104.3a	116.3a	128.2b	136.2b	100.6	115.4b	146.7a	149.5a
	150	105.9a	113b	133.5a	141a	100.9	123.3a	140.3b	151.9a
65	0	88.4c	92.5c	97.9c	101.6c	82.7c	90.1c	99.7c	104.3c
	75	94.9b	98.9b	100.6c	112.3b	86.2c	94.6b	101.7c	110.2b
	112.5	95.2b	104.7a	110.9b	113.8b	92.6b	97.6b	107.7b	110.5b
	150	101.9a	105.4a	115.4a	124a	97.8a	104.4a	113.8a	123.3a
40	0	76.8c	78.4c	87.5c	91.9c	71.9c	74.9c	83b	84.9c
	75	81.6b	86.2b	92.1b	94.4bc	75.7b	81.3b	83b	85.4c
	112.5	85.4a	88.9b	93.7b	97.2b	81.8a	84.4a	86.6b	92.5b
	150	85.8a	93.8a	97.6a	107.5a	81.7a	86.4a	91.2a	106.5a
	MSD	3.3 (N)	3.3 (P)	3.1 (W)		3.8 (N)	3.8 (P)	3.0 (W)	
	CV (%)	9.1				10.7			

*Means followed by the same letter (s) along the column are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

Table 8: Effect of irrigation water rates on potato leaf stomatal conductance

	59 DAP			73 DAP			87 DAP		
	Irrigation rate (% FC)			Irrigation rate (% FC)			Irrigation rate (% FC)		
RTrial I	100	65	40	100	65	40	100	65	40
Mean	131.7a*	112.7b	98.7c	148.2a	125.7b	112.2c	124.1a	102.3b	91.2c
MSD	4.8 (N)	3.8 (W)		5.7 (N)	4.5 (W)		5.2 (N)	4.1 (W)	
CV (%)	11.9			12.6			14		
RTrial II									
Mean	138.9a	123.7b	104c	150a	132.3b	117.3c	115.4a	108.9b	83.4c
MSD	5.3 (N)	4.2 (W)		5.8 (N)	4.6 (W)		4.3 (N)	3.4 (W)	
CV (%)	12.4			12.3			12.0		

*Means followed by the same letter (s) along the row at the same DAP are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. FC = Field Capacity, MSD = Minimum Significant Difference. Mean separation was done within each season.

Therefore water stress resulted in decrease in the net leaf stomatal conductance. Furthermore, leaf stomatal conductance increased from 59 DAP and was highest at 73 DAP after which it reduced regardless of irrigation water application rate later in the growth season. Average leaf stomatal conductance at 87 DAP decreased by 24.1 and 35 mmol$m^{-2}s^{-1}$ with high compared to 21 and 33.9 mmol$m^{-2}s^{-1}$ observed with low irrigation water rate in RTrials I and II, respectively. Therefore although decreases in leaf stomatal conductance were also observed with high irrigation water rate greater reduction resulted from low irrigation water application rate at the later growth stages. Therefore, higher irrigation water application rates maintained higher leaf conductance compared to lower application rates in both RTrials (Table 8).

Similarly leaf stomatal conductance increased with N and P application rate. High rates of N and P application increased leaf stomatal conductance from 59 to 79 DAP after which there were declines regardless of their application rate. High compared to low P application rate increased the leaf stomatal conductance by 22.8 and 27.2 mmol $m^{-2}s^{-1}$ while high N application increased the same by 24.6 and 24.2 mmol m^{-2} s^{-1} at 87 DAP in RTrials I and II, respectively (Table 9).

Table 9: Effect of N and P rates on potato leaf stomatal conductance

RTrial I	59 DAP					73 DAP				87 DAP				
P rate (kg P/ha)	N rate (kg N/ha)					N rate (kg N/ha)				N rate (kg N/ha)				
	0	75	112.5	150	Mean	0	50.6	75.9	101.2	0	50.6	75.9	101.2	Mean
0	93.1	95.4	106.3	113.4	102.1d	106.6c	108.5d	120.8d	124.1d	84.8	89.4	98.4	108.1	95.2d
50.6	101.6	105.8	114.6	122.4	111.1c	112bc	119.2c	131c	133.3c	92.4	95.2	107.3	110.4	101.3c
75.9	104.9	116.1	120.6	132.2	118.4b	116.9b	129.7b	137.5b	144.5b	97.7	104.6	112.8	120.8	108.9b
101.2	110.4	120.7	126.8	145.3	125.8a	125.2a	136.3a	148.2a	164.7a	102.2	108.2	125.3	136.5	118a
Mean	102.5d*	109.5c	117.1b	128.3a		115.2	123.4	134.4	141.7	94.3c	99.3c	110.9b	118.9a	
MSD	4.8 (P)	4.8 (N)				5.7 (P)	5.7 (N)			5.2 (P)	5.2 (N)			
CV (%)	11.9					12.6				14				
RTrial II														
0	100.2	107.2	111.1	117.7	109.1d	111.3c	112.5c	124.9d	128.6c	74.5d	93.6c	91.9d	99.8d	89.9
50.6	105.6	114.1	119.4	130.5	117.4c	116.1bc	122.2b	134.3c	141.3b	87.9c	94.2c	100.9c	108.7c	97.9
75.9	110.8	124.6	136.6	137.4	127.3b	120.9b	135.3a	143.9b	146.9b	93.1b	101.5b	111.4b	115.5b	105.4
101.2	120.1	131.8	140.6	147.8	135.1a	130a	140a	152.3a	170.5a	101.9a	110.9a	125.5a	130.3a	117.2
Mean	109.2d*	119.4c	126.9b	133.4a		119.6	127.5	138.9	146.9	89.4	100.1	107.4	113.6	
MSD	5.3(P)	5.3 (N)				5.8 (P)	5.8 (N)			4.3 (P)	4.3 (N)			
CV (%)	12.4					12.3				12				

*Means followed by the same letter(s) along the row for N main effects and the column for P rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. Some interactions were not significant. MSD = Minimum Significant Difference. Mean separation was done within each season.

Generally potato leaf stomatal conductance significantly increased with irrigation, N and P application rates. Significant difference in the leaf stomatal conductance was observed among the treatments throughout the growth period in both RTrials I and II ($P \leq 0.05$).

4.2.5. Leaf chlorophyll content index (CCI)

The average leaf chlorophyll content index of potato increased significantly over the growth period with irrigation water, N and P application rates. Interactions between irrigation water, N and P rates resulted to significant differences in leaf chlorophyll content index at all growth stages both in RTrials I and II. Significant differences were also observed between irrigation water and P rates at all growth stages, except at 59 DAP in RTrial I. However, interactions between N and P were not significant at 59 and 79 DAP in RTrial II (Appendices 13, 14 and 15).

Water stress due to low irrigation water rate resulted in decrease in the leaf chlorophyll concentration. High irrigation water rate resulted to a higher amount of chlorophyll compared to low irrigation water rate. Similarly application of higher rates of N led to high chlorophyll concentration in both RTrials. However, application of high N rates with 40% and 65% irrigation water rates reduced the leaf chlorophyll concentration at 73 and 87 DAP both in RTrials I and II.

The leaf CCI increased with integrated irrigation water, N and P from 59 DAP and was highest 73 DAP after which it decreased 87 DAP. Integration of high compared with low N and P application rates together with 100% irrigation water rate increased the leaf chlorophyll concentration by 16.2 and 16.5, 19.8 and 19.6, and 15 and 20.3 CCI at 59, 73 and 87 DAP both in RTrials I and II respectively. When low irrigation water rate was integrated with high compared with low N and P application rates the leaf chlorophyll concentration increased by 10.1 and 7.2, 18.8 and 14.9, and 17.8 and 9.1 CCI at the same growth stages both in RTrials I and II respectively. The highest leaf chlorophyll concentration was 53.7 and 53.6 CCI that resulted from combined application of 100% irrigation water, 112.5 kg N/ha and 101.2 kg P/ha 73 DAP while the lowest was 20.9 and 22.2 CCI recorded with 40% irrigation water, 0 kg N/ha and 0 kg P/ha both in RTrials I and II respectively. Therefore integration of high irrigation water, N and P application compared to low irrigation water greatly increased the leaf chlorophyll concentration in potato. Integration of low irrigation water and higher N and P rates beyond 112.5 kg N/ha and 75.9 kg P/ha reduced the leaf chlorophyll concentration at all growth stages in both RTrials (Table 10).

Table 10: Effect of irrigation water, N and P rates on potato leaf chlorophyll content index

Trial I		CCI at 59 DAP				CCI at 73 DAP				CCI at 87 DAP			
		P rate (kg P/ha)				P rate (kg P/ha)				P rate (kg P/ha)			
	kg N/ha	0	50.6	75.9	101.2	0	50.6	75.9	101.2	0	50.6	75.9	101.2
Irrigation water rate 100 (% FC)	0	26.6d*	33.6c	35.9b	38.2a	33d	39.8c	42.2b	46.8a	22.6c	28.6b	29.7b	32.7a
	75	30.3c	35.2b	36.2b	38.9a	37.1d	42.1c	45.2b	49.3a	26.5c	29.6b	29.8b	33.8a
	112.5	33.1d	36.6c	39.2b	43.2a	40.5d	46.6c	51.4b	53.7a	29.5c	30.3c	32.2b	36.4a
	150	35.3d	38.6c	40.5b	42.8a	41.4d	44.5c	49.2b	52.8a	27.5d	30.6c	35.2b	37.6a
65 (% FC)	0	27.4d	29.5c	32.2b	34.8a	30.1c	35.3b	36.2b	41.9a	23.1c	23.6c	26.1b	30.1a
	75	29.4d	31.7c	33.8b	36.4a	34c	38.9b	40.2b	45.4a	23.2c	27.4b	28.6b	31.4a
	112.5	31d	33.7c	39.4b	42.7a	35.5c	42.4b	48.9a	48.8a	26.1c	31b	34.6a	34.4a
	150	31.8d	35.9c	41.4a	38.6b	37d	42.2c	48.3a	45.7b	26.1d	29.3c	35.6a	32.9b
40 (% FC)	0	23.6d	28.8c	30.4b	33.6a	29.2c	30.9b	35.7a	36.8a	20.9c	22.7b	26.3a	26.3a
	75	27.3c	30.4b	33.4a	33.9a	30.9c	36.6b	40.2a	39.7a	22.7c	24.3b	27.9a	28.3a
	112.5	28.9c	30.4b	33.2a	33.2a	36.1c	39.9b	47.1a	48a	25.5c	26.5c	38.7a	36.7b
	150	27.8c	32.5b	36.9a	33.7a	37.2d	41.6c	47.7a	40.3b	25.5c	27.3b	31a	27.5b
	MSD	1.1 (N,P)		0.9 (W)		1.5 (N,P)		1.2 (W)		1.1(N,P)		0.8 (W)	
CV (%)		16.2				18.1				18.2			
Trial II													
Irrigation water rate 100 (% FC)	0	29.4d	35.1c	37.5b	39.5a	32.9c	41.7b	42.7b	47.8a	25.7c	28.8b	29.7b	34.1a
	75	32d	36.6c	38.1b	39.9a	36.9d	44.6c	47.4b	51.4a	29.2c	31.3b	32.1b	35.7a
	112.5	32.6d	36.9c	39.7b	42.5a	42.8c	49.2b	49.9b	53.6a	31c	32.6b	33.5b	35a
	150	36.5d	39c	41.6b	45.9a	43.9d	48c	51.1a	52.5a	29.5d	32.6c	39.7b	46a
65 (% FC)	0	28.6d	31.2c	32.5b	36.2a	31.8d	37.6c	44b	45.9a	23.7c	25.8b	28.8a	29.5a
	75	29.9d	33.6c	34.7b	38.7a	35.4d	38.5c	46.2b	47.9a	24.9d	28.1c	29.9b	31.5a
	112.5	33.6d	36.1c	37.6b	39.6a	41.8c	44.4b	45.7b	48.5a	27.9d	31.4c	32.6a	33.3a
	150	28.8d	32c	38.2b	40.3a	37.9d	45.8c	47.6b	50.6a	25.3d	28.8c	36.7a	32.9b
40 (% FC)	0	27.9c	30.9b	31.7b	33.7a	30b	31.5b	38.2a	37.70	22.2d	23.9c	29.1a	27.8b
	75	28.7c	31.5b	35.6a	35.7a	31.7c	37b	40.3a	41.6a	24.6d	26.7c	30.7a	28.1b
	112.5	29.9d	31.7c	35.7a	34.1b	35.7d	38.9c	41.8b	44.9a	24.5c	26.1b	31.3a	30.5a
	150	28.9d	32.6c	38.3a	35.1b	39.3b	43.8a	43.7a	42.7a	26.5c	28.8b	30.2a	28.2b
	MSD	1.1 (N,P)		0.9 (W)		1.6 (N,P)		1.3(W)		1.1(N,P)		0.8(W)	
CV (%)		15.5				18.9				17.5			

*Means followed by the same letter(s) along the row at the same DAP and irrigation water and N rate are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

Stronger relationships to leaf CCI were observed with irrigation water, N and P mineral nutrient supply. There were significant increases in leaf CCI with increase in irrigation water, N and P application rate at 59, 73 and 87 DAP ($P \leq 0.05$).

4.2.6. Leaf area index (LAI)

Leaf area index significantly differed among the treatments at 51 and 64 DAP (Appendices 16 and 17). Potatoes that received high irrigation water, N and P rates had significantly higher LAI than those that received lower rates. Leaf area index significantly increased between 51 and 64 DAP with integrated application of high irrigation water, N and P rates in both RTrials. Leaf area index was greater with high irrigation water at 100%, N at 150 kg N/ha and P at 101.2 kg P/ha, which was 2.6 and 1.3 at 51 DAP and 3.5 and 3.1 at 64 DAP. Furthermore, low irrigation water rate at 40 % together with low N and P rates of 0 kg N/ha and 0 kg P/ha had the least LAI, which was 0.28 and 0.19 at 51 DAP and 0.28 and 0.24 at 64 DAP both in RTrials I and II, respectively. Irrespective of N and P rates LAI was significantly greater with high irrigation water at 100% followed by 65% and was lowest with 40% irrigation water rate. High compared to low irrigation water together with high N and P application rates increased the LAI by 1.54 and 0.61 at 51 DAP and by 2.06 and 1.78 at 64 DAP both in RTrials I and II, respectively. Similarly LAI significantly increased from low to high rates of N and P at all irrigation water rates. However, slight but significant differences were observed when 40% and 65% irrigation water rates was supplied together with high N and P rates of 150 kg N/ha and either 75.9 kg P/ha or 101.2 kg P/ha (Table 11).

4.2.7. Days to 50% flowering

The number of days to 50% flowering of potato significantly depended on the irrigation water, N and P rates. Significant interactive effects were observed both due to irrigation water by N rates and N by P rates in RTrials I and II. Interactive effects of irrigation water by P were not significantly different (Appendix 18).

The days to 50% flowering decreased with irrigation water, N and P rates. Provision of 100% irrigation water during growth enhanced early synchronization of flowering in potato. Supply of 100% irrigation water decreased the days to 50% flowering to 53.5 and 54.7 from 68.3 and 69.8 observed with 40% irrigation water rate. High compared with low irrigation water rate reduced the days to 50% flowering by 14.9 and 15.2 in RTrials I and II, respectively (Figure 4).

Table 11: Effect of irrigation water, N and P application rate treatments on potato LAI

Trial I		LAI at 56 DAP				LAI at 64 DAP			
		P rate (kg P/ha)				P rate (kg P/ha)			
	kg N/ha	0	50.6	75.9	101.2	0	50.6	75.9	101.2
Irrigation water rate 100 (% FC)	0	0.78d*	0.85d	1.46c	1.58d	1.05d	1.14d	1.95c	2.12d
	75	0.92c	1.02c	1.45c	1.76c	1.23c	1.37c	1.95c	2.37c
	112.5	1.34b	1.22b	1.76b	2.14b	1.63b	1.8b	2.35b	2.87b
	150	1.37a	1.8a	2.36a	2.64a	1.84a	2.46a	3.17a	3.54a
65 (% FC)	0	0.44d	0.65d	1.02d	1.11d	0.59d	0.87d	1.37d	1.48d
	75	0.65c	0.73c	1.1c	1.32c	0.87c	0.98c	1.48c	1.75c
	112.5	0.93b	1.05b	1.3b	1.4b	1.24b	1.4b	1.74b	1.88b
	150	0.97a	1.13a	1.34a	1.51a	1.29a	1.54a	1.79a	2.03a
40 (% FC)	0	0.21d	0.35d	0.53d	0.69d	0.28d	0.47d	0.71d	0.93d
	75	0.37c	0.48c	0.82c	0.91c	0.49c	0.64c	1.1c	1.22c
	112.5	0.5b	0.60b	0.88b	1.07b	0.67b	0.8b	1.18b	1.44b
	150	0.62a	0.64a	0.93a	1.1a	0.83a	0.85a	1.25a	1.48a
	MSD	0.02(N)	0.02 (P)	0.02 (W)		0.03 (P)	0.03 (N)	0.02 (W)	
	CV (%)	5.80				6.05			
Trial II									
Irrigation water rate (% FC) 100 (% FC)	0	0.59d*	0.64d	0.76d	0.82d	0.91d	0.98d	1.63d	1.83d
	75	0.69c	0.75c	0.78c	0.91c	1.06c	1.18c	1.67c	2.04c
	112.5	0.76b	0.81b	0.88b	1.03b	1.41b	1.55b	2.03b	2.45b
	150	0.85a	1.11a	1.16a	1.29a	1.59a	2.08a	2.73a	3.05a
65 (% FC)	0	0.38d	0.55d	0.59d	0.64c	0.51d	0.75d	1.18d	1.28d
	75	0.55c	0.62c	0.65c	0.76b	0.75c	0.84c	1.27c	1.53c
	112.5	0.6b	0.68b	0.71b	0.78b	1.07b	1.21b	1.49b	1.62b
	150	0.63a	0.73a	0.75a	0.84a	1.12a	1.31a	1.55a	1.75a
40 (% FC)	0	0.2d	0.31d	0.39d	0.45d	0.24d	0.41d	0.61d	0.8c
	75	0.35c	0.45c	0.54c	0.59c	0.42c	0.55c	0.95c	1.05b
	112.5	0.42b	0.48b	0.56b	0.66b	0.58b	0.69b	1.01b	1.24a
	150	0.51a	0.52a	0.59a	0.68a	0.71a	0.73a	1.08a	1.27a
	MSD	0.02 (N)	0.02 (P)	0.02 (W)		0.04 (N)	0.04 (P)	0.03 (W)	
	CV (%)	8.23				8.83			

*Means followed by the same letter(s) along the column for different irrigation water rate with N by P rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

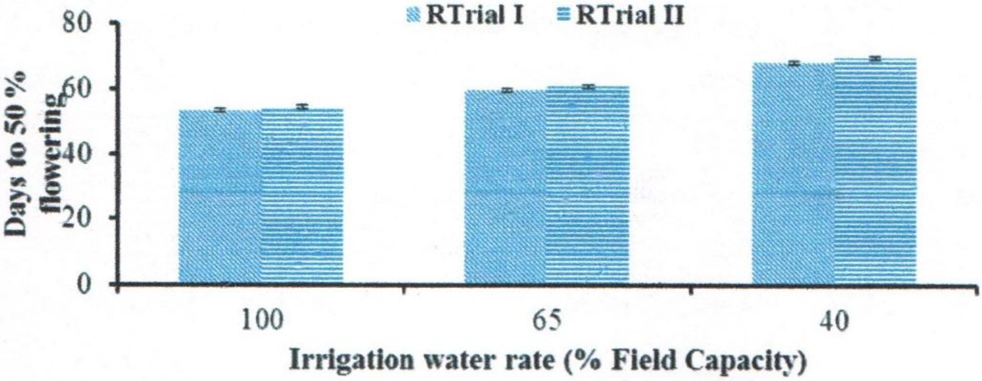


Figure 4: Effect of irrigation water rate on days to 50% flowering in potato

Potatoes where both 100% irrigation water and high N rate at 150 kg N/ha were supplied, attained 50% flowering at 47.6 and 48.5 DAP compared to 74.2 and 75.5 DAP where 40% irrigation water and N rate of 0 kg N/ha were supplied which was an equivalent of 26.6 and 27 days earlier in RTrials I and II, respectively. However, regardless of N application rate, 100% irrigation water attained 50% flowering earlier compared to other water treatments. High compared with low irrigation water rate when combined with high N application rate reduced the days to 50% flowering by 13.4 and 14.9 days in RTrials I and II respectively (Table 12). However, irrespective of irrigation water rate days to 50% flowering reduced with increase in N application rate.

High N and P application rates enabled potato to attain 50% flowering earlier compared to low application rates both in RTrials I and II. Application of high rates of N and P at 150 kg N/ha and 101.2 kg P/ha reduced days to 50% flowering to 52.3 and 53.3 compared to 0 kg N/ha and 0 kg P/ha which attained the same 69.4 and 68.1 days. High compared to low P regardless of N application rate reduced the days to 50% flowering by 4.7 and 4 in RTrials I and II, respectively. However, the days to 50% flowering reduced when high P and N rates were integrated (Table 12). Overall, irrigation water, N and P rates significantly reduced the days to 50% flowering of potato ($P \leq 0.05$).

Table 12: Effect of irrigation water, N and P rates on the days to 50% flowering in potato

RTrial I	Irrigation water rate (% FC)			P rate (kg P/ha)			
N rate (kg N/ha)	100	65	40	0	50.6	75.9	101.2
0	58.8a*	64.6a	74.2a	69.4a	66.8a	65a	62.2a
75	55.3b	61.8b	71.3b	64.6b	63b	62.2b	61.3b
112.5	52.2c	58.7c	66.9c	61.2c	59.9c	58.3c	57.6c
150	47.6d	53.8d	61d	56.9d	54.8d	52.6d	52.3d
MSD (N)	0.8 (N)	0.8 (P)	0.6 (W)				
CV (%)	2						
RTrial II							
0	59.2a*	65.8a	75.5a	68.1a	67.2a	66.4a	65.6a
75	57.5b	63.2b	72.7b	66.3b	64.9b	64b	62.6b
112.5	53.4c	59.7c	68.3c	63.1c	61.1c	59.2c	58.4c
150	48.5d	54.9d	62.8d	58.4d	56d	53.8d	53.3d
MSD (N)	0.7 (N)	0.7 (P)	0.6 (W)				
CV (%)	1.9						

*Means followed by the same letter(s) along the column for different irrigation water and P with N are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

4.2.8. Days to physiological maturity

Although the number of days to potato physiological maturity significantly depended on all the treatments, only the interactive effects of irrigation water and P application rates significantly affected the days to physiological maturity (Appendix 19).

There was a delay for the potato to attain physiological maturity with 100% irrigation water and high P rate in both RTrials I and II. Water stress and low P encouraged early senescence. Potato plants supplied with low levels of both irrigation water at 40% and 0 kg P/ha attained physiological maturity in 89.6 and 88.3 days compared to 109.8 and 108.7 days where high levels of irrigation water at 100% and 101.2 kg P/ha were supplied. This shows that potato plants, stressed due to low irrigation water and low P application rates, reduced the maturity date by 20.2 and 20.3 days in RTrials I and II, respectively (Table 13, Plate 3). High levels of N at 150 kg N/ha delayed potato physiological maturity by 18.6 and 19.7 days in RTrials I and II, respectively (Figure 5). However, irrigation water, N and P rates significantly influenced potato physiological maturity both in RTrials I and II ($P \leq 0.05$).

Table 13: Effect of irrigation water and P rates on the days to physiological maturity in potato

	Irrigation water rate (% FC) in **RTrial I**				Irrigation water rate (% FC) in **RTrial II**			
P rate (kg P/ha)	100	65	40	Mean	100	65	40	Mean
0	95.1d*	92.1d	89.6d	92.3	93.8d*	90.8d	88.3d	90.9
50.6	98.6c	95.2c	92.6c	95.4	97.3c	93.7c	91.5c	94.2
75.9	104.5b	98.8b	94.7b	99.3	103.3b	97.8b	93.8b	98.3
101.2	109.8a	102.6a	100.7a	104.3	108.7a	101.3a	99a	10
Mean	101.9	97.2	94.4		100.8	95.9	93.2	
MSD (P)	1.1				1.1			
MSD (W)	0.9				0.9			
CV (%)	1.8				1.8			

*Means followed by the same letter(s) along the column for different irrigation water with P are not significantly different in both RTrials I and II at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

4.2.9. Potato total biomass (biological yield)

The total biomass of potato significantly depended on all the treatments together with their interactive effects (Appendix 20). The total biomass of potato increased with the increase in irrigation water, N and P application rates both in RTrials I and II. Application of irrigation water and N increased the potato total biomass production.

The highest biological yields of 222.5 and 272.2 g per plant was observed with 65% irrigation water rate together with N application rate of 112.5 kg N/ha compared to 125.6 and 135.6 g obtained with 40% irrigation water and 0 kg N/ha in RTrials I and II, respectively (Table 14).

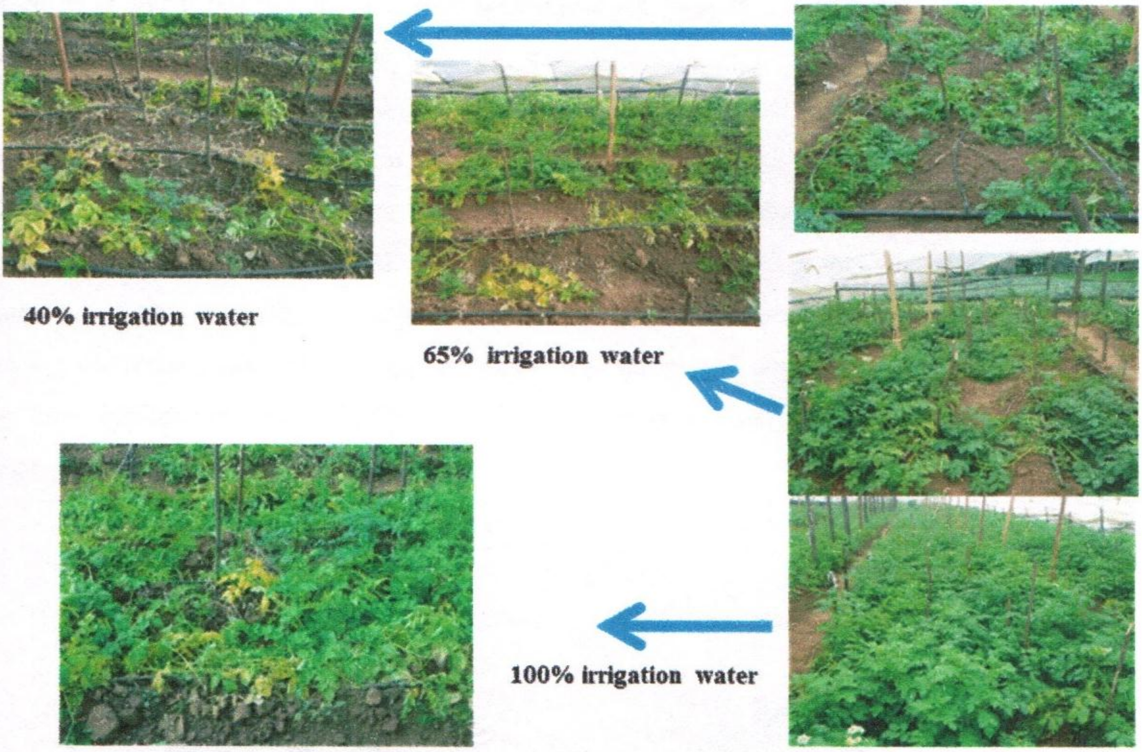


Plate 3: Effect of irrigation water rate on potato physiological maturity

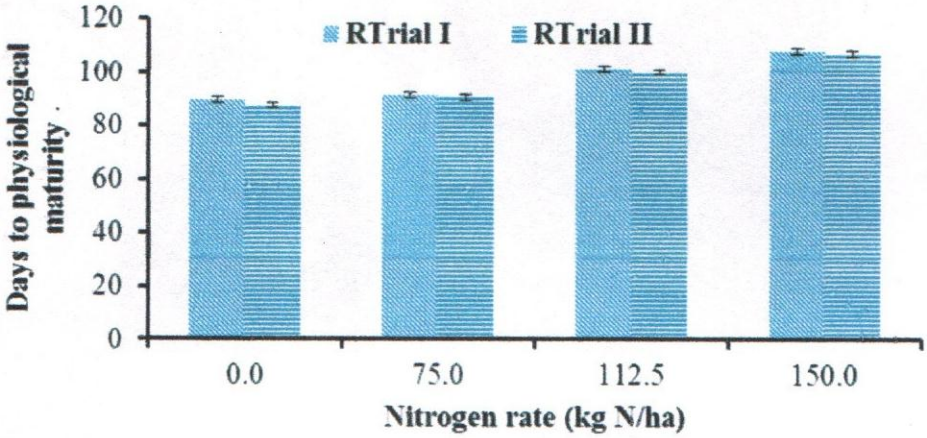


Figure 5: Effect of N rate on days to physiological maturity of potato

Similarly N and P application improved potato total biomass production from 110.5 and 119.5 g with low application rates of 0 kg N/ha by 0 kg P/ha to 233.9 and 283 g with 112.5 kg N/ha by 75.9 kg P/ha both in RTrial I and II respectively. Integration of irrigation water with N application improved the total biomass more than that of N with P. However, high application of N and P beyond application rate of 112.5 kg N/ha by 75.9 kg P/ha suppressed the total biomass production (Table 14).

The tubers biomass contributed the highest proportion of the total biomass compared to shoot biomass regardless of irrigation water rate. The 100% irrigation water (Plate 3), high N and P rates had the highest shoot biomass, while 65% had the highest tuber biomass and consequently the highest total biomass. Lowest total biomass of 90.37 g was recorded with the integration of 40% irrigation water, 0 kg N/ha and 0 kg P/ha rates and the highest biomass was 325.3 g observed where 65% irrigation water, was integrated with 112.5 kg N/ha and 75.9 kg P/ha application rates (Table 15). Overall irrigation water, N and P rates had significant effect on potato total biomass ($P \leq 0.05$).

Plate 4: Effect of water stress on growth and development of potato

Table 14: Effect of irrigation water, N and P rates on potato total biomass (biological yield)

RTrial I	Irrigation water (% FC)				P rate (kg P/ha)				
N rate (kg/ha)	100	65	40	Mean	0	50.6	75.9	101.2	Mean
0	160.6d*	158.4d	125.6d	148.3	110.5c	142.7b	169.8a	169.8a	148.3
75	181.2c	186.1c	136.4c	167.9	138.8c	158.8b	188.7a	185.4a	167.9
112.5	221.3a	222.5a	166.9a	203.6	162.8c	198.4b	233.9a	219.2a	203.6
150	198.9b	201.5b	151.9b	184.1	164.1d	174.1c	205.7a	192.6b	184.1
Mean	190.5	192.2	145.2		144	168.5	199.5	191.7	
MSD	5.9 (N)	5.9 (P)	4.6 (W)						
CV (%)	9.5								
RTrial II									
0	179d*	181.8d	135.6d	165.5	119.5d	158.9c	196a	187.5b	165.5
75	208.2c	218.8c	149.2c	192.1	154.1d	175.9c	224.4a	213.8b	192.1
112.5	263.7a	272.2a	187.4a	241.1	181.7d	237.4c	2834a	262.2b	241.1
150	221.8b	230.8b	166.4b	206.1	179.9d	191.3c	242.1a	211.1b	206.1
Mean	218	225.9	159.6		158.8	190.9	236.4	218.7	
MSD	5.3(N)	5.3 (P)	4.2 (W)						
CV (%)	7.5								

*Means followed by the same letter(s) along the column for different irrigation water and P with N are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

4.3. Effect of Integration of Irrigation Water, N and P Rates on Seed Potato Tuber Yield and Yield Components

4.3.1. Number of tubers per plant

Number of tubers was significantly affected by all the treatments both in RTrials I and II. The results showed that number of tubers also significantly depended on interaction of irrigation water either with N or P (Appendix 21).

Overall, application of irrigation water significantly increased the number of tubers. Application of intermediate irrigation water rate at 65% produced the highest number of tubers. High irrigation water beyond 65% reduced the number of tubers by 1.2 and 1.3 tubers in RTrials I and II, respectively (Table 16).

Table 15: Effect of irrigation, N and P rates on shoot, tuber and total biomass in RTrial II

% FC	N rate (kg N/ha)	Shoot dry mass (g per plant)				Tuber dry mass (g per plant)				Total dry mass (g per plant)			
		P rate (kg P/ha)				P rate (kg P/ha)				P rate (kg P/ha)			
		0	50.6	75.9	101.2	0	50.6	75.9	101.2	0	50.6	75.9	101.2
100	0	42.9	47.1	49.9	58.9	97.3	127.2	153.9	138.7	140.3	174.3	203.8	197.7
	75	46.9	54.5	56.4	63.8	124.3	134.9	180.8	171.5	171.1	189.4	237.2	235.3
	112.5	51.4	55.3	67.6	74	140.8	193.1	247.7	224.8	192.2	248.4	315.3	298.8
	150	57.9	67.3	71.1	76.3	128.2	142.6	184.2	157.1	186.1	209.8	255.3	233.4
65	0	34.8	43.9	46.2	49.4	93	128.5	172.6	158.9	127.9	172.3	218	208.3
	75	44.6	48.1	49.9	56.6	132.7	150.5	218.1	174.6	177.3	198.6	268.3	231.2
	112.5	48.3	50.2	50.8	53.7	148.2	230.9	274.5	232.2	196.5	281.6	325.3	285.9
	150	50.1	53.4	58.9	63.5	151.5	156.2	224.1	165.5	201.7	209.6	282.9	228.9
40	0	29.2	35.2	40.5	44.7	61.2	94.9	124.9	111.6	90.4	130	165.5	156.3
	75	33.1	38.5	40.5	50.9	80.9	101.2	127.6	124	113.9	139.7	168.1	174.9
	112.5	37.9	45.4	49	53.1	118.5	137.2	159.5	148.8	156.6	182.7	208.5	201.9
	150	43.9	43.4	49.9	50.5	108	111	138.2	120.6	151.9	154.4	188.2	171.1
MSD (P)		2.1				4.9				5.3			
MSD (N)		2.1				4.9				5.3			
MSD (W)		1.7				3.3				4.2			
CV (%)		11.8				9.3				7.5			

*Means followed by the same letter(s) along the column for different irrigation water and P with N are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

Application of lower irrigation water rate at 40% also greatly reduced the number of tubers compared with 100% irrigation water rate. Also the number of tubers increased with application of N regardless of the amount of irrigation water supplied until 112.5 kg N/ha when it reduced with high N rate of 150 kg N/ha. Number of tubers increased with P application from 0 kg P/ha to 101.2 kg P/ha with 65% irrigation water, but they insignificantly decreased after 75.9 kg P/ha both with 40% and 100% irrigation water. Higher compared to lower P rates regardless of irrigation water increased the number of tubers by 1.1 and 1.4 in both RTrials I and II, respectively. Unlike P, high N application rates beyond 112.5 kg N/ha significantly depressed the tuber number. However, high compared to low N rate increased the number of tubers by 1 and 1.4 in both RTrials I and II, respectively (Table 16). Generally, plants in RTrial I had less number of tubers than those in RTrial II.

Table 16: Effect of irrigation water, N and P rates on number of tubers per plant

Trial I	N rate (kg N/ha)					P rate (kg P/ha)				
%FC	0	75	112.5	150	Mean	0	50.6	75.9	101.2	Mean
100	5.1d*	5.7c	6.5a	6.1b	5.8	5.4c	5.7b	6.2a	6.1a	5.8
65	6d	6.6c	8.1a	7.2b	6.9	6.1d	6.7c	7.2b	7.8a	6.9
40	4.3c	4.7b	5.4a	5.3a	4.9	4.5c	4.9b	5.2a	5.1a	4.9
Mean	5.2	5.66	6.7	6.2		5.3	5.8	6.2	6.4	
MSD	0.2 (N)	0.2 (P)	0.1(W)							
CV (%)	15.1									
Trial II										
100	6.8d*	7.7c	8.5a	8.1b	7.8	7.2c	7.5b	8.2a	8.1a	7.8
65	7.9d	8.6c	10.1a	9.7b	9.1	7.9d	8.6c	9.6b	10.1a	7.8
40	5.8d	6.3c	7.4a	7.1b	6.6	6.1c	6.5b	6.9a	6.9a	6.6
Mean	6.8	7.5	8.6	8.3		7.1	7.5	8.2	8.4	
MSD	0.2(N)	0.2(P)	0.2(W)							
CV (%)	14.9									

*Means followed by the same letter(s) along the row for different N and P rates with irrigation water rate are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. FC= Field Capacity irrigation water. Mean separation was done within each season.

4.3.2. Tuber yield

The seed potato tuber yield (t/ha) significantly differed amongst the levels of irrigation water, N and P rates in both RTrials. Tuber yield significantly depended on the integration of irrigation water either with N or P and that of N with P (Appendix 22). Irrigation water application increased seed potato tuber yield. The highest seed tuber yield was recorded with 65% followed by 100% whereas 40% irrigation water rate had the least yield. Intermediate irrigation water application at 65% significantly increased the seed tuber yield to 32.5 and 38.4 t/ha compared to 22.1 and 27.1 t/ha recorded with 40% irrigation water irrespective of N or P application rate. This translated to an increase by 10.4 and 11.3 t/ha although application of irrigation water beyond 65% reduced the seed potato yield by 2.3 and 3.1 t/ha both in RTrials I and II, respectively. However, integration of irrigation water and N application significantly improved the seed potato tuber yields (Table 17).

Table 17: Effect of irrigation water, N and P rates on seed potato tuber yield (t/ha)

RTrial I	N rate (kg N/ha)					P rate (kg P/ha)				
%FC	0	75	112.5	150	Mean	0	50.6	75.9	101.2	Mean
100	21.6d*	28.2c	34.2b	36.7a	30.2	22.6d	27.5c	33.9b	36.6a	30.2
65	23.5d	30.4c	35.7b	40.5a	32.5	25.4d	30.5c	35.7b	38.4a	32.5
40	17.2c	20.4b	24.8a	26.1a	22.1	17.9c	20.8b	24.6a	25.1a	22.1
Mean	20.7	26.3	31.6	34.4		21.9	26.3	31.4	33.4	
MSD	1.4(N)	1.4(P)	1.1(W)							
CV (%)	7.9									
RTrial II										
100	24.8c*	33.4b	41.8a	41.3a	35.3	27.6d	32.5c	39.9b	41.2a	35.3
65	27.4c	35.8b	45.5a	44.9a	38.4	30.2d	35.7c	43.2b	44.6a	38.4
40	20.3c	25.6b	31.3a	31.5a	27.2	21.7c	25.7b	30.5a	30.9a	27.1
Mean	24.2	31.6	39.5	39.3		26.5	31.3	37.9	38.9	
MSD	1.3(N)	1.3(P)	1(W)							
CV (%)	5.9									

*Means followed by the same letter(s) along the row for different N and P rates with irrigation water application are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

The 65% irrigation water together with high N rate of 150 kg N/ha increased the seed tuber yield to 40.5 and 44.9 t/ha, compared to 17.2 and 20.3 t/ha when 0 kg N/ha was applied together with the lowest irrigation water rate of 40% in RTrials I and II, respectively. However, irrespective of the irrigation water rate the seed potato tuber yields significantly increased with N application rate from 0 kg N/ha to 150 kg N/ha in RTrial I and 0 kg N/ha to 112.5 kg N/ha in RTrial II after which there were no significant increases. High compared to low N rate increased the seed potato yield by 13.7 and 15 t/ha in RTrials I and II, respectively. Similarly integration of irrigation water with P rates significantly increased seed potato tuber yield (Plate 4). Where 65% irrigation water was applied together with 0 kg P/ha compared to 101.2 kg P/ha, seed potato yield increased from 25.4 and 30.2 to 38.4 and 44.6 t/ha in RTrials I and II, respectively. In potatoes supplied with 40% irrigation water, the seed potato yield increased from 17.9 and 21.7 to 25.1 and 30.9 t/ha when 0 kg P/ha and 101.2 kg P/ha were applied in RTrials I and II, respectively (Table 17).

Plate 5: Effect of integration of irrigation water, N and P rates on seed potato tuber yields

Combination of N and P significantly increased seed potato yield. However, P application rate beyond 75.9 kg P/ha with low levels of N up to 75 kg N/ha did not significantly increase the seed potato yield. The higher P rate significantly increased total seed tuber yields compared to low P rate. Seed potato yield increased by 11.39 and 12.41 t/ha when high compared to low P rate was applied. Higher increases were observed where 75.9 kg P/ha and 101.2 kg P/ha were supplied with high N rates. Seed potato yield increased from 15.90 and 18.3 to 24.5 and 26.8 t/ha for 0 kg N/ha by 0 kg P/ha and 0 kg N/ha by 101.2 kg P/ha, and from 26.6 and 30.4 to 41.3 and 46.1 t/ha for 150 kg N/ha by 0 kg P/ha and 150 kg N/ha by 101.2 kg P/ha in RTrials I and II, respectively (Table 18).

Table 18: Effect of N and P rates on seed potato tuber yield

P rate	N rate (kg N/ha) in RTrial I					N rate (kg N/ha) in RTrial II				
(kg P/ha)	0	75	112.5	150	Mean	0	75	112.5	150	Mean
0	15.9c*	21.1c	24.4d	26.6d	21.9	18.3d	25.3c	31.9d	30.4d	26.5
50.6	19.3b	24.7b	29.3c	31.9c	26.3	23.2c	30.5b	35.7c	35.8c	31.3
75.9	23.3a	29.3a	35b	38b	31.4	28.4a	35.1a	43.4b	44.6b	37.9
101.2	24.5a	30.2a	37.6a	41.3a	33.5	26.8b	35.5a	47.2a	46.1a	38.9
Mean	20.7	26.3	31.6	34.4		24.2	31.6	39.5	39.3	
MSD (P)	1.4					1.3				
MSD (N)	1.4					1.3				
CV (%)	7.9					5.9				

*Means followed by the same letter(s) along the column for different N by P rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

4.3.3. Tuber grading

Size distribution of seed potato into different grades after harvest significantly depended on irrigation water, N and P application rates in both RTrials (Table 19). Integration of irrigation water and N significantly affected the ware, seed size II and chats distribution. Integration of W and P, as well as N and P affected the ware and seed size II, respectively in both RTrials (Appendices 23, 24, 25 and 26).

Ware seed potato tuber yield increased from 40% to 65% and was highest with 100% irrigation water (Plate 5). High compared with low irrigation water rate increased the ware potato by 4.3 and 5.1 t/ha in RTrials I and II, respectively. While the ware potato increased with increase in irrigation water rate, the seed size II, size I and the chats decreased beyond 65% irrigation water rate. Increased application of irrigation water beyond 65% reduced the seed size II yield by 2.5 and 2.9 t/ha, seed size I by 1.6 and 2.1 t/ha, and the chats by 0.7 and 1.8 t/ha in RTrials I and II, respectively. Therefore application of 100% irrigation water reduced yield of seed sizes II and I, as well as the chats. Highest seed sizes II and I yield were recorded with 65% and the least with the 40% irrigation water rates. The yield of chats increased with low irrigation water application at 40% compared to 100% (Table 19).

Integration of irrigation with N increased yield of seed per grade. Application of N from 0 to 150 kg N/ha increased the yield of ware, seed potato size II and I by 5.3 and 5.5 t/ha, 6.3 and 6.4 t/ha, and 3.8 and 5.4 t/ha, while the yield of chats reduced by 0.8 and 1.0 t/ha, irrespective of irrigation rate in RTrials I and II, respectively. However, application of N beyond 112.5 kg N/ha with 100% and 40% irrigation reduced seed size I (Table 19).

Integration of irrigation with P significantly increased seed potato yield across the grades. Increased P resulted in significant yield increases per size distributions (Table 20). The yield of ware, sizes II and I tubers increased with P application from 0 to 101.2 kg P/ha with 65% followed by 100% and 40% FC, respectively. However, P application rates beyond 75.9 kg P/ha reduced or stagnated seed size I, resulting to more production of seed size II. In addition, the higher P application rate from 0 kg P/ha to 101.2 kg P/ha reduced the yield of chats regardless of the irrigation water level. Application of P from 0 kg P/ha to 101.2 kg P/ha increased the yield of ware, seed potato size II and I by 4.7 and 4.6 t/ha, 4.7 and 5.3t/ha, and 3.9 and 5.2 t/ha, while the yield of chats reduced by 0.9 and 1.1 t/ha irrespective of irrigation water rate in RTrials I and II, respectively (Table 20).

Generally, integration of N and P rates did not significantly affect the production of ware, seed sizes II and I, and the chats in both RTrials.

40% irrigation water

65% irrigation water

100% irrigation water

Plate 6: Effect of irrigation water rate on seed potato tuber size distribution

4.3.4. Harvest index

The potato harvest index (HI) significantly depended on irrigation water, N and P rates and only interactive effects of P with N affected it in both RTrials (Appendix 27).

The HI significantly increased with increase in irrigation water application from 40% upto 65% beyond which it decreased with 100% irrigation water rate. High irrigation water rate at 100% compared with 65% decreased the HI by 5.3% and 4.9% in RTrials I and II, respectively. However, there were no significant differences between 40% and 100% irrigation water rates in RTrial I (Table 21).

The HI significantly increased with combined N and P application from 0 kg N/ha and 0 kg P/ha to 112.5 kg N/ha and 75.9 kg P/ha after which it decreased or remained constant with further application. Application N and P from 0 kg N/ha and 0 kg P/ha to 112.5 kg N/ha and 75.9 kg P/ha increased the seed potato HI by 8.5% both in RTrials I and II, respectively (Table 22). Increase in HI depended on combined increase in both N and P application rates.

Table 19: Effect of irrigation water and N rates on seed potato size distribution

RTrial I	Irrigation rate (100% FC)				Irrigation rate (65% FC)				Irrigation rate (40% FC)				Mean			
N rate (kg N/ha)	Ware	Size II	Size I	Chats	Ware	Size II	Size I	Chats	Ware	Size II	Size I	Chats	Ware	Size II	Size I	Chats
0	5.4d*	5.9d	9d	1.3a	4.2d	7.2d	10.1c	1.9a	2.4d	4.8d	7.8c	2.3a	3.9	5.9	8.9	1.8
75	8.2c	8.1c	10.7c	1.2a	6.1c	10.7c	11.9b	1.6b	4.3c	6.1c	8.2c	1.9b	6.2	8.3	10.3	1.6
112.5	9.7b	10.2b	13.3a	1a	7.8b	12.5b	14.2a	1.2c	5.1b	7.4b	10.9a	1.4c	7.7	9.9	12.8	1.2
150	12.2a	12.3a	11.4b	0.8b	9.2a	15.8a	14.7a	0.8d	6.3a	8.8a	9.7b	1.3c	9.3	12.3	11.9	0.9
Mean	8.9	9.1	11.1	1.1	6.8	11.6	12.7	1.4	4.5	6.7	9.1	1.7				
MSD (N)	0.8	0.6	0.9	0.2												
MSD(W)	0.7	0.4	0.8	0.2												
CV (%)	19.5	9.8	14.6	21.4												
RTrial II																
0	6.4d*	6.9d	9.9d	1.5a	5.1d	8.5c	11.7d	2.2a	2.8c	5.8d	9d	2.8a	4.8	7.1	10.2	2.2
75	9.9c	9.7c	12.3c	1.6a	7.4c	12.4b	14.1c	1.9b	5b	7.5c	10.8c	2.2b	7.4	9.9	12.4	1.9
112.5	12.1b	12.8b	15.6a	1.2b	9.7b	16.7a	17.7a	1.4c	6.5a	9.6b	13.5a	1.8c	9.7	12.8	15.6	1.5
150	13.1a	13.5a	13.9b	0.9c	10.5a	16.8a	16.6b	1d	6.9a	10.5a	12.5b	1.6c	10.3	13.4	14.3	1.2
Mean	10.4	10.7	12.9	1.3	8.2	13.6	15	1.6	5.3	8.3	11.4	2.1				
MSD (N)	0.6	0.7	0.9	0.2												
MSD(W)	0.4	0.6	0.7	0.2												
CV (%)	11.2	10.9	11.1	19.7												

*Means followed by the same letter(s) along the column for different irrigation water with N rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

Table 20: Effect of irrigation water and P rates on seed potato size distribution (t/ha)

RTrial I	Irrigation rate (100% FC)				Irrigation rate (65% FC)				Irrigation rate (40% FC)				Mean			
kg P/ha	Ware	Size II	Size I	Chats	Ware	Size II	Size I	Chats	Ware	Size II	Size I	Chats	Ware	Size II	Size I	Chats
0	5.6d*	6.6d	8.9c	1.5a	4.4d	8.8d	10.4c	1.7a	3.3c	4.7d	7.6c	2.4a	4.4	6.7	8.9	1.9
50.6	8.1c	8.2c	10.1b	1.2b	6.2c	10.9c	11.8b	1.5b	3.9bc	6.2c	8.6b	1.9b	6.1	8.5	10.2	1.6
75.9	9.9b	9.9b	13.1a	0.9c	7.6b	12.3b	14.6a	1.3c	4.8b	7.4b	10.9a	1.5c	7.4	9.9	12.9	1.2
101.2	11.3a	12.3a	12.3a	0.7d	9.1a	14.3a	14.1a	0.9d	6.1a	8.6a	9.4b	1.1d	9.2	11.4	11.9	0.9
Mean	8.7	9.3	11.1	1.1	6.8	11.6	12.7	1.4	4.5	6.7	9.1	1.7				
MSD (P)	0.8	0.6	0.9	0.2												
MSD(W)	0.4	0.6	0.7	0.2												
CV (%)	19.5	9.8	14.6	21.4												
RTrial II																
0	7.4d*	7.6d	10.7d	1.9a	5.7d	10.4d	12.1d	2a	3.8d	6.3d	8.9d	2.7a	5.6	8.1	10.5	2.2
50.6	9.5c	9.8c	11.9c	1.4b	7.5c	12.3c	14.2c	1.7b	4.9c	7.9c	10.4c	2.3b	7.4	9.9	12.2	1.8
75.9	11.5b	12b	15.3a	1.1c	8.9b	14.8b	17.9a	1.6c	5.8b	8.9b	13.9a	1.9c	8.9	11.7	15.7	1.5
101.2	13.3a	13.4a	13.8b	0.8d	10.6a	16.9a	15.9b	1.2d	6.7a	10.1a	12.7b	1.4d	10.2	13.4	14.1	1.1
Mean	10.4	10.7	12.9	1.3	8.2	13.6	15	1.6	5.3	8.3	11.4	2.1				
MSD (P)	0.6	0.7	0.9	0.2												
MSD(W)	0.4	0.6	0.7	0.2												
CV (%)	11.2	10.9	11.1	19.7												

*Means followed by the same letter(s) along the column for different irrigation water with P rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

Table 21: Effect of irrigation water rates on HI of seed potato

Irrigation water rate (% FC)	PTrial I	PTrial II
100	63.9b*	69.7c
65	69.2a	74.6a
40	64.6b	71.3b
MSD (W)	0.9	0.7
CV (%)	2.7	1.9

*Means followed by the same letter(s) along the column for different irrigation water, N and P rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. Interactions were not significant at $P \leq 0.05$. MSD = Minimum Significant Difference. Mean separation was done within each season.

Table 22: Effect of N and P rates HI of seed potato

	PTrial I				PTrial II			
P rate	N rate (kg N/ha)				N rate (kg N/ha)			
(kg P/ha)	0	75	112.5	150	0	75	112.5	150
0	61.2b*	63.6c	65.5b	65.8c	66.9c	70b	73.4b	70.9c
50.6	63a	64.9b	66.5b	66.9a	69.4b	72.1a	73.4b	71.7c
75.9	63.7a	67a	69.7a	69.5a	70.6a	72.7a	75.4a	74.8a
101.2	63.5a	64.3b	69a	69.2a	67.9c	70.9b	75.8a	73.9b
MSD (P)	1.1				0.9			
MSD (N)	1.1				0.9			
CV (%)	2.7				1.9			

*Means followed by the same letter(s) along the column for different N by P application rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

4.3.5. Specific density, starch and dry matter contents

The specific gravity, starch content and DM of seed potato significantly depended on irrigation water, N and P rates in RTrials I and II (Appendices 28 and 29). Irrigation water rate significantly decreased seed potato specific density, starch and dry matter contents of potato tubers (Table 23).

The specific density, starch and dry matter contents increased from 40% to 65% and decreased by 0.03, 2.6%, 3.7% and 0.04, 3.7%, 5.2% in RTrials I and II, respectively.

Table 23: Effect of irrigation water, N and P rates on seed potato specific gravity, starch and dry matter contents

	RTrial I			RTrial II		
Irrigation water rate (% FC)	Specific density	Starch (%)	Dry matter (%)	Specific density	Starch (%)	Dry matter (%)
100	1.07b*	13.2b	26.9b	1.07c	13.5c	27.3c
65	1.09a	15.8a	30.6a	1.1a	17.2a	32.5a
40	1.09a	15.3a	29.9a	1.09b	15.9b	30.8b
MSD (W)	0.01	1.3	1.8	0.01	0.7	0.9
N rate (kg N/ha)						
0	1.07b	13.3b	27.1b	1.08b	14.2b	28.3b
75	1.08ab	14.6ab	28.9ab	1.08b	15.1b	29.5b
112.5	1.09a	15.9a	30.8a	1.1a	16.8a	32a
150	1.09a	15.3a	29.8a	1.09a	16.2a	31.1a
MSD (N)	0.01	1.6	2.3	0.01	0.9	1.3
P rate (kg P/ha)						
0	1.06c	12.5c	25.8c	1.07c	13.9c	27.9c
50.6	1.08b	14.4b	28.6b	1.08bc	15b	29.5b
75.9	1.09a	16.2a	31.1a	1.09ab	16.2a	31.1a
101.2	1.09a	16.2a	31.1a	1.1a	17.1a	32.4a
MSD (P)	0.01	1.1	1.5	0.01	1	1.4
CV (%)	0.89	6.4	4.6	0.84	5.6	4.1

*Means followed by the same letter(s) along the column for different irrigation water, N and P application rates for specific gravity, starch and dry matter content are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. Interactions were not significant at $P \leq 0.05$. MSD = Minimum Significant Difference. Mean separation was done within each season.

Lowest specific density, starch and dry matter contents were observed with 100% followed by 40% and the highest was recorded with 65% irrigation water rate (Table 23).

Application of N and P significantly increased seed potato specific density, starch and dry matter contents. Higher rates of N and P led to higher levels of seed potato specific density, starch and dry matter contents in RTrials I and II. Specific density, starch and dry matter contents significantly increased with N rate up to 112.5 kg N/ha, after which they non-significantly reduced. Application of 150 kg N/ha compared to 112.5 kg N/ha reduced the specific density, starch and dry matter contents by 0.01, 0.7%, 0.9% and 0.01, 0.7%, 0.9% in RTrials I and II, respectively (Table 23).

Similarly P application significantly increased the seed potato specific density, starch and dry matter content up to 75.9 kg P/ha beyond which there was no significant increase at 101.2 kg P/ha. Overall, the lowest seed potato specific density, starch and dry matter content was 1.1, 12.5%, and 25.8% recorded with the lowest P application at 0 kg P/ha and the highest was 1.1, 17.2%, and 32.5% with 65% irrigation water (Table 23). Unlike high N and P application rates which were positively correlated to specific density, starch and dry matter content, a strong negative relationship was observed with 100% irrigation water.

4.3.6. Tissue N and P contents

Tuber N and P contents were significantly affected by the irrigation water, N and P rates and especially where irrigation and N rates were integrated (Appendices 30 and 31).

Application of P significantly increased the tissue N and P contents in seed potato tubers. Tuber tissue N increased from 3.29% and 3.59% to 3.55% and 3.99%, while tissue P increased from 0.27% and 0.29% to 0.32% and 0.34% with low P rate of 0 kg P/ha compared to high P rate of 101.2 kg P/ha in RTrials I and II, respectively. Therefore P rate from 0 kg P/ha compared to 101.2 kg P/ha increased the tissue N and P contents by 0.26% and 0.05% in RTrial I and 0.4% and 0.05% in RTrial II (Table 24).

Integration of irrigation water with N rates significantly increased the tissue N and P contents in seed potato tubers. However, 100% compared to 65% irrigation water rate significantly reduced the tuber tissue N and P contents. The 100% irrigation water application resulted in 2.59% and 2.94% N content, compared to 3.24% and 3.25% with 65% irrigation water supplied together with low N rate of 0 kg N/ha in RTrials I and II, respectively. Similarly, 100% irrigation rate reduced the tuber tissue P content to 0.18% and 0.22%, compared to 0.25% and 0.27% observed with 65% irrigation water supplied with low N rate of 0 kg N/ha in RTrials I and II, respectively (Table 24).

Increasing N from 0 to 150 kg N/ha regardless of irrigation water rate increased tissue N and P contents in the seed potato tubers. When 65% irrigation water rate was supplied together with 0 kg N/ha compared to 150 kg N/ha the tissue N and P contents increased by 1.36% and 0.18% in RTrial I and 1.51% and 0.17% in RTrial II (Table 25). However, regardless of irrigation water rate tuber tissue N and P contents increased with N application rate. Low tuber tissue N and P contents were observed with low N rate of 0 kg N/ha compared to high content, which resulted with 150kg N/ha rate within a given irrigation water rate (Table 25). Overall, the irrigation water, N and P application rates had significant effects on tuber N and P contents at harvest.

Table 24: Effect of P application rate treatments on tuber tissue N and P contents

	RTrial I		RTrial II	
P rate (kg P/ha)	Tissue N (%)	Tissue P (%)	Tissue N (%)	Tissue P (%)
0	3.29d*	0.27d	3.59d	0.29d
50.6	3.38c	0.28c	3.69c	0.3c
75.9	3.46b	0.3b	3.84b	0.32b
101.2	3.55a	0.32a	3.99a	0.34a
Mean	3.42	0.29	3.78	0.31
MSD (P)	0.04	0.01	0.05	0.01
CV (%)	1.73	5.1	1.93	3.7

*Means followed by the same letter(s) along the column for different P rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

4.3.7. Water and nutrient use efficiencies

4.3.7.1. Water use efficiency

Water use efficiency (WUE) significantly depended on all tested factors. Integrating N with either irrigation or P significantly affected WUE (Appendix 32). High irrigation water alone depressed WUE, which was 10.8 and 12.7 kg/m^3 where 100% irrigation water was supplied compared to 16.9 and 20.8 kg/m^3 obtained with low irrigation water in RTrials I and II, respectively. Low irrigation water at 40% followed by 65% had the highest while 100% had the least WUE. High irrigation water at 100% compared to 40% reduced WUE by 6.1 and 8.1 kg/m^3 (Figure 6). Application of N irrespective of irrigation rate increased WUE from 0 to 150 kg N/ha both in RTrials I and II, respectively. The higher WUE was recorded when either of the irrigation rate was combined with high N rate at 150 kg N/ha. The lowest WUE was recorded when 100% irrigation rate was integrated with the lowest N rate at 0 kg N/ha in both RTrials. Contrary to irrigation, application of both N and P significantly increased WUE. N and P rates increased WUE from 8.5 and 9.8 kg/m^3 to 14.1 and 16.2 kg/m^3 observed with low compared to high rates in RTrials I and II, respectively (Table 26).

Nitrogen rate irrespective of P rate improved WUE. Increasing N from 0 to 150 kg N/ha increased WUE from 11.1 and 12.9 kg/m^3 to 18 and 20.7 kg/m^3, which was equivalent to 7.1 and 7.9 kg/m^3 in RTrials I and II, respectively. Similarly, application of P from 0 to 101.2 kg P/ha increased WUE irrespective of N rate from 11.7 and 14 kg/m^3 to 17.4 and 20.5 kg/m^3, which was equivalent to 5.8 and 6.5 kg/m^3 in RTrials I and II, respectively (Table 26).

Table 23: Effect of irrigation water and N rates on tuber tissue N and P contents

RTrial I	Irrigation water (% FC)	Tissue N N rate (kg N/ha)					Tissue P N rate (kg N/ha)				
		0	75	112.5	150	Mean	0	75	112.5	150	Mean
	100	2.59d*	2.85c	3.21b	3.54a	3.05	0.18d	0.23c	0.27b	0.33a	0.25
	65	3.24d	3.49c	3.78b	4.1a	3.65	0.25d	0.3c	0.36b	0.43a	0.33
	40	3.14d	3.41c	3.69b	3.99a	3.56	0.21d	0.26c	0.31b	0.38a	0.29
	Mean	2.99	3.25	3.56	3.88		0.21	0.26	0.31	0.38	
	MSD (N)	0.04					0.01				
	MSD (W)	0.03					0.01				
	CV (%)	1.73					5.1				
RTrial II											
	100	2.94d	3.27c	3.62b	4.09a	3.48	0.22d	0.25c	0.29b	0.35a	0.28
	65	3.25d	3.67c	4.22b	4.76a	3.98	0.27d	0.31c	0.36b	0.44a	0.34
	40	3.15d	3.59c	4.09b	4.67a	3.88	0.24d	0.29c	0.34b	0.39a	0.31
	Mean	3.11	3.51	3.98	4.51		0.24	0.28	0.33	0.39	
	MSD (N)	0.05					0.01				
	MSD (W)	0.04					0.01				
	CV (%)	1.93					3.7				

*Means followed by the same letter(s) along the row for different irrigation water with N rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

WUE was greatly reduced by low N and P rates, while it was increased with integrated high rates (Table 26).

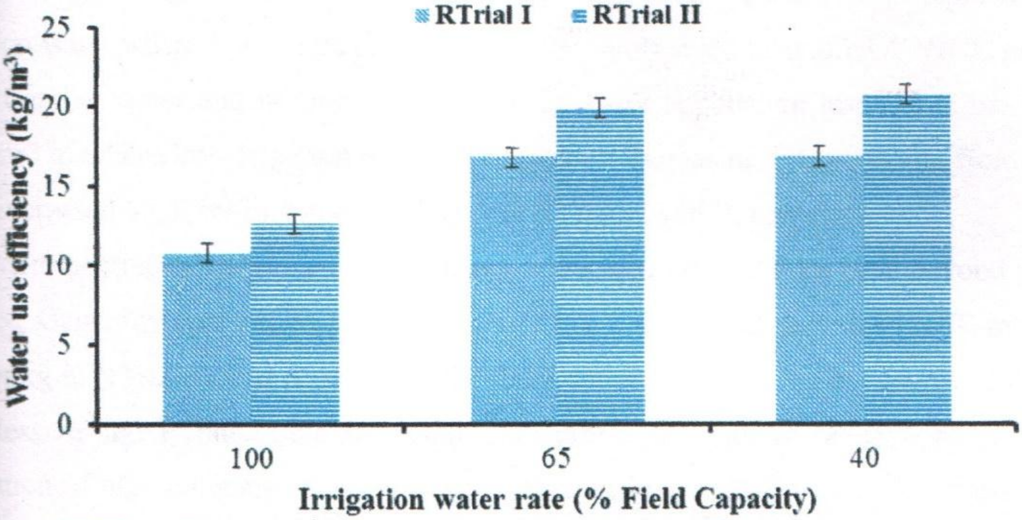


Figure 6: Effect of irrigation water rate on potato water use efficiency

Table 26: Effect of N and P rates on potato water use efficiency

RTrial I	P rate (kg P/ha)				Irrigation water (% FC)		
N rate (kg N/ha)	0	50.6	75.9	101.2	100	65	40
0	8.5d*	10.3d	12.3d	13.1d	7.7d	12.2d	13.1d
75	11.1c	12.9c	15.4c	15.7c	10.1c	15.8c	15.6c
112.5	12.9b	15.3b	18.5b	19.5b	12.3b	18.5b	18.9b
150	14.1a	16.8a	19.9a	21.4a	13.2a	21a	19.9a
MSD	0.8 (N)	0.8 (P)	0.6 (W)				
CV (%)	8.4						
RTrial II							
0	9.8c	12.4c	15.1d	14.1c	8.9c	14.3c	15.5c
75	13.3b	16.2b	18.7c	18.6b	11.9b	18.6b	19.5b
112.5	16.8a	18.8a	22.8b	24.9a	14.9a	23.6a	23.9a
150	16.2a	18.9a	23.5a	24.3a	14.8a	23.3a	24.1a
MSD	0.8(N)	0.8 (P)	0.6 (W)				
CV (%)	6.9						

*Means followed by the same letter(s) along the column for different P or irrigation rates by N rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

4.3.7.2. Nitrogen use efficiency

Irrigation water, N and P rates significantly affected NUE. Integrating N or P with irrigation water significantly affected NUE (Table 27; Appendix 33). Application of irrigation water where low N rate of 0 kg N/ha was supplied led to zero NUE. NUE increased with irrigation water and N rates. High irrigation water application resulted to better NUE compared to where low irrigation water was supplied. Increasing irrigation rate from 40% to 100% increased NUE by 14.4 and 13.3 kg/kg in RTrials I and II, respectively.

Irrespective of irrigation rate, N increased NUE up to 112.5 kg N/ha beyond which it declined. Generally application of N beyond 112.5 to 150 kg N/ha decreased NUE by 1.9 and 14.5 kg/kg in RTrials I and II, respectively. Application of N and P also improved the NUE regardless of the P rate. Like irrigation, application of P alone reduced NUE to zero. Integration of high compared to low N and P rates improved NUE. Increasing P rate from 0 to 101.2 kg P/ha regardless of N rate increased NUE from 21.7 and 28.2 kg/kg to 30.5 and 42.7 kg/kg, which was equivalent to 8.8 and 14.5 kg/kg in RTrials I and II, respectively. The highest NUE was recorded when 112.5 kg N/ha was integrated with 101.2 kg P/ha. Regardless of P rate, high N rate of 150 kg N/ha reduced NUE in both RTrials (Table 27).

4.3.7.3. Phosphorus use efficiency

Irrigation, N and P rates significantly affected the phosphorus use efficiency (PUE). Furthermore, integrating N or P with irrigation water significantly affected PUE (Table 28; Appendix 34). Application of irrigation water, N and P increased PUE. Increasing irrigation water rate from 40% to 100% and N rate from 0 to 150 kg N/ha significantly increased PUE from 48.9 and 63.8 kg/kg to 122.3 and 133.3 kg/kg, which was equivalent to 73.4 and 69.5 kg/kg in RTrials I and II, respectively (Table 28). Therefore, integration of irrigation and N rates increased PUE.

Further integrated application of N and P greatly increased the PUE. The PUE increased from 0 kg/kg observed with 0 kg P/ha and 0 kg N/ha to 150.8 and 186.6 kg/kg that resulted from combined application of 75.9 kg P/ha and 150 kg N/ha in RTrials I and II, respectively. Application of P increased PUE and regardless of N rate, low P at 0 kg P/ha led to zero PUE. PUE increased with combined N and P rate from 0 to 75.9 kg P/ha beyond which additional P to 101.2 kg P/ha decreased PUE by 5.5 and 49.9 in RTrials I and II, respectively (Table 28).

Combined application of irrigation water and P also resulted to high potato PUE. Application of 100% irrigation water together with 75.9 kg P/ha compared with 40%

irrigation water and 0 kg P/ha increased the PUE by 148 and 162.4 kg/kg. Irrespective of irrigation water rate, 0 kg P/ha application resulted to zero PUE (Table 29)

Table 27: Effect of irrigation water, N and P rates on potato NUE

N rate (kg N/ha)	Irrigation water (% FC) 100	65	40	Mean	P rate (kg P/ha) 0	50.6	75.9	101.2	Mean
Trial I									
0	0c*	0c	0c	0	0b	0c	0c	0c	0
75	35.1b	36.9b	17.3b	29.8	27.9a	28.8b	32.1b	30.4b	29.8
112.5	44.8a	43.6a	27.3a	38.6	30.2a	35.6a	41.9a	46.6a	38.6
150	40.4a	45.6a	23.9a	36.6	28.6a	33.7a	39.5a	44.8a	36.6
Mean	31.5	30.1	17.1		21.7	24.5	28.4	30.5	
MSD	4.8 (N, P)	3.8 (W)							
CV (%)	15.2								
Trial II									
0	0c	0c	0c	0	0c	0c	0c	0d	0
75	46.1b	44.7b	28.3b	39.7	35.7b	37.3b	39.5b	46.3c	39.7
112.5	60.2a	64.6a	39.3a	54.8	44.7a	48.4a	53.3a	72.8a	54.8
150	44.2b	46.8b	29.9b	40.3	32.4b	33.9b	43.3b	51.7b	40.3
Mean	37.7	39	24.4		28.2	29.9	34	42.7	
MSD (N)	5.4 (N, P)	4.3 (W)							
CV (%)	14.5								

*Means followed by the same letter(s) along the column for different irrigation water and P are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

4.3.8. Economic analysis

The net economic benefit (NEB) significantly depended on irrigation, N and P rates. Combination of irrigation water with either N or P, and that of N and P also influenced the gross benefit of seed potato production per unit area (Appendix 35). Irrigation water and N rates significantly increased the NEB of seed potato production enterprise from Ksh. 260,928 and 332,046 when low irrigation water rate of 40% was integrated with low N application rate of 0 kg N/ha, compared to Ksh 738,199 and 877,021 obtained with integration of 65%

irrigation water rate and high N application rate of 112.5 kg N/ha in RTrials I and II, respectively (Table 30).

Table 28: Effect of irrigation water, N and P rates on potato PUE

RTrial I	Irrigation water (% FC)			P rate (kg P/ha)			
kg N/ha	100	65	40	0	50.6	75.9	101.2
0	71.6b*	66.3b	48.9a	0a	66.8b	97.2c	85.2c
75	77.5b	72.3b	50.3a	0a	69.8b	107.3b	89.7b
112.5	111.5a	105.8a	59.2a	0a	97.1a	140.7a	130.8a
150	122.3a	123a	55.3a	0a	104.7a	150.8a	145.3a
MSD	17.5 (N, P)	13.8 (W)					
CV (%)	20						
RTrial II							
0	89.5bc	80.7b	63.8a	0a	95.3a	132.8c	83.9d
75	79.4c	94.1b	75.9a	0a	103.4a	128.7d	100.5c
112.5	93.1b	124.3a	79.8a	0a	74.8b	151.1b	170.3a
150	133.3a	123.3a	65.8a	0a	106.5a	186.6a	136.7b
MSD	15.9 (N, P)	12.6 (W)					
CV (%)	14.8						

*Means followed by the same letter(s) along the column for different irrigation water and P rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

Table 29: Effect of irrigation water and P rates on potato PUE

Irrigation	P rate (kg P/ha) in **RTrial I**				P rate (kg P/ha) in **RTrial I**			
(% FC)	0	50.6	75.9	101.2	0	50.6	75.9	101.2
100	0.0c*	96.7b	148a	138a	0.0d	97.4c	162.4a	135.5b
65	0.0c	101.3b	136.6a	129.5a	0.0d	109c	171.1a	142.2b
40	0.0c	55.8b	87.3a	70.7ab	0.0c	78.5b	115.9a	90.9b
MSD	17.5 (P)	13.8 (W)			15.9 (P)	12.6 (W)		
CV (%)	20				14.8			

*Means followed by the same letter(s) along the row for different irrigation water and P rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

Table 30: Effect of irrigation water, N and P rates on seed potato net economic benefit (Ksh)

RTrial I	N rate (kg N/ha)				P rate (kg P/ha)			
Irrigation rate (% FC)	0	75	112.5	150	0	50.6	75.9	101.2
100	215365c*	320247b	449208b	447944b	218305b	299293b	453978b	461187b
65	362278a	510025a	738199a	633455a	403935a	510964a	681385a	647674a
40	260928b	295984b	423101b	410775c	240824b	316050b	428793b	405121c
MSD (W)	28788							
MSD (N)	36533							
MSD (P)	36533							
CV (%)	13.96							
RTrial II								
100	274545c	422706c	602229b	561626b	309519b	401614b	577916b	572058b
65	454736a	637742a	877021a	834344a	509966a	634901a	836000a	822975a
40	332046b	432665b	576698c	558864b	329456b	427336b	578472b	565010b
MSD (W)	28991							
MSD (N)	36790							
MSD (P)	36790							
CV (%)	10.9							

*Means followed by the same letter(s) along the column for different irrigation water with N and P rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

NEB significantly increased with integrated application of irrigation water and N rate from 40% up to 65% FC, after which it slightly declined with 100% FC irrigation rate and increased application of N beyond 112.5 kg N/ha. Integration of 65% compared to 40% irrigation water with 112.5 kg N/ha increased the seed potato NEB by KSh. 315,098 and 300,323. Increasing the irrigation water beyond 65% to 100% FC together with 112.5 kg N/ha decreased the seed potato NEB by KSh. 288,991 and 274,792 in RTrials I and II, respectively. A low NEB was recorded when 100% and 40% irrigation rates were integrated with low and high N application rates, respectively (Table 30).

Similarly application of irrigation water from 40% to 65% FC together with P from 0 up to 75.9 kg P/ha increased the seed potato NEB beyond which it reduced. The highest NEB of the seed potato production enterprise of Ksh 681,385 and 836,000 resulted from integrated application of 65% irrigation water and 75.9 kg P/ha compared to the lowest which was Ksh. [illegible],305 and 309,519 obtained with integration of 100% irrigation water and 0 kg P/ha. Increased integration of irrigation water from 40% to 65% FC together with P application rate from 0 to 75.9 kg P/ha increased the NEB by Ksh 252,592 and 257,528 in RTrials I and II, respectively (Table 30).

Integration of N and P also significantly increased the seed potato production enterprise NEB. The highest NEB was Ksh 661,747 and 847,727 that resulted from integrated application of 101.2 kg P/ha and 112.5 kg N/ha. Increasing N and P application from 0 kg P/ha and 0 kg N/ha to 101.2 kg P/ha and 112.5 kg N/ha increased the NEB by Ksh. 490, 210 and 619,591 in RTrials I and II, respectively (Table 31).

4.4. Effects of Irrigation Water, N and P Rates on Postharvest Physiological Characteristics of Seed Potato Tubers and Their Resultant Growth

4.4.1. Seed potato tuber relative weight loss

The relative weight loss of seed potato tubers at 90 days after storage (90 DAS) significantly depended on irrigation water, N and P rates. Integration of irrigation water with either N or P also significantly influenced the relative weight loss of the seed potato tubers. Slight differences were also observed from combination of N and P rates in both PTrials I and II (Appendix 36).

A lower relative weight loss during storage was observed with low irrigation water rate of 40% compared to 65% and 100%. A relative weight loss of 12.4% and 10.5% was observed with high compared to 7.5% and 5.9% for low irrigation water rate both in PTrials I and II, respectively (Table 32).

Table 31: Effect of integrated N and P rates on seed potato net economic benefit (Ksh)

PTrial I	N rate (kg N/ha) in			
P rate (kg P/ha)	0	75	112.5	150
0	171537c*	256139c	358061c	472813c
50.6	234779b	347036b	447114b	365016b
75.9	350134a	461469a	599341a	629649a
101.2	361645a	437029a	661747a	603170a
MSD (P)	36533			
MSD (N)	36533			
CV (%)	13.96			
PTrial II				
0	228136d	350748c	515291d	437747c
50.6	310829c	478364b	595218c	567391b
75.9	471690a	593657a	783027b	808142a
101.2	404448b	568049a	847727a	793166a
MSD (P)	36790			
MSD (N)	36790			
CV (%)	10.9			

*Means followed by the same letter(s) along the column for different N by P rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

The 100% compared to 40% irrigation water rates together with 0 kg N/ha increased the relative weight loss at 90 DAS. Nitrogen decreased the relative weight loss of seed potato tubers regardless of the irrigation water rate (Table 32). Weight loss decreased from 12.4% and 10.5% with low N rate of 0 kg N/ha to 9.9% and 7.8% with high N rate of 150 kg N/ha, when supplied with 100% irrigation water rate in PTrials I and II, respectively. With low irrigation water rate, weight loss reduced from 7.5% and 5.9% to 7.1% and 5.4% both with the low and high N rates of 0 and 150 kg N/ha, respectively. Greater reduction in weight loss resulted with high compared to low irrigation water rate when high N rate of 150 kg N/ha was supplied. However, significant decrease in weight loss was only evident where high irrigation water rate was supplied. Application of high N rate did not significantly decrease the weight loss of seed potato tubers where 40% and 65% irrigation water rates were supplied (Table 32).

Table 32: Effect of irrigation water, N and P rates on relative weight loss (%) of seed potato tubers at 90 DAS

		N rate (kg N/ha)					P rate (kg P/ha)				
PTrial I		0	75	112.5	150	Mean	0	50.6	75.9	101.2	Mean
Irrigation (% FC)	100	12.4a*	11.3ab	10.7bc	9.9c	11.1	12.7a	11.2b	10.6c	9.8d	11.1
	65	9.3a	9.2a	8.8a	8.7a	8.9	9.4a	8.9b	8.9b	8.8b	8.9
	40	7.5a	7.4a	7.1a	7.1a	7.3	7.6a	7.4a	7.1b	6.9b	7.3
Mean		9.7	9.3	8.9	8.6		9.9	9.2	8.9	8.5	
MSD		1.4(N)	0.5 (P)	1.1 (W)							
CV (%)		3.7									
PTrial II											
Irrigation (% FC)	100	10.5a	9.3ab	8.7bc	7.8c	9.1	11.1a	9.1b	8.3c	7.9c	9.1
	65	7.3a	6.8a	6.5a	6.4a	6.7	7.5a	6.8b	6.6b	6.1c	6.7
	40	5.9a	5.6a	5.5a	5.4a	5.6	6.8a	5.3b	5.2b	5.1b	5.6
Mean		7.9	7.2	6.9	6.6		8.4	7.1	6.7	6.4	
MSD		1.4 (N)	0.5 (P)	1.1(W)							
CV (%)		5.9									

*Means followed by the same letter(s) along the row for N and P rates by irrigation water rate are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. FC= Field Capacity. Mean separation was done within each season.

Similarly, P application decreased the relative weight loss of seed tubers regardless of the irrigation water rate. The relative weight loss of seed tubers decreased with increases in P rate. However, significant differences between the P rates were only evident with 100% irrigation water rate. With 40% and 65% irrigation water rates, significant decrease was only evident up to 50.6 kg P/ha after which high rate of P up to 75.9 and 101.2 kg P/ha did not significantly decrease the relative weight loss of seed potato tubers. Like N application, greater reduction in relative weight loss was observed when high P was combined with high irrigation water rate (Table 32).

4.4.2. Seed tuber firmness

Seed potato firmness (kgf) or softness at harvest was significantly dependent on the effects of irrigation water, N and P application. There were no consistent effects on the integration of the irrigation water, N and P application in both PTrials (Appendix 37).

Similarly irrigation water, N and P application significantly affected the firmness of the seed potato tubers 90 DAS. In storage, integration of N and P significantly affected the seed potato firmness (Appendix 38).

Irrigation water application significantly decreased the seed potato firmness at harvest from 10.4 and 11.4 kgf with 40% application to 9.2 and 10.2 kgf with 100%, an equivalent decrease of 1.2 and 1.3 kgf in PTrials I and II, respectively (Table 33). Potatoes which received 40% irrigation water had more firm seeds compared to those supplied with 100%. In contrast, while high irrigation water application decreased the seed potato firmness, N and P application significantly increased their firmness. Application of high N rate at 112.5 kg N/ha compared with low N rate of 0 kg N/ha increased the seed potato firmness to 10.1 and 11.2 kgf from 9.5 and 10.3 kgf an equivalent increase of 0.6 and 0.9 kgf in PTrials I and II, respectively. However, high N application from 112.5 kg N/ha to 150 kg N/ha significantly decreased the seed potato firmness.

Application of P also increased the seed potato firmness from 9.1 and 9.9 kgf with 0 kg P/ha and a constant increase was observed up to 10.6 and 11.6 kgf with high rate of 101.2 kg P/ha, which was an increase in firmness by 1.5 and 1.6 kgf both in PTrials I and II, respectively (Table 33). Furthermore, firmness of the seed potato was also significantly dependent on the irrigation water supplied in the field. After 90 days storage, potatoes which were supplied with high irrigation water were less firm compared to those which received less irrigation water. The 100% irrigation rate had a firmness of 5.9 and 6.7 kgf compared to [illegible] and 8.1 kgf observed with 40% irrigation rate in PTrials I and II, respectively. High compared to low irrigation rate led to reduction of the seed potato firmness after storage by 1.7 and 1.5 kgf in PTrials I and II, respectively (Figure 7).

Application of N and P fertiliser also maintained the firmness of seed potato tubers at 90 DAS. However, application of high N rates of 112.5 to 150 kg N/ha regardless of P rate led to a decrease in the seed potato tuber firmness by 0.1 and 0.3 kgf after storage in PTrials I and II. In contrast, high P rates significantly enabled the seed potato tubers to remain firm even after storage. Regardless of N rate, better firmness was observed in seed potato tubers where 101.2 kg P/ha was applied compared to 0 kg P/ha. High compared to low application of P maintained the seed potato tuber firmness at 90 DAS by 1.2 and 1.8 kgf in PTrials I and II, respectively (Table 34).

Table 33: Effect of irrigation water, N and P rates on seed potato firmness (kgf) at harvest

Irrigation water rate (% FC)	PTrial I	PTrial II
100	9.2c*	10.2c
65	9.8b	10.8b
40	10.4a	11.4a
MSD (W)	0.2	0.2
N rate (kg N/ha)		
0	9.5c	10.3d
75	9.8b	10.7c
112.5	10.1a	11.2a
150	9.8b	11b
MSD (N)	0.3	0.2
P rate (kg P/ha)		
0	9.1d	9.9d
50.6	9.6c	10.6c
75.9	10b	11b
101.2	10.6a	11.6a
MSD (P)	0.3	0.2
CV (%)	4.6	3.1

*Means followed by the same letter(s) for each trial and factor are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. Interactions were not significant at $P \leq 0.05$. MSD = Minimum Significant Difference. FC= Field Capacity. Mean separation was done within each season.

4.4.3. Seed tuber total soluble solids concentration (%)

Seed potato tuber total soluble solids (TSS) significantly depended on the irrigation water, N or P rates or either of their combinations at harvest (Appendix 39). Furthermore, 40DAS seed potato TSS significantly depended on the irrigation water, N or P rates. However, integration of the irrigation water with either N or P, or N with P combination did not significantly affect the seed potato tuber TSS in both PTrials I and II (Appendix 40).

Irrigation water application decreased the TSS in seed potato tubers across all N rates. High irrigation rate of 100% decreased the TSS to 5.5% and 5.5% compared to 40% which increased the TSS to 6.0% and 6.1% when low N rate of 0 kg N/ha was supplied in PTrials I and II, respectively (Table 35).

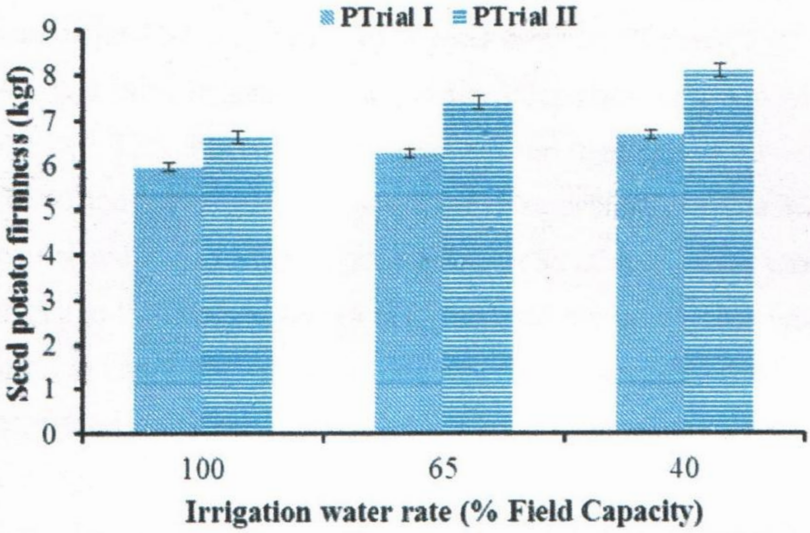


Figure 7: Effect of irrigation water rate on seed potato firmness (kgf) at 90 DAS

Table 34: Effect of N and P rates on seed potato firmness (kgf) at 90 DAS

	PTrial I					PTrial II				
P rate	N rate (kg N/ha)					N rate (kg N/ha)				
(kg P/ha)	0	75	112.5	150	Mean	0	75	112.5	150	Mean
0	5.4d*	5.6d	5.9d	5.6d	5.7	5.4d	5.7d	7.6d	7.2d	6.5
50.6	6c	6.1c	6.2c	6.2c	6.2	6.1c	6.8c	8.1c	7.8c	7.2
75.9	6.5b	6.6b	6.7b	6.5b	6.6	6.8b	7.1b	8.4b	8.1b	7.6
101.2	6.9a	6.8a	6.9a	6.8a	6.9	7.6a	7.9a	8.9a	8.6a	8.3
Mean	6.2	6.3	6.4	6.3		6.5	6.9	8.3	7.9	
MSD (P)	0.1					0.2				
MSD (N)	0.1					0.2				
CV (%)	2.9					3.8				

*Means followed by the same letter(s) along the column for different N by P application rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

Regardless of N rate, high compared to low rate reduced the TSS by 0.3% and 0.3% in PTrials I and II. Nitrogen significantly increased the TSS regardless of irrigation rate progressively from 0 to 150 kg N/ha, except with 100% irrigation water where non-significant increase was observed. However, higher increases in TSS were recorded with 40% followed by 65% irrigation water rate. Across all N application rates, 100% irrigation water recorded the lowest TSS both in PTrials I and II. Similarly, P rates from 0 to 101.2 kg P/ha significantly increased the TSS, regardless of irrigation water. Highest TSS was recorded with 101.2 kg P/ha and 40% irrigation water, while integration of 0 kg P/ha and 100% irrigation had the lowest TSS. Regardless of irrigation rate high compared with low P rate increased TSS by 0.9% and 0.8% both in PTrials I and II, respectively (Table 35).

Integration of N and P significantly increased the TSS of seed potato tubers. Increased application of both N and P from low to high rate increased the seed potato tubers TSS from 5.3% and 5.5% to 6.7% and 7.1%, which was an equivalent increase of 1.4% and 1.6% in PTrials I and II, respectively. The seed potato TSS progressively increased with integration of N and P rates (Table 36).

After 90 days storage the TSS reduced compared with that recorded at harvest. TSS decrease at 90DAS significantly depended on individual effects of irrigation water, N and P rates. High irrigation water rate of 100% significantly decreased the seed potato TSS to 4.4% and 4.7% compared to 5.5% and 5.7% recorded with 40% irrigation water rate in PTrials I and II, respectively. However, contrary to high irrigation rate, which led to reduction of TSS in storage, high rate of either N or P from 0 to 150kg N/ha and 0 kg P/ha to 101.2kg P/ha significantly maintained the TSS in both PTrials (Table 37).

4.4.4. Seed potato tuber sprouting characteristics

After 90 days of storage, sprouting capacity of seed potato tubers significantly depended on the individual effects of irrigation water, N and P rates, but was not affected by their combinations (Plate 6, Appendix 41). The sprout length other than being significantly dependent on irrigation, N and P rates was also affected by the integration of irrigation water and P rates (Appendix 42).

Irrigation water rate significantly decreased the number of sprouts and percentage sprouting. High irrigation rate of 100% reduced the number of sprouts to 3.8 and 4.7, compared to intermediate irrigation water rate of 65%, which increased them to 4.7 and 5.7, which was equivalent to 0.9 and 1.1 sprouts reduction in PTrials I and II, respectively. Irrigation water rate of 100% had 58.9% and 66.4% sprouting compared to intermediate irrigation water rate of 65%, which had 67.3% and 81.6% sprouting in PTrials I and II, respectively. Nitrogen significantly increased the number of sprouts and the percentage sprouting of seed potato tubers (Table 38).

Application of N from 0 to 150 kg N/ha significantly increased the number of sprouts from 3.8 and 4.6 to 4.8 and 5.5, and sprouting from 54.8% and 66.3% to 68.7% and 78.6% in

PTrials I and II, respectively. However, non-significant increases were observed between 0 and 75 kg N/ha, and between 112.5 and 150 kg N/ha in both PTrials.

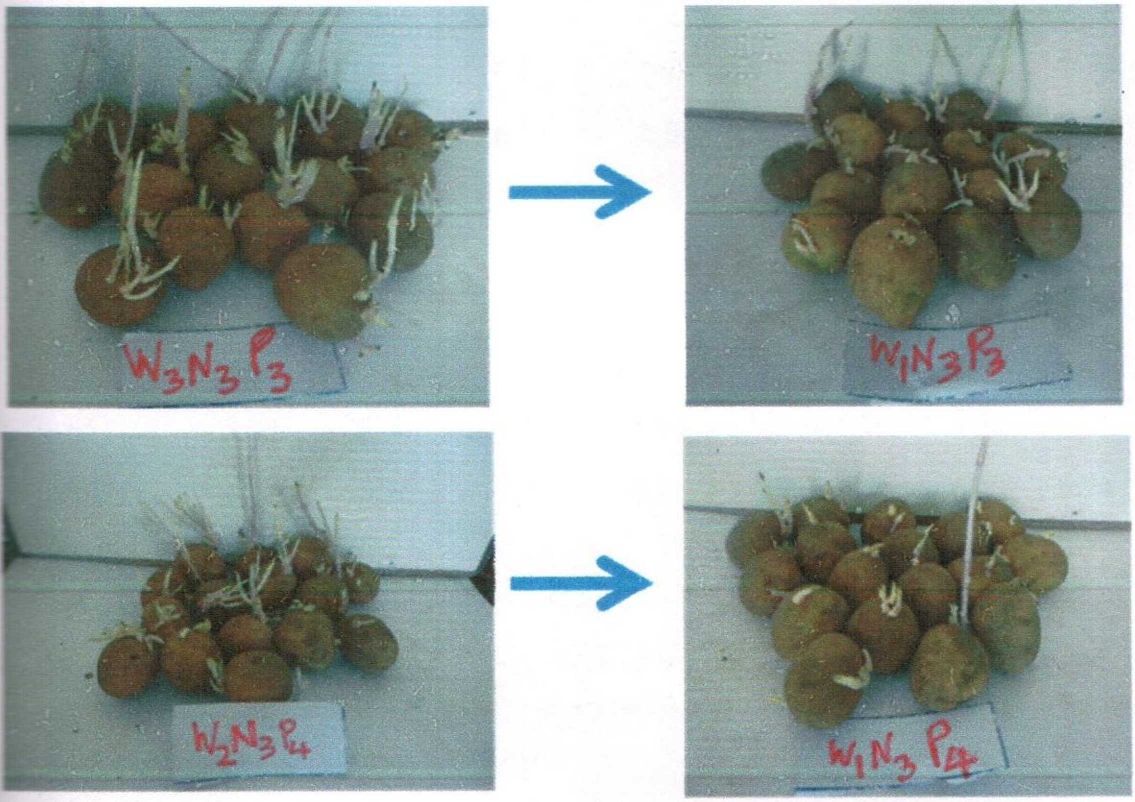


Plate 7: Effect of irrigation water, N and P rates on seed potato tuber sprouting characteristics

Increase of P rate from 0 to 101.2 kg P/ha also significantly increased the number of sprouts and the percentage sprouting of seed potato tubers. The number of sprouts increased from 3.8 and 4.5 to 4.8 and 5.7, and sprouting from 53.6% and 64.7% to 67.9% and 81.4% with 0 and 101.2 kg P/ha in both PTrials (Table 38). Comparatively, higher sprout numbers and a better percentage sprouting were observed in PTrial II compared to PTrial I, regardless of irrigation, N and P rates (Table 38).

Table 35: Effect of irrigation water, N and P rates on seed potato total soluble solids content (%) at harvest

Irrigation (% FC)	N rate (kg N/ha)				P rate (kg P/ha)			
PTrial I	0	75	112.5	150	0	50.6	75.9	101.2
100	5.5c*	6b	6.2a	6.2a	5.5d	5.8c	6b	6.3a
65	5.7c	6b	6.2a	6.2a	5.6d	5.9c	6.2b	6.4a
40	6c	6.2b	6.3b	6.5a	5.7c	6.2b	6.6a	6.7a
MSD	0.1(N)	0.1 (P)	0.1 (W)					
CV (%)	3.8							
PTrial II								
100	5.5c	6.2b	6.4a	6.4a	5.9d	6.1c	6.2b	6.5a
65	5.8d	6.3c	6.4b	6.5a	5.9d	6.2c	6.3b	6.6a
40	6.1d	6.3c	6.5b	6.8a	5.8d	6.3c	6.6b	6.9a
MSD	0.1(N)	0.1 (P)	0.1 (W)					
CV (%)	2.4							

*Means followed by the same letter(s) along the row for different N and P rates with irrigation water are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

Table 36: Effect of N and P rates on seed potato total soluble solids content (%) at harvest

	PTrial I				**PTrial II**			
P rate	N rate (kg N/ha)				N rate (kg N/ha)			
(kg P/ha)	0	75	112.5	150	0	75	112.5	150
0	5.3c*	5.7d	5.6d	5.7d	5.5d	6d	5.9dd	5.9d
50.6	5.7b	5.9c	6c	6.3c	5.7c	6.2c	6.3c	6.4c
75.9	5.9a	6.2b	6.4b	6.6b	5.9b	6.3b	6.4b	6.8b
101.2	5.9a	6.4a	6.7a	6.7a	6a	6.5a	7a	7.1a
MSD	0.1(N)	0.1 (P)			0.1(N)	0.1 (P)		
CV (%)	3.8				2.4			

*Means followed by the same letter(s) along the column for different N by P application rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

Table 37: Effect of irrigation water, N and P application rate treatments on seed potato total soluble solids concentration at 90 DAS

Irrigation water (% FC)	PTrial I	PTrial II
100	4.4c*	4.7c
[illegible]	4.8b	5.2b
[illegible]	5.5a	5.7a
MSD (W)	0.1	0.1
N rate (kg N/ha)		
0	4.6d	4.9d
75	4.8c	5.1c
112.5	5b	5.3b
150	5.3a	5.5a
MSD (N)	0.1	0.1
P rate (kg P/ha)		
0	4.4d	4.8c
[illegible]	4.9c	5.2b
[illegible]	5.1b	5.3a
[illegible]	5.2a	5.4a
MSD (P)	0.1	0.1
CV (%)	3.4	2.4

*Means followed by the same letter(s) along the column for different irrigation water, N and P rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. Interactions were not significant at $P \leq 0.05$. MSD = Minimum Significant Difference. Mean separation was done within each season.

Increasing N rate from 0 to 150 kg N/ha significantly increased the seed potato sprout length from 7.8 and 3.2 cm with 0 kg N/ha to 12.0 and 5.63 cm with high N rate at 150 kg N/ha in both Trials (Figure 8). However, higher sprout length was observed in PTrial I compared to PTrial II regardless of irrigation, N or P rates. Overall, lower number of sprouts and percentage sprouting were observed with high irrigation water rate when coupled with lower rates of both N and P fertiliser in both PTrials I and II, respectively ($P \leq 0.05$).

Table 38: Effect of irrigation water, N and P rates on sprouts and sprouting percentage

	Number of sprouts		Percentage sprouting	
Irrigation water (% FC)	**PTrial I**	**PTrial II**	**PTrial I**	**PTrial II**
100	3.8c*	4.7c	53.9c	66.4c
65	4.7a	5.7a	67.3a	81.6a
40	4.3b	5.1b	61.3b	72.3b
MSD (W)	0.2	0.2	2.9	2.9
N rate (kg/ha)				
0	3.8c	4.6c	54.8c	66.3c
75	4.1c	5.1b	57.9c	72.2b
112.5	4.3b	5.4a	61.9b	76.6a
150	4.8a	5.5a	68.7a	78.6a
MSD (N)	0.3	0.3	3.6	3.8
P rate (kg/ha)				
0	3.8d	4.5d	53.6d	64.7d
50.6	4.1c	5c	58.3c	71.4c
75.9	4.4b	5.3b	63.5b	76.2b
101.2	4.8a	5.7a	67.9a	81.4a
MSD (P)	0.3	0.3	3.6	3.8
CV (%)	9.6	8.3	9.6	8.3

*Means followed by the same letter(s) along the column for irrigation water, N and P rates of each PTrial are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. Interactions are not significantly different at $P \leq 0.05$. MSD = Minimum Significant Difference. Mean separation was done within each season.

The sprout length at 90 DAS also significantly depended on irrigation water and P rates. Low irrigation water rate at 40% together with low P rate of 0 kg P/ha reduced the sprout length to 4.7 and 3.2 cm compared to 9.9 and 4.1 cm recorded for high irrigation water rate of 100% with the same P rate of 0 kg P/ha in both Trials. However, application of high P rate at 101.2 kg P/ha significantly increased the sprout length to 8.9 and 4.4 cm with 40% irrigation water rate compared to 16.2 and 7.4 cm observed with 100% irrigation water rate in both Trials. Low compared to high irrigation water rate decreased the sprout length, whereas higher rates of P increased the sprout length (Table 39).

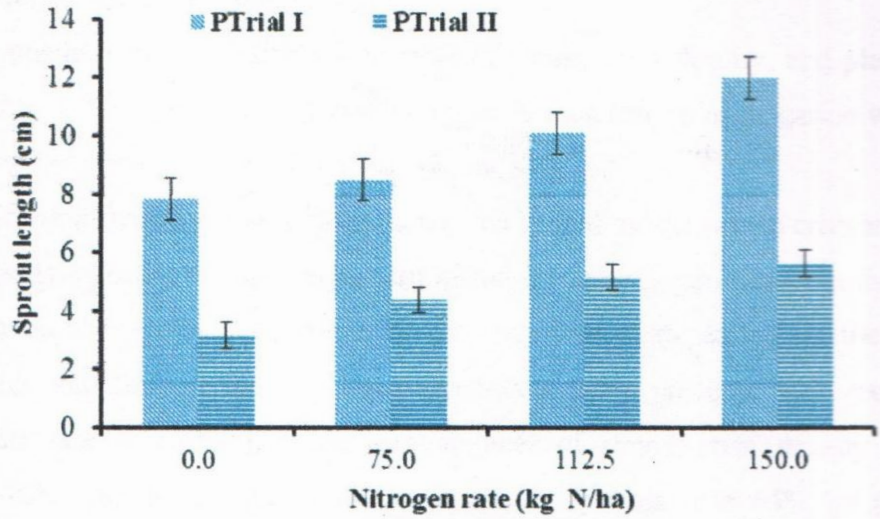


Figure 8: Effect of N rate on seed potato sprout length at 90 DAS

Table 39: Effect of irrigation water and P rates on seed potato sprout length

PTrial I	P rate (kg P/ha)				N rate (kg N/ha) in			
Irrigation water (% FC)	0	50.6	75.9	101.2	0	75	112.5	150
100	9.9d*	11.2c	13.6b	16.2a	10.7d	11.7c	13.2b	15.3a
65	7d	8.1c	9.9b	12.9a	7.4c	7.9c	10.3b	12.5a
40	4.7c	5.2c	7.5b	8.9a	5.4c	5.9c	6.8b	8.2a
MSD	0.7 (P, N)	0.6 (W)						
CV (%)	9.6							
PTrial II								
100	4.1d	5.1c	5.6b	7.4a	4.1d	5.5c	5.9b	6.7a
65	3.2d	4.1c	4.8b	5.5a	3.1d	4.3c	4.9b	5.3a
40	3.2c	3.7b	3.9ba	4.4a	2.4c	3.4b	4.6a	4.9a
MSD	0.4 (P, N)	0.4 (W)						
CV (%)	4.6							

*Means followed by the same letter(s) along the row for irrigation water by P or N rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

4.4.5. Seed potato tuber field performance evaluation

4.4.5.1. Number of stems and plant height

In the postharvest evaluation the number of stems, stem density, and plant height at 22, 36, 50 and 57 DAP significantly depended on individual effects of irrigation water, N and P rates (Table 40; Appendices 43, 44, 45, 46, 47, and 48).

The different irrigation water rates during the growth of the potato crop at production stage significantly affected the growth pattern of the resultant potato plants in the field. The resultant stem number, stem density and height significantly depended on the amount of irrigation water supplied earlier on. Seed generated from potatoes that received high irrigation water rate at 100% had the least number of stems, stem density and height compared to 40% and intermediate 65% irrigation water rates. The 65% irrigation water resulted in seed potato which generated more vigorous plants which had greater stem numbers, stem density and stems with greater height. However, regardless of the amount of initial irrigation water supplied the height of the resultant plants increased throughout the growth period but higher increases were observed with plants from seed which were generated using low irrigation water. The stem numbers, density and height in resultant plants increased from those generated from potato seed grown with 40% and were highest with 65% after which they reduced with 100% irrigation water rate. For example 100% compared with 65% irrigation water rate reduced the stem numbers, density and height 57 DAP by 1.3 and [illegible], 15.1 and 12.6, and 13.4 cm and 10.3 cm in PTrials I and II respectively (Table 40).

Unlike high irrigation water application which did not favour the fast growth of the resultant potato plants, N and P application led to production of seed potato whose resultant plants were very vigorous. Low N rate of 0 and 75 kg N/ha non-significantly increased the resultant potato plants stem numbers and stem density until after 112.5 kg N/ha application. Resultant plants of potato seed that had received 112.5 kg N/ha had more stems and higher stem density. However, 150 kg N/ha potato seeds did not express in the field significantly different from the 112.5 kg N/ha generated ones. Plant height was similarly affected by N application. There were non-significant increases in plant height up to 112.5 kg N/ha from 22 to 50 DAP after which there was a significant decrease in plant height 57 DAP with 150 kg N/ha generated plants (Table 40).

Table 40: Effect of irrigation water, N and P rates on post treatment performance evaluation of stem number and density and plant height

PTrial I			Plant height for various DAP (cm)				PTrial I		Plant height for various DAP (cm)			
Irrigation rate (% FC)	Stem number	Stem density	22	36	50	57	Stem numbers	Stem density	22	36	50	57
100	2.9c*	34.6c	8c	23.9c	52.3c	70.5c	3.9c	46.9c	5.9c	17.7c	37.7c	49.8c
65	4.2a	49.6a	12a	32.2a	64.9a	83.8a	5a	59.5a	8.4a	23.4a	45.6a	60.1a
40	3.6b	42.7b	10.8b	28b	58.6b	76.9b	4.4	52.1b	7.5b	20.4b	40.9b	54.9b
MSD (W)	0.4	4.6	0.6	1.4	2.4	4.6	0.3	4.1	0.5	0.9	1.9	2.3
Nitrogen rate (kg N/ha)												
0	3.1c	36.6b	9.1c	23.7d	53.2c	70.7c	3.9b	45.8b	6.8c	17.7c	38.7c	50.9b
75 .	3.4bc	40.8b	10.2b	27.2c	57.9b	75.1bc	4.3b	50.4b	7bc	19.8b	39.9bc	53.2b
112.5	3.9a	46.8a	10.6ab	29.2b	59.4b	79.9ab	4.9a	58.9a	7ab	21.8a	42.8ab	56.5a
150	3.8ab	45.1ab	11.3a	32.2a	63.7a	82.5a	4.8a	56.3a	7.9a	22.8a	44.3a	59.1a
MSD (N)	0.5	5.8	0.7	1.7	3.1	5.8	0.4	5.2	0.6	1.2	2.5	2.9
Phosphorus rate (kg P/ha)												
0	2.8b	32.9b	8.2d	24.3d	53.4b	66.4c	3.6c	42.2c	5.8d	18.3d	38.5c	49.5d
50.6	3.2b	38.2b	9.5c	27.5c	55.9b	73.2b	4.2b	49.7b	6.6c	19.9c	39.9bc	52.9c
75.9	3.9a	46.8a	10.9b	29.2b	61.3a	81.8a	4.9a	58.3a	7.7b	21.2b	41.2b	57.2b
101.2	4.3a	51.4a	12.4a	31.3a	63.6a	86.8a	5.2a	61.3a	9.1a	22.6a	46a	60.3a
MSD (P)	0.5	5.8	0.7	1.7	3.1	5.8	0.4	5.2	0.6	1.2	2.5	2.9
CV (%)	8.7	11.1	11.5	9.8	8.5	12.2	6.5	7.9	12.7	9.8	9.8	8.45

*Means followed by the same letter(s) along columns for different irrigation water, N and P application rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. Interactions were not significant at $P \leq 0.05$. MSD = Minimum Significant Difference. Mean separation was done within each season.

Generally, the stem numbers and density increased from low N rate at 0 kg N/ha to 112.5 kg N/ha after which there was a decrease. High application of N at 150 kg N/ha compared with 112.5 kg N/ha in potatoes produced seed which led to decrease in the stem numbers and density of resultant plants by 0.1 and 0.2, and 1.7 and 2.6 while the plant height increased at all growth stages in PTrials I and II, respectively. Furthermore, application of P in potato crop field produced seed potato whose resultant plants expressed significant differences in stem numbers and density, and including plant height. However, for stem numbers significant differences were observed from P rate, 50.6 kg P/ha after which there were non-significant increases beyond 75.9 kg P/ha. In most of the growth stages plant height progressively increased with increase in P rate both in PTrials I and II (Table 40).

4.4.5.2. Tuberization

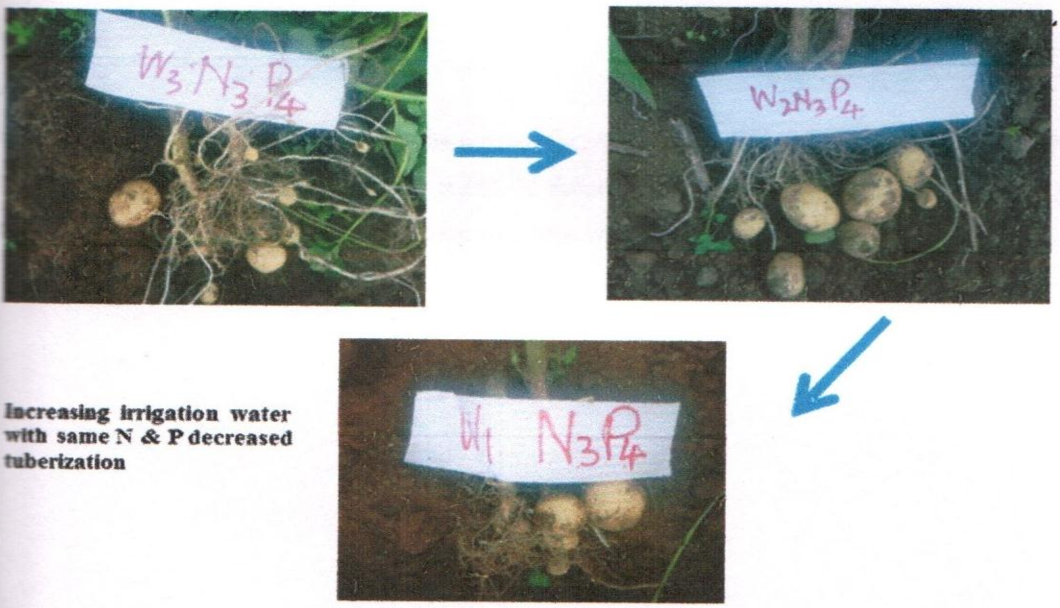
The number of tubers harvested from plants established from seed potato that was produced with different irrigation water, N and P application rates significantly varied between the different potato plants evaluated (Table 41; Appendix 49).

Number of tubers per plant increased from potato seed that had received low irrigation water at 40% together with 0 kg N/ha and 0 kg P/ha to those that was raised under intermediate irrigation water rate at 65% together with 112.5 kg N/ha and 75.9 kg P/ha both in PTrials I and II, respectively (Table 41). Seed that received low irrigation water application at 40% significantly produced more tubers per plant compared to those that received 100% but not better than 65% irrigation water (Plate 7). Application of 100% compared with 65% irrigation water to seed potatoes regardless of N and P application rates led to decrease in tuber numbers (tuberization capacity) in resultant plants. The highest number of tubers per resultant plant was 16.7 and 22 observed with seed potato that was raised with 65% FC together with 112.5 kg N/ha and 75.9 kg P/ha both in PTrials I and II. The lowest number of tubers per resultant plant was 4.3 and 8.3 observed with seed potato that was raised with 100% FC together with 0 kg N/ha and 0 kg P/ha. When high irrigation water at 100% FC was integrated with 112.5 kg N/ha and 75.9 kg P/ha the resultant plants from the generated seed produced 11.7 and 13.3 tubers compared with 16.7 and 22 tubers observed with seed potato that was raised with 65% irrigation water which was an equivalent decrease of 5 and 8.7 tubers in PTrials I and II, respectively. Therefore, increasing irrigation water beyond 65% FC reduced the postharvest tuberization capacity of seed potato tubers.

Furthermore, N and P application affected the postharvest field performance of seed potato produced. Production of seed potato through application of N from 0 to 112.5 kg N/ha together with 65% irrigation water led to increased number of tubers produced by the resultant plants from 8.3 and 11.3 to 11.7 and 16.7, which was an equivalent increase of 3.4 and 5.4 tubers in both PTrials I and II, respectively. Therefore, increase in N application from 0 kg N/ha to 112.5 kg N/ha during seed production increased tuberization capacity of the resultant plants. However, increase in N application to 150 kg N/ha in the field produced seed potato whose resultant plants were characterised by significantly low number of tubers than those produced by 112.5 kg N/ha generated seeds (Table 41).

Unlike N, seed potato where P was applied from 0 to 101.2 kg P/ha resulted in significantly higher number of tuber production per resultant plant. Higher number of tubers was observed with plants whose seed potato was from field plants where high P rates were applied. When integrated with 65% irrigation water and 112.5 kg N/ha seed potato from where low P rate of 0 kg P/ha was applied resulted in plants that produced fewer tubers amounting to 8.3 and 11.3, compared to 16.7 and 22 produced by plants from seed potato supplied with 75.9 kg P/ha in the field which was an equivalent increase of 8.4 and 10.7 (Table 41).

Overall, low to intermediate irrigation water, high N and P application rates at 112.5 kg N and 75.9 kg P/ha resulted in seed potato which when established in the field the resultant plants produced more tubers (greater tuberization).



Increasing irrigation water with same N & P decreased tuberization

Plate 8: Effect of irrigation water rate on tuberization capacity of the resultant plants

Table 41: Effect of irrigation water, N and P rates on post-treatment performance evaluation of tuberization capacity

Irrigation water rate		Tuber numbers per plant RTrial I				Tuber numbers per plant RTrial I			
		P rate (kg P/ha)				P rate (kg P/ha)			
	kg N/ha	0	50.6	75.9	101.2	0	50.6	75.9	101.2
100 (% FC)	0	4.3c*	6.7c	7.3c	8.3b	8.3c	9.3b	12c	12c
	75	7.3b	8b	8c	8.7b	8.7c	9.7b	12.7bc	12.7c
	112.5	8.3a	9a	11.7a	11.7a	11.3a	11.7a	13.3b	16a
	150	7.3b	8b	9.7b	9b	9.7b	12.3a	14.3a	15b
65 (% FC)	0	8.3d	9.7d	11c	12.3c	11.3c	14d	15d	18.7b
	75	9.7c	11c	13.3b	13.3b	14.3b	15.3c	18c	19.3b
	112.5	11.7a	14.7a	16.7a	15.3a	16.7a	20a	22a	21.7a
	150	10.7b	12.7b	13.7b	15.7a	15b	18.3b	19.7b	19.3b
40 (% FC)	0	7.7c	8.7c	8.7d	8.7c	10.3c	11.7c	12.7c	14.7c
	75	8.7b	9.7b	11.3b	13a	12b	13.3b	14.7b	16.7a
	112.5	9.7a	11.3a	12.7a	12b	14.7a	15a	17.3a	16.7a
	150	8.7b	10.3b	10.3c	11.7b	12.3b	13.7b	14b	15.7b
	MSD	1.0 (N, P)		0.8 (W)		0.8 (N, P)		0.7 (W)	
	CV (%)	6.8				4.4			

*Means followed by the same letter(s) along the column for interaction between same irrigation water, N and P application rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Effect of Irrigation Water, N and P Integration on Potato Growth and Development

In Kenya, farmers grow seed potato during the rainy season using fertiliser rates of commercial potato production. In this study, 100% irrigation water rate represented a normal rainy season, and fertiliser rates were varied from zero to commercial potato production rates. Water, which is the most important component of life, is rapidly becoming a critically scarce commodity for humans and crop production, and its limited supply is one of the major abiotic factors that adversely affect agricultural crop production worldwide in many ways (Waraich *et al.*, 2011a). Proper nutrition is the basic need of every living organism as the nutrients are not only required for better plant growth and development, but they are also helpful to alleviate different kinds of abiotic stresses like drought stress. However, recent trends indicate that productivity and fertility of soils are globally declining due to degradation and intensive use of soils without consideration of proper soil management practices (Gruhn *et al.*, 2000; Cakmak, 2002).

In the present study, potato plants supplied with high irrigation water, N and P rates had greater sprout emergence, stem number and height, higher leaf stomatal conductance and chlorophyll content index, larger LAI and total biomass yield, early 50% flowering and stayed longer to reach physiological maturity than those supplied with lower rates. Potatoes supplied with 100% irrigation water had better growth and development compared to those supplied with 65%, which had intermediate and those supplied with 40% rate had the least. It is possible that low irrigation water led to droughty conditions within the potato plant, which possibly resulted in low leaf stomatal conductance and chlorophyll content index and consequently reduced photosynthetic activity. Loggini *et al.* (1999), and Apel and Hirt (2004) reported that drought inhibits or slows down photosynthetic carbon fixation mainly through limiting the entry of CO_2 into the leaf or directly inhibiting metabolism. Probably potato supplied with high compared to low irrigation water experienced higher rates of leaf stomatal conductance, which lead to high metabolism and consequently greater chlorophyll content index. Chlorophyll is the key pigment involved in the primary reactions of photosynthesis which is the global biological process that provides primary biomass and energy for almost all living beings (Shpilyov *et al.*, 2013). High chlorophyll content index might have led to higher photosynthetic activity within the potato supplied with high irrigation water. Van der Zaag (1992) reported that insufficient water supply reduces foliage growth and efficiency in use of intercepted light by reducing the rate of photosynthesis, and consequently stimulating maturity through death of the leaves. This possibly explains why potato plants supplied with low irrigation water, N and P mineral nutrients attained physiological maturity earlier and had lower total dry matter (biomass) accumulation.

Nitrogen and phosphorus are crucial elements required for different roles in potato plant growth and development. Low N and P probably impaired potato plant growth and development, leading to low germination, stem number, leaf stomatal conductance and photosynthetic capacity. Probably, the low photosynthetic rates due to reduced chlorophyll content led to limitation of assimilate supply. The potato plants supplied with low N and P rates, consequently senesced and attained the physiological maturity earlier compared to plants supplied with high N, and P rates. Early physiological maturity could have occurred not because of achieving the required growth period, but due to nutrient stress (stunting). Such stress may explain the observed low total biomass accumulation, and hence, lower plant growth and development as observed in potatoes supplied with low irrigation water, N and P rates in this study.

The amount of irrigation water, N and P applied was an important factor in determining the rate of growth and development of potato plant. It was observed that the key to potato plant growth and development depended on establishment of more stem numbers and large LAI that is durable through the reproductive phase. This was achieved through high irrigation water, N and P rates. Nitrogen is one of the most important nutrients that limit crop production. Furthermore, potatoes receiving high irrigation water, N and P rates showed high stomatal conductance and chlorophyll content probably due to high photosynthetic rate. This resulted in more total biomass production by having taller stems with high shoot and tuber dry mass. Early foliage development due to high irrigation water, N and P rates indicated by high LAI possibly lead to a high interception of solar radiation and radiation use efficiency (RUE), mainly due to the greater photosynthetic surface area of the resultant potato crop. Fulham and Allison (2012) reported that RUE was increased by irrigating and that this was also associated with significant increase in total DM and tuber yield compared with non-irrigated plots. Therefore, LAI could be a significant feature in determining photosynthetic activity. Kara and Mujdeci (2010) reported that LAI is a key structural characteristic of plants due to the role green leaves play in controlling many biological and physical processes in plant canopies. The increased LAI due to high irrigation water, N and P rates could have resulted in increased photosynthetic capacity and supply of assimilates necessary for high growth and development. Elsewhere, N has also been reported to increase the total chlorophyll content, meristematic cells and growth, leading to the formation of branches in addition to leaf expansion (Tabassum *et al.*, 2013).

A marked difference was observed in total biomass accumulation for different irrigation water, N and P rates, which was probably due to differences in leaf area and photosynthetic rates. Amanullah *et al.* (2010) reported that increased dry matter accumulation in the haulm in irrigated treatment may be attributed to more synthesis and translocation of photoassimilates from the haulm and also due to availability of more nutrients from the soil under different irrigation regimes. Therefore, the high irrigation water, N and P rates might have synergistically enhanced leaf area and photosynthetic rate. The extent of leaf formation has been reported to influence light absorption within a plant and the mechanism behind increased growth has been attributed to increased leaf area (McNaught *et al.*, 1983).

The low stomatal conductance and chlorophyll content observed in potato plants that received low irrigation water, N and P rates could have lead to low LAI and consequently to low interception of solar radiation and hence low photosynthetic capacity to support potato plant growth. Consequently, this resulted in potato plants with lower height, which achieved physiological maturity early resulting in low shoot and tuber biomass gain. This suggests that low irrigation water, N and P rates could have led to less vegetative and reproductive (tuber) growth. Photosynthesis in plants has been reported to be as a result of interaction among different factors like carbon dioxide concentration, ambient temperature, chlorophyll content, and water and nutrient supply, which influence LAI (Tabassum *et al.*, 2013).

Overall greater growth and development was observed with high irrigation water, N and P rates. However, treatments which received high irrigation water together with low N and P rates and vice-versa did not record greater growth and development. This suggests that the effect of irrigation water, N or P was closely related to the ability of potato plant to utilize them from the soil. Waraich *et al.* (2011b) reported that when water inside the plant declines below a threshold level, stomata close and decrease transpiration rate resulting in reduction in water transport through the plant, consequently affecting roots ability to absorb water and nutrients as effectively as supposed to be done under normal transpiration. Therefore, it is possible that normal transpiration required certain amounts of irrigation water below which the high N or P rates cannot lead to greater potato growth and development. It therefore seems there is a synergistic relationship between the irrigation water, N and P rates towards potato growth and development. Probably, availability of N and P to the potato crop depends on the amount of irrigation water supplied. Furthermore, the utilisation of the applied irrigation water by the potato crop depends on the amount of N or P applied.

Segal *et al.* (2000) reported that high irrigation amounts and frequency provide desirable conditions for water movement in soil and uptake by roots. However, it is possible that under moisture stress conditions resulting from low irrigation water rate, mobility of N and P was interfered with and therefore curtailing the benefits of these mineral nutrients. Kim *et al.* (2010) reported that increased N fertilizer can increase N uptake for a positive effect on chlorophyll content, photosynthetic rates, leaf expansion, total number of leaves and dry matter accumulation. Similarly, in this study, high irrigation water, N and P rates could have increased water, N and P uptake by the potato plant which led to a positive effect on leaf stomatal conductance, chlorophyll content, LAI, and total biomass accumulation. Kumar *et al.* (2013) reported that the increased dry matter production when inorganic and organic minerals are applied is attributable to higher photosynthetic activity and translocation of photosynthates. This probably explains why low potato growth and development was observed where low irrigation water together with high N or P rates were applied.

Although greater vegetative growth and development was observed with integration of high irrigation water, N and P rates this did not result in the highest total biomass accumulation. The results show that integration of 65% compared to 100% irrigation water together with high N and P rates results in the highest total biomass production due to greater tuber biomass. When integration of high irrigation water, N and P rates supported more of the vegetative growth and development, probably it interfered with reproductive growth by promoting high shoot biomass at the expense of tuber biomass.

It can be concluded that for purposes of growing potatoes for seed production, integration of intermediate irrigation water, high N and P rates encourages balanced growth and development of potato plants. This balance enables potato plants avoid excessive vegetative growth at the expense of the reproductive growth.

5.2 Effect of Integration of Irrigation Water, N and P Rates on Seed Potato Tuber Yield and Yield Components

5.2.1. Effects on seed potato tuber number, yield and size distribution

The growth, development, and consequently yield of crops are highly influenced by available soil moisture (Alem, 1993). In this study, high irrigation water, N and P rates increased tuber yield attributes. The number and size distribution of tubers increased with moderate increase of irrigation water, N and P rates, but decreased with oversupply. The highest seed potato tuber yield was obtained when 65% irrigation water was integrated with higher N and P application rates.

The processes involved in seed potato tuber production like vegetative growth, tuber set and seed bulking help determine seed potato yield. Potato tuber initiation and bulking are the two growth phases that have different sensitivities to low water application (Ahmadi *et al.*, 2011). Therefore, low irrigation water rate could have resulted in water stress during tuber set and early bulking growth stages; and hence the greatest reduction in tuber yields.

The number of tubers formed per plant is called tuber set and the number of tubers that achieve maturity is related to available moisture and nutrition (USAID, 2011). Kleinkopf *et al.* (2003) reported that during tuber initiation stage, tubers are formed on stolons and the number of tubers carried to harvest is determined by environmental conditions during this growth stage. This explains why tuber initiation and set, and their consequent maintenance are very crucial in determining the number of tubers per plant, which is a major yield determinant. The number of tubers per plant also depends on the number of stems per plant. Olsen and Hornbacher (2002) reported that there is a general relationship between stem numbers and tuber numbers whereby an increase in stem numbers often indicates an increase in tuber numbers. It is possible that potato supplied both with low irrigation water, N and P rates experienced water and nutrition deficiency stresses, which resulted in fewer stems with low tuber set, maintenance and yield at harvest. It has been reported that improvement in yield under irrigation may be due to higher availability of soil moisture, which helps in better nutrient uptake by the crop, resulting in assimilation of photosynthates into sinks (Singh, 2004; Thakuria *et al.*, 2004; Yadav *et al.*, 2009). Therefore, seed tuber number successfully produced by a potato plant varies with irrigation water, N and P rates.

Seed potato tuber yield increase is a function of the number of tubers and their relative increase in size. The number of seed tubers probably depends on tuber initiation capacity of a given potato plant, and the ability to maintain the initiated tubers until they are mature for harvesting. Tuber initiation has been reported to occur over a relatively short period of about 10-15 days when potato plants require large quantities of nutrients and water (Tantowijoyo and van de Fliert, 2006). The high irrigation water, N and P rates might have favoured initiation and maintenance of tubers, resulting in high tuber numbers per plant. Tuber set has been reported to be particularly sensitive to moisture stress and there are generally fewer tubers set when available soil moisture is maintained below 65% of the available soil water capacity (WPC, 2003). After initiation and maintenance, tubers must also increase in size during the bulking period as this might determine ultimate weight. The total yield depends on the length of the tuber growing period and the average growth of the tubers per day (Van Der Zaag, 1992). At the bulking stage the photoassimilates generated through photosynthesis in the vegetative phase become critical for the expansion of the tubers. Increased LAI due to irrigation water, N and P application might have allowed plants to trap more radiant energy required for enhanced photosynthetic activity, which in turn increased the amount of photoassimilates produced and available for seed potato bulking. Increased radiation interception, particularly at the time of tuber initiation has a positive effect on final tuber yield (White *et al.*, 2007). The high number of seed tubers with greater size led to high yields in plots that received higher irrigation water, N and P rates due to the greater LAI that might have resulted in high accumulation of photoassimilates.

Potato crops need P only during the vegetative growth and tuber initiation stages, while N is required up to tuber bulking stage (Tantowijoyo and Van De Fliert, 2006). Phosphorus sometimes affects tuber set and therefore is seen as an element contributing to tuber quality in this respect (Ekelof, 2007). This study showed that integration of irrigation water, N and P fertilizer positively increased potato tuber yield. Application of 65% irrigation water followed by 100% recorded the highest tuber yield due to the high number of tubers initiated and maintained, while 40% irrigation water produced the least seed potato tuber yield across all N and P rates. The differences in yield could also be explained by balanced growth of plants that received 65% irrigation water, N and P supply. It is possible that application of 100% compared to 65% irrigation water with high N and P rates encouraged more vegetative growth and development at the expense of reproductive growth of tuber number and seed potato yield. A potato crop that attains physiological maturity late like those supplied with high irrigation water, N and P rates may have utilized most of the photoassimilates in maintenance of the vegetative phase than in tuber bulking and enlargement, and hence the lower seed potato tuber yield. Tuber bulking and enlargement continue as photoassimilates are translocated from the vegetative phase into the tubers (reproductive phase) and consequently increase seed potato tuber yield.

The benefit of 65% irrigation water, high N and P rates could have been the provision of optimal conditions, which favoured moderate potato plant growth and development. Wang *et al.* (2007) reported that water stress reduces nutrient uptake by roots and transportation of nutrients from roots to stems due to restricted transpiration rates and membrane permeability. Water stress primarily reduces potato canopy expansion (Jefferies, 1995, Wang *et al.*, 2003; Fleisher *et al.* 2008) and can delay tuber initiation and bulking (Susnoschi and Shimshi, 1985; Walworth and Carling, 2002). Nitrogen and P application probably led to high rates of potato growth and development, resulting in high LAI and generally high amounts of photoassimilates. The increase in photoassimilates resulted in increase in both the number and bulking capacity of tubers. The high tuber and average shoot dry biomasses for potatoes that received high N and P rates suggests that most assimilates were channelled towards tuber growth rather than vegetative growth.

Generally potatoes that received 40% irrigation water, low N and P rates had lower yields and those that received 65% irrigation water and high N and P rates had the highest seed potato tuber yields. This suggests that the degree of yield response to irrigation water, N and P application decreases markedly as water and mineral nutrient availability for potato crop reduces. Potatoes that received 100% irrigation water rate were intermediate in seed potato tuber yields.

Increasing irrigation water, N and P rates greatly influenced the seed potato size distribution. In this study higher quantities of ware potato were obtained with 100% irrigation water, high N and P rates. This was due to availability of more N and P nutrients for use by the potato plants to grow. Potato plants that received high irrigation water, N and P rates attained 50% flowering earlier and took longer period to attain physiological maturity. This result indicates that they had earlier tuber initiation and longer duration of tuber bulking, resulting in large-sized potato tubers (wares). Correa *et al.* (2009) reported that the early tubers exert dominance over the late tubers and hence at the end of the cultivation cycle, the tubers exhibit different sizes. This possibly also suggests that early tuber initiation due to high irrigation water, N and P rates rendered the early tubers dominant to develop into more ware potatoes and fewer small-sized tubers. Nutrient stress for no fertilizer treatment restricted seed potato tuber size enlargement, resulting in more size I and chat potato tubers. Probably the soil moisture stressed conditions due to low irrigation water together with the low N and P rates restricted the seed potato forming processes. El-Ghamry and El-Shikha, (2004) reported that potato is relatively sensitive to water stress that leads to yield reduction and loss in tuber grade. Low irrigation water regardless of N and P rates probably interfered with the mobility and uptake of these nutrients by the potato, thereby lowering growth, development, and provision of photoassimilates required for tuber bulking. Probably the low provision of assimilates resulted in decreased bulking capacity and reduction in the size of the potato tubers to yield more size I and chat than ware and size II tubers.

Kleinkopf *et al.* (2003) reported that the bulking rate of any potato cultivar is a function of the physiology of the plant and its environment. This explains why provision of high irrigation water, N and P rates probably led to establishment of a high LAI, which increased photosynthetic capacity, photoassimilates produced, tuber bulking capacity and proportion of ware and size II seed potato tubers. Conversely, lesser vegetative growth led to small sized tubers due to small LAI source and lesser bulking capacity. The 100% irrigation water together with the highest N and P rates led to production of greater proportion of ware-sized potato tubers that are not suitable for use as seed due to their large size. The highest yield of seed potato size II and I was obtained when 65% irrigation water and the highest N and P rates were integrated. This combination also resulted in the highest seed potato yield per unit area. Therefore to obtain adequate seed potato tubers, proper irrigation water, N and mineral nutrient integration should be adopted.

The harvest index (HI) of seed potato significantly increased with irrigation water, N and P rates. Other researchers have shown that N, an important constituent of chlorophyll, plays a vital role in metabolic process, and increases LAI by increasing leaf production and expansion rate that effect interception of photosynthetically active radiation (PAR) and consequently final dry matter production (Whitefield and Smith, 1989; Asif *et al.*, 2012). Probably high irrigation water, N and P rates increased the LAI during the early growing season to intercept most of the incoming radiation and increase photoassimilates for use in tuber development. With low irrigation water, N and P application rates, decreased seed potato tuber yield could have been caused primarily by reduction in radiation use efficiency when drought was imposed at tuber initiation and bulking stages. Best performance of potato crop depended on availability of irrigation water, N and P during these stages.

A strong correlation was observed between the seed potato yield and the total biomass yield. Although high biomass was observed for high irrigation water, this suppressed and decreased seed potato tuber productivity compared to vegetative growth, resulting in low HI. This result implied that most of the photoassimilates, for treatments that received high irrigation water, were channelled to vegetative growth. The 65% irrigation water probably enhanced balanced vegetative growth that channelled most of the photoassimilates to tuber development characteristics, resulting in high HI. High N and P rates indicate there were greater supply of the requirements for tuber initiation and bulking, resulting in high seed potato yield and hence greater HI. Higher rate of N has been reported to decrease potato HI (Mazurczyk and Lis, 2000; Belanger *et al.*, 2001) due to excessive growth of the aboveground plant parts (Mazurczyk *et al.*, 2009). In the present study higher N and P rates increased HI possibly due to higher aboveground growth at the expense of tuber growth.

Thus integration of high irrigation water, N and P rates generally improve potato tuber yield and yield components and is not suitable for increasing seed potato tuber yields. Lower irrigation, N and P rates do not lead to economic improvements in seed potato tuber yield.

5.2.2. Effects on specific density, starch, dry matter, tissue N and P contents

Specific density, starch and dry matter contents increased with irrigation water, N and P application rates. However, they decreased with over application of both irrigation water and N. One of the most important qualities of seed potato is high starch and dry matter contents, which are determined by specific gravity. As the specific gravity increased, the starch and dry matter content of seed potato increased. Therefore, there was a correlation between specific gravity, starch and dry matter contents. The 100% compared to 40% and 65% irrigation rates led to a decrease in seed potato specific density and consequently starch and dry matter contents. Excessive water, whether from rainfall or irrigation, and a general increase in soil fertility results in tubers with low dry matter (Fernando and Slater, 2010).

The potato plants supplied with high irrigation water could have experienced a high rate of growth and development in terms of height, LAI and total biomass. Therefore, most of the photoassimilates were used in maintenance of high growth and development. This vegetative growth may have affected the physiological state of tubers, which in turn influenced the growth pattern, specific density, starch and DM contents. Conversely, low to moderate irrigation water probably decreased potato growth and development, causing photoassimilates to be translocated for storage in the seed potato tubers that ended up having high specific density, starch and dry matter contents.

Makaraviciute (2003) reported that dry matter, starch, protein and sugar contents in potato tubers increase or decrease, depending on the mineral fertilizer forms, rates and correlations. Where 40% or 100% irrigation rates were applied with either low or high N and P rates, seed potato had low specific density, starch and dry matter contents. This suggested that if potato growth and development is either poor or massive due to low or high irrigation water, N and P rates, the specific density, starch and dry matter contents of the tubers will not be high. Balanced potato growth and development as a result of 65% irrigation water together with intermediate N and P rates lead to high specific density, starch and dry matter contents, compared to the two extremes.

According to this study, low N and P rates had the least specific density, starch and dry matter contents. However, high N and P rates did not greatly improve the specific density, starch and dry matter contents, compared to intermediate application rates. This result indicates that high N or P rates promoted potato growth and development at the expense of accumulation of dry matter and starch in the seed potato tubers. Very low levels of N and P decrease starch and dry matter probably by reducing the photosynthetic rate. The potato plant has been reported as being basically a starch factory and over 90% of the dry weight of a potato tuber is a direct result of photosynthetic process (Thornton, 2002). The high irrigation water, N and P rates probably increased growth rates, prompting solids accumulated through photosynthesis to be rapidly utilized for growth and development as they were formed, resulting in low specific density, starch and dry matter contents.

Fernando and Slater (2010) reported that unlike P that increases DM, nitrogen has the most effect in promoting top growth, which if too lush can prolong the growing season causing tubers not to bulk but to have lower dry matter at harvest. DM mainly depends on maturity of the potato tuber, composition of the soil, and fertilization conditions (Burt, 1989; Francakova *et al.*, 2012). Therefore, low to intermediate N rates increase dry matter content of tubers, whereas high N rates produced the opposite effect.

The starch and dry matter contents directly influence seed potato quality and growth of the resultant potato crop. Potatoes with a high specific gravity have been reported to produce higher yields than potatoes with low specific gravity (USAID, 2011). Information on specific density, starch and DM contents may help explain the different quality characteristics of seed potato tubers grown using different water and mineral nutrient supply conditions. The quality characteristics may affect subsequent commercial potato production. This information will help explain the qualities of seed potato and also their suitability for increased potato production. These quality characteristics are therefore important considerations when growing potato destined for seed use.

Irrigation water, N and P rates significantly influence N and P contents in seed potato tubers. Low N and P contents in the seed potato tubers resulted in potatoes that received 100% irrigation water together with low N and P rates. Jones *et al.* (2013) reported that nitrogen content of tubers was significantly affected by watering regime and it was significantly higher when restricted watering regime was used. Similarly in this study, the highest seed potato tuber N and P contents resulted for intermediate followed by low irrigation water rates. Application of 100% irrigation water resulted in continuous growth and development, thereby delaying physiological maturity and limiting deposition of both N and P in the seed tubers, as they sustained the late growth. Probably balanced growth, which led to high N and P contents observed with 65%, followed by 40% irrigation rates, compared to 100% irrigation rate can be explained by the fact that potato plants attained physiological maturity early and minimised use of stored N and P. The 40% irrigation rate might have been limited N and P contents due to reduced uptake of the applied N and P by the low available soil moisture. In addition, utilisation of the applied N and P by the crop was probably low, making the 40% irrigation rate emerge second to 65% irrigation rate in terms of tissue N and

P contents. Similarly, N and P rates also influenced potato growth and development, as well as seed potato tuber tissue N and P contents. Application of P fertilizers has been reported to increase N and Mg contents, but reduce Mn content in tubers (Hammond and White, 2005). White *et al.* (2009) reported that these effects are a result of not only complex interactions between mineral elements in the soil and uptake by plants, but also of effects of tissue mineral composition on redistribution within the plant.

In this study, although high N and P rates stimulated high growth and development, they increased tuber tissue N and P contents, which are important in improving the seed potato quality characteristics. High irrigation water delayed physiological maturity and extended utilisation of photoassimilates that could have been stored in the seed tubers, resulting in low tuber tissue N and P contents.

5.2.3. Effects on water, N and P use efficiencies and net economic benefit

The potato NUE, PUE and net economic benefit increased, while WUE decreased with irrigation water, N and P rates. Elsewhere, WUE has been reported to decrease with the increase of irrigation rate or frequency (Amanullah *et al.*, 2010; Badr *et al.*, 2012). In the present study, application of 100% irrigation water alone compared to 40% irrigation water did not lead to high WUE. Probably, high compared to low irrigation water rate alone did not enhance efficiency of utilisation of any available nutrients in the soil, thereby resulting in low growth and development in relation to water supplied. High irrigation water rate alone might have reduced crop growth, available N and P uptake and hence WUE by potato plants. High irrigation water could have been the only growth factor available in greater amounts, while the others were limiting.

Nitrogen and phosphorus application improved WUE. Badr *et al.* (2012) reported improved WUE with N supply in potato, but decreased WUE as the irrigation rate was increased. This shows that supply of N and P in potato cropping systems is essential for controlling yield and WUE. High WUE was observed as the rate of N and P was increased. This suggests that where low N and P rates were supplied, potato plants did not fully utilise available soil moisture and consequently growth and development were reduced, resulting in low yields. Sufficient quantities of P have been reported to stimulate early root growth and WUE (DAFF, 2013). The low WUE with high irrigation alone and high WUE with high N and P rates probably indicate that better plant performance requires supply of water, N and P at certain optimal levels. Low amount of any growth factor reduces utilisation of the others, even if at high rate, thereby reducing plant performance, yield and WUE. Additionally, nutrient imbalances influence uptake of a single nutrient, even if supplied abundantly. Vitousek *et al.* (2009) reported that nutrient additions to intensive agricultural systems range from inadequate to excess and that nutrient imbalance is a serious problem in soils. Irrigation regime is crucial in determining plant ability to take up the N available in the soil since a well-watered crop is more capable to take advantage of the applied fertilizer (Costa *et al.*, 1997). This aspect is particularly relevant for estimating WUE at different irrigation, N and P rates and consequently their impact in seed potato production.

The 0 kg N/ha regardless of the irrigation water and P rates lead to zero NUE. This was similar to 0 kg P/ha, which also led to zero PUE. These results suggest that no supply of either N or P does not improve their use, because if their levels are limiting within the soil, this will reflect on the final seed potato yield. However, Crop NUE has been reported to decrease with increased N supply though the magnitude of the decline is dependent on environmental factors outside the supply of N (Andrews and Lea, 2013). High compared to low irrigation rates led to high NUE or PUE. Liu *et al.* (2012) reported that soil water and fertilizer management are important in enhancing N uptake and utilization efficiency through reduction of losses in ammonia volatilization. Probably, where high irrigation water was applied, there was more of the soil water available, which resulted in better uptake and utilization of the N and P applied and consequently increasing their use efficiency by the potato plant in growth and development. Balancing irrigation water, N and P rates is one of the key factors that influence N and P uptake and use. Optimal irrigation water application could significantly reduce any possible loss of both N and P and thus enhance their use. This result suggests that synchronized application of irrigation water, N and P is advantageous both in improving their availability and utilization, as well as seed potato tuber production and quality. Water deficit in soil may affect nutrient availability and absorption by plant roots (Roosta *et al.*, 2009). It is, therefore, crucial to understand that combining water and nutrient use efficiencies improves growth, yield and quality of seed potato tubers.

Net economic benefit analysis is a very important component of seed potato production enterprise. The gross value of production depends not only on yield, but also tuber quality. Improving seed quality is a key strategy for increasing potato productivity worldwide (Fuglie *et al.*, 2000). In the present study, the net economic benefit was determined only for sizes I and II, which are the currently desired seed potato sizes in Kenya. The net economic benefit showed the suitability of methods adapted for production. The NEB was mainly based on the average yields and the current cost of irrigation water, N and P applied. Irrigation water, N and P application increased the net economic benefit of seed potato benefit.

intermediate irrigation water, N and P rates led to higher net economic benefit, compared to lower rates, because they led to production of more quantities of seed sizes I and II.

One of the most important considerations while producing seed potatoes is the net economic benefit per unit area of production. The results obtained indicate that intermediate irrigation water, N and P rates can be adapted to enhance seed potato production and contribute greatly to the economic viability of seed potato production enterprise.

5.3. Effects of Irrigation Water, N and P Integration on Postharvest Physiological Characteristics of Seed Potato Tubers and Their Resultant Growth

5.3.1 Effects on relative weight loss, firmness and total soluble solids

Reduction in seed potato weight after storage can be an indication of deterioration of seed potato quality and was found to depend on potato growing conditions tested in this study. The seed potato tuber relative weight loss decreased with increase in irrigation water rate, and increased with increase in N and P rates. The seed potato tubers from high compared to lowest and intermediate irrigation water rates had the greatest relative weight losses. Ohachin and Iwata (1981) reported that weight loss in stored potato may be due to higher respiration rate, increased membrane permeability and more sprout development. This probably suggests that potato supplied with high irrigation water rate absorbed more of it into the seed tubers which lead to more water being available for physiological processes such as transpiration and respiration and sprouting, resulting in greater weight loss. Sprouting has been reported to cause increased weight loss and conversion of starch to sugars (Frazier *et al.*, 2004). This then suggests that the seed potato harvested from plants grown with low irrigation water rate were in a relatively inactive physiological state during storage compared to those harvested from plants supplied with high irrigation water rate, which were probably characterized by high metabolic activities. The water content has been reported to affect the rate of metabolic and deteriorative reactions (Vertucci and Roos, 1990).

Neubauer *et al.* (1967) reported that weight loss resulted primarily due to evaporation of water. In this study, seed potato tuber weight at 90 DAS was less than at harvest. This continued throughout the storage period due to a net loss of seed moisture (desorption) to the environment. Asomaning (2011) reported that all seeds are hygroscopic and automatically absorb or desorb moisture by diffusion along a water potential gradient between the seed and the surrounding air. This suggests that when seed potato tubers from high irrigation water rates were placed in storage they lost moisture to the environment due to high initial moisture content and consequently decreased in weight. However, greater loss in weight was observed with potato supplied with high compared to low irrigation water rate, especially when low N and P rates were applied. Probably high N and P rates assisted in binding water molecules within the seed potato, resulting in low evaporation. This may explain why low irrigation rate, compared to high N and P rates, experienced high relative water loss.

The seed potato tubers from low or intermediate irrigation, high N and P rates had high starch and dry matter contents. Gold and Hay (2008) reported that the dry matter in starchy seeds attracts and holds water molecules. This probably explains why the seed potato tubers grown under high irrigation, low N and P rates experienced greater weight loss at 90 DAS due to low dry matter and starch contents. The weight loss was also attributed to physiological aging of tubers and water loss as seed potato equilibrated its moisture level. Loss of moisture as observed with 100% irrigation rate has been reported to lead to quality loss and non-marketable produce (Kibar, 2012). When low to intermediate irrigation, high N and P rates were applied minimal weight loss resulted during storage. Probably N and P application improved the strength and integrity of seed potato membranes, and minimized the metabolic and deteriorative reactions that lead to weight loss. It is possible that potatoes supplied with high irrigation, low N and P rates were physiologically disadvantaged and consequently experienced increased weight loss. Varied seed potato growing conditions had an impact on the seed physiological age, which led to varied relative water loss. In general, the most effective treatments to reduce weight loss of tubers were integration of low to intermediate irrigation water rates with high N and P rates.

Firmness of seed potato tubers determines susceptibility of the tubers to mechanical injuries, faulty curing and decay in storage, which lead to rapid deterioration. Potato plants supplied with high compared to low irrigation water produced seed tubers that were less firm. This was probably because potato plants supplied with high irrigation water experienced high rate of growth and development, which may have lowered the physiological state of tubers, mainly tissue strength, integrity and firmness. Most of the photoassimilates produced by the plants might have been used in maintenance of high growth and development at the expense of membrane strength and integrity. Low and intermediate irrigation water rates probably decreased potato plant growth and development rates, which limited utilisation of most of the photoassimilates that then became available for better membrane strength, integrity and firmness. This result suggests that the latter potato plants were also more efficient in utilizing N and P applied than those supplied with high irrigation water rate.

There was a decrease in seed potato firmness in storage across all treatments. The decrease was possibly due to physiological aging of the seed potato tubers. However, more decrease in firmness was observed in seed potato tubers harvested from plots supplied with high irrigation water, low N and P rates. Seed potato tubers from plants supplied with low irrigation water, high N and P rates had minimal firmness reduction. Decrease in firmness has been attributed to greater utilization of photoassimilates as substrates in respiration (Burt *et al.*, 1959). The seed potato tubers from high irrigation rate had longer sprouts, occasioned by utilization of photoassimilates in energy production during sprouting and respiration during storage and hence the decrease in firmness.

The TSS in seed potato tubers determines tuber physiology, which affects growth of the resulting potato plants. Maximum decrease of TSS, both at harvest and 90 DAS, was found in seed potato tubers harvested from plots supplied with high irrigation water and low N and P rates. TSS in seed potato tubers increased with the decrease in irrigation water rate from 100% to 40% FC. It also increased from lowest to the highest N and P rates. Application of low irrigation water and high N and P rates may have activated TSS synthesis through increase in enzymes in the seed potato tubers. Potato plants supplied with low irrigation water might have utilized less of the photoassimilates in growth and development, resulting in accumulation of most of these in the tuber tissues. Potato plants supplied with high irrigation water could have channeled most of the photoassimilates towards maintenance of high growth and development and less in storage in seed tubers. Also the treatments supplied with high N and P rates resulted in more photoassimilates being available for growth, development and storage in tubers. Bataglia *et al.* (1985) in Hernandez *et al.* (1994) reported that N fertilization may play an important role not only because of the concentration of N metabolites, but also because it affects the incorporation of assimilates through the increase of the photosynthetic capacity. Probably the high N and P application rates increased the potato photosynthetic capacity, resulting in accumulation of photoassimilates and hence TSS content in tubers. High growth and development rates observed in potato plants supplied with high irrigation water may have resulted in a decrease in photosynthates transferred to the tubers as TSS. However, there was a decrease of TSS in seed potato tubers during storage due to utilization of some by the emerging sprouts.

Firmer tubers with high TSS avoid physical damage and also improve the resultant sprout emergence and vigour. While firmness determines physical strength, TSS increases tuber food reserves, which are critical in growth of the resultant plants. Seed potato tubers have refractive index of crop juices calibrated in percentage sucrose or degree Brix of between 3-8 units (Harrill, 1998). High TSS indicates better seed potato than minimum TSS.

Selection of the right seed potato planting material is one of the most challenging tasks a farmer undertakes to obtain good yields. Small-scale potato farmers are constrained by limited seed potato tuber quantity and quality. As reported by Struik (2006) various quality characteristics affect seed potato tubers. The physiological status of seed potato has been reported to have a great impact on sprouting, number of stems per plant, number of tubers per stem, tuber-size distribution, and tuber yield (Van der Zaag and Van Loon, 1987). The mineral composition of potato tubers is determined to a great extent by the availability of mineral elements in the soil and whose uptake depends on available water. Application of mineral fertilizers increases seed potato tuber TSS. This is true for fertilizers containing both macronutrients such as N, P, K, Ca and Mg (White *et al.*, 2009) and micronutrients such as B, Zn, Fe, Mn, Cu, Mo, Se and I (Karenlampi and White, 2009). The content of potato tuber minerals has been reported to be very different because of differences in nutrient supply and weather conditions (availability of assimilates) (Kolbe and Stefan-Beckmann, 1997). In this study, interaction of the different irrigation water by the applied mineral nutrients may also have influenced the results. Concerning the macroelements N and P that are vital for potato seed quality, P application may play a crucial role in providing rigidity to seed membranes, resulting in firmer seed potato tubers than N application.

Control of seed potato tuber quality through integration of irrigation water, N and P rates is an essential element in the sustainability of the seed industry as it is the basis of high seed potato tuber quality that determines yields obtained. Potato tuber physical and chemical quality characteristics represented by firmness and TSS were influenced by integrated water and nutrient supply. Consequently, this study provides useful information concerning the potential of suitable water and nutrient supply levels in improvement of seed potato quality, which will result in enhanced ware potato productivity. Information herein can be used towards improving the physical and chemical components of seed potato tubers to suit desired potato plant growth.

3.2 Effects on sprouting characteristics and field performance evaluation

The number of sprouts and sprouting percentage decreased with increase in irrigation water, N and P rates. However, the sprout lengths were much longer with the 100% irrigation water rate, while the number of short sprouts was greater in the seed potato tubers grown using low irrigation water rate. Neubauer *et al.* (1967) reported that when seed potato were stored under different relative humidity environments, dry potatoes grew the most numerous short sprouts, while humidified tubers grew much longer and fewer sprouts.

Potato plants supplied with low irrigation water rate attained physiological maturity early and therefore their seed tubers were physiologically older than those from plants supplied with high irrigation water rate. However, the seed potatoes from low irrigation water rate contained less moisture content and were physiologically inactive in storage, resulting in late germination and short sprout length. The high moisture content in the seed potato tubers obtained from high irrigation water rate might have stimulated enzymatic activity, enhancing rapid germination of the eyes and end of the sprouting period. The high moisture facilitated physiological processes leading to early sprouting, as well as longer, but fewer sprouts. The stimulated sprouting in the tubers obtained from high irrigation water rate could have had a negative influence as it caused loss of energy, moisture and enhanced withering.

Potato plants supplied with high irrigation water rate had high growth and development, which could have resulted in less of the photoassimilates being deposited in the tubers. Consequently, these seed potato tubers had low TSS content, which could not have sustained more sprouts. The low TSS possibly resulted in fewer, but longer sprouts. The longer sprouts were primarily due to early germination. However, longer sprouts are tender and susceptible to mechanical damage. Due to the balanced growth and development of potatoes supplied with intermediate irrigation water rate, their seed tubers had average moisture and TSS contents, which resulted in high sprout number, percentage and length. Although potato plants supplied with low irrigation water had seed tubers with high TSS, probably the slightly low moisture content in them could not have promoted better performance as compared to those grown using intermediate irrigation water.

Sprouting refers to development of shoots on tubers. Each seed potato tuber has from two to as many as 10 buds or "eyes". The eyes regenerate shoots that grow into new plants under favourable conditions. Sprouting of tuber "eyes" starts at the end of the dormancy period (Junkeviciene *et al.*, 2011). It is possible that seed potato produced using high irrigation water rate had their natural dormancy broken early and were actively converted their starch into sugar and other nutrients needed for sprout germination and growth, resulting in greater sprout length. Fresh potato tubers are in a state of endogenous dormancy, which must be terminated before sprout growth commences (Kandil *et al.*, 2012). Fresh potato tubers remain dormant for up to 10 weeks, depending on the variety and seasonal weather conditions during the growth period (Kurzinger, 2007). Therefore, tuber sprouting during storage results after cessation of endodormancy. Sanli *et al.* (2010) reported that potato tubers start sprouting when dormancy is broken and sprouts continue to elongate as long as they can obtain nutrients from tubers. The amount of moisture and TSS within the seed potato tuber as a result of different irrigation water rates probably influenced the seed potato quality, including the physiological processes, which led to differences in sprouting characteristics.

It is possible that potato plants supplied with high irrigation, low N and P rates were physiologically disadvantaged, resulting in reduced sprouting. Seed potato growing conditions of different irrigation, N and P rates had an impact on the physiological age, which led to varied sprouting characteristics. In general, the most effective treatments that increased sprouting characteristics were integration of low to intermediate irrigation water rates with high N and P rates. Farmers in the informal sector should, therefore, be made aware of these optimal conditions, under which to grow potatoes destined for use as seed.

When the harvested seed potato tubers were planted in the field to evaluate their growth vigour, better performance was observed with seed potato tubers obtained from potatoes supplied with 65% (intermediate) followed by 40% irrigation water rates. Seed potato tubers from potato plants supplied with 100% irrigation water and lower rates of N and P showed the least growth vigour and performance. In storage, potato losses weight equally from respiration and evaporation (Fernando and Slater, 2010), which impact on its physiological age. Olsen and Hornbacher (2002) reported that age is one of the most important physiological factors associated with seed potato performance, such that as a seed tuber ages it tends to have a short dormancy period, emerges early, produces multiple stems, initiates tubers early and produces more tubers, but of small size. In this study, it is possible that the seed growing conditions of different irrigation water, N and P rates had an impact on the seed physiological age, and consequently variation in post-treatment field performance.

The progress from physiologically young to physiologically mature tubers has been reported to affect yield parameters of the subsequent crop (Oliveira *et al.*, 2012), which include date of emergence, stem number, canopy growth pattern, maturity date, total tuber yield and tuber size distribution (Christiansen *et al.*, 2006). It is possible that potatoes supplied with intermediate irrigation water (65%), high N and P rates experienced balanced growth and development that resulted in seed potato tubers which had better physiological maturity than those supplied with higher or lower irrigation water and similar N and P rates. These seed tubers probably had moisture and TSS contents that enhanced germination of more eyes, sprout maintenance and sprouting percentage. These seed tubers possibly were physiologically better and resulted in better sprouting characteristics, which enabled them to perform better in the field under prevailing management conditions. Their better performance was due to high number of stems, stem density, plant height and the number of tubers on resultant plants. In this study, almost twice to thrice tuber numbers were obtained, compared to those obtained at the Rainshelter trial.

Kleinkopf *et al.* (2003) reported that initiated tubers not carried to harvest are re-absorbed by the plant as it adapts to environmental conditions during growth. The number of tubers that actually reach maturity has also been reported to depend on available moisture and soil nutrients (FAO, 2009).Therefore, not all of the initiated tubers are carried to maturity due to the re-adsorption by the potato plant. This probably explains why the number of tubers decreases at potato maturity.

5.4. General Conclusions and Recommendations

5.4.1 General conclusions

The overall combination of irrigation water, N and P rates affects soil moisture and nutrient content during the potato growing period. This result influences the physiological status of the potato plants, including growth and development status, and the subsequent quality characteristics of the seed potato tubers.

Integration of high irrigation water at 100%, N and P rates at 150 kg N/ha and 101.2 kg P/ha increases potato growth and development rates, provides more photoassimilates for tuber development and leads to more ware potatoes, thereby decreasing the yield of the desired seed potato sizes I and II.

The low irrigation water at 40%, N and P rates at 0 kg N/ha and 0 kg P/ha increases the yield of chats, which are not suitable for use as seed potatoes.

The high rates of N and P also increases the ware potato yields, and improves the physiological quality of the seed potato tubers. High irrigation rate at 100% lowers physiological quality of seed potato tubers.

5.4.2. General recommendations

It is recommended to avoid high irrigation water rates at 100% FC and low N and P rates at 0 kg N/ha and 0 kg P/ha due to their potential negative effects on the size distribution and physiological characteristics of seed potato tubers by reducing the growth vigour and yields of resultant potato crop. The time between planting and emergence is the most delicate period in potato crop production, and this is influenced by seed potato quality, which depends on the growth factors supplied in the field, and determines the seed potato crop performance. Seed quality, therefore, together with the prevailing conditions at planting, plays a major role in potato crop establishment following planting. Although seed potato tubers may appear healthy, they may have poor germination and poor vigour if they were grown under stressful conditions. Therefore, farmers in the informal sector should be aware of the conditions within which they are growing seed potato destined for use in maximizing potato productivity at the farm level.

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APPENDICES

Appendix 1: Irrigation water (L) supplied per main plot at various DAP

		Replicate 1			Replicate 2			Replicate 3		
Day	DAP	65%	40%	100%	40%	100%	65%	100%	65%	40%
1	3	1000	1000	1000	1000	1000	1000	1000	1000	1000
2	4	1000	1000	1000	1000	1000	1000	1000	1000	1000
3	11	435.5	268	670	268	670	435.5	670	435.5	268
4	15	435.5	268	670	268	670	435.5	670	435.5	268
5	19	435.5	268	670	268	670	435.5	670	435.5	268
6	23	435.5	268	670	268	670	435.5	670	435.5	268
7	27	435.5	268	670	268	670	435.5	670	435.5	268
8	31	435.5	268	670	268	670	435.5	670	435.5	268
9	35	435.5	268	670	268	670	435.5	670	435.5	268
10	39	435.5	268	670	268	670	435.5	670	435.5	268
11	43	435.5	268	670	268	670	435.5	670	435.5	268
12	47	435.5	268	670	268	670	435.5	670	435.5	268
13	51	435.5	268	670	268	670	435.5	670	435.5	268
14	55	435.5	268	670	268	670	435.5	670	435.5	268
15	59	435.5	268	670	268	670	435.5	670	435.5	268
16	63	435.5	268	670	268	670	435.5	670	435.5	268
17	67	435.5	268	670	268	670	435.5	670	435.5	268
18	71	435.5	268	670	268	670	435.5	670	435.5	268
19	75	435.5	268	670	268	670	435.5	670	435.5	268
20	79	435.5	268	670	268	670	435.5	670	435.5	268
21	83	435.5	268	670	268	670	435.5	670	435.5	268
22	87	435.5	268	670	268	670	435.5	670	435.5	268
23	91	435.5	268	670	268	670	435.5	670	435.5	268
24	96	435.5	268	670	268	670	435.5	670	435.5	268
25	101	435.5	268	670	268	670	435.5	670	435.5	268
26	106	435.5	268	670	268	670	435.5	670	435.5	268
Total		12,452	8,432	18,080	8,432	18,080	12,452	18,080	12,452	8,432

Appendix 2: Average volumetric water content observed after 2 hours, one, two and three days after irrigation

Sampling	Replicate	Water	VWC1	VWC2	VWC3	VWC4
1	1	1	16.9	11.9	8.8	6.5
1	2	1	24.7	15.3	8.6	6.5
1	3	1	17.3	11.9	9.3	5.6
1	1	2	12.2	8	6.9	4.9
1	2	2	11.4	8.2	6	4.7
1	3	2	12.7	8.1	6.6	4.4
1	1	3	7.7	5.7	4.2	2.9
1	2	3	7.4	6.3	4.5	2.7
1	3	3	7.1	6.5	4.6	2.9
2	1	1	17.4	11.1	8.2	6.1
2	2	1	21.9	14.4	9.7	6.8
2	3	1	17.9	12.7	9.3	6
2	1	2	11.4	8.1	7.2	4.8
2	2	2	12.3	8.9	6.5	4.6
2	3	2	11.7	8.6	6.3	4.8
2	1	3	7.8	5.5	4.2	2.8
2	2	3	7.5	6.9	4.9	3
2	3	3	7.4	5.9	4.3	3
3	1	1	18.4	12.8	8.1	6
3	2	1	23.3	15.9	9.7	6.5
3	3	1	18.3	12.2	9.9	6.2
3	1	2	11.5	8.2	7.1	4.9
3	2	2	12.2	8.3	6.9	4.9
3	3	2	11.3	8.2	6.5	4.9
3	1	3	7.1	5.4	4.9	3.1
3	2	3	7	5.7	4.8	3.2
3	3	3	7.8	5.2	4.5	2.6
Mean percent VWC for irrigation water in four sampling periods		100%	19.6	13.1	9.1	6.2
		65%	11.9	8.3	6.7	4.8
		40%	7.4	5.9	4.5	2.9

Appendix 3: ANOVA table for potato percentage sprout emergence (germination) in RTrials I and II

Source	DF	SS **RTrial I**	Mean Square	F Value	Pr > F	SS **RTrial II**	Mean Square	F Value	Pr > F
Rep.	2	16.210556	8.105278	1.27	0.2863	70.789306	35.394653	2.63	0.0792
Water	2	47.213472	23.606736	3.71	0.0294	249.747639	124.873819	9.27	0.0003
N	3	337.457222	112.485741	17.66	<0.0001	682.434167	227.478056	16.89	<0.0001
P	3	2035.900000	678.633333	106.56	<0.0001	4186.549167	1395.516389	103.60	<0.0001
Rep. * Water	4	22.510694	5.627674	0.88	0.4782	142.048194	35.512049	2.64	0.0408
Water * N	6	16.224861	2.704144	0.42	0.8603	65.154583	10.859097	0.81	0.5685
Rep. * Water * N	18	175.075417	9.726412	1.53	0.1057	124.997500	6.944306	0.52	0.9422
Water * P	6	105.612083	17.602014	2.76	0.0179	29.467917	4.911319	0.36	0.8990
N * P	9	49.240556	5.471173	0.86	0.5653	74.289722	8.254414	0.61	0.7823
Water * N * P	18	120.607361	6.700409	1.05	0.4165	231.756528	12.875363	0.96	0.5179
Error	72	458.530000	6.368472			969.851667	13.470162		
Corrected Total	143	3384.582222				6827.086389			

Appendix 4: ANOVA table for stem numbers per plant in RTriasl I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	0.03174180	0.01587090	0.56	0.5732	0.00998463	0.00499231	0.13	0.8752
Water	2	0.14902355	0.07451178	2.62	0.0744	0.21506188	0.10753094	2.87	0.0578
N	3	0.60321731	0.20107244	7.06	0.0001	0.75545334	0.25181778	6.73	0.0002
P	3	2.97900707	0.99300236	34.88	<0.0001	3.78938640	1.26312880	33.75	<0.0001
Rep. * Water	4	0.01052064	0.00263016	0.09	0.9848	0.01780813	0.00445203	0.12	0.9757
Water * N	6	0.01159138	0.00193190	0.07	0.9988	0.02333598	0.00388933	0.10	0.9959
Rep. * Water * N	18	0.05052648	0.00280703	0.10	1.0000	0.06801536	0.00377863	0.10	1.0000
Water * P	6	0.03281289	0.00546881	0.16	0.9863	0.05217181	0.00869530	0.20	0.9776
N * P	9	0.06972934	0.00774770	0.23	0.9899	0.09997726	0.01110858	0.25	0.9862
Water * N * P	18	0.09713053	0.00539614	0.16	1.0000	0.12872082	0.00715116	0.16	1.0000
Rep. * Water * N * P	72	0.57645989	0.00800639	0.24	1.0000	0.74269688	0.01031523	0.23	1.0000
Error	288	9.67305617	0.03358700			12.73112094	0.04420528		
Corrected Total	431	14.28481706				18.63373343			

Appendix 5: ANOVA table for plant height at 45 DAP in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				**RTrial II**			
Rep.	2	262.976852	131.488426	2.58	0.0770	314.773935	157.386968	3.00	0.0511
Water	2	6077.976852	3038.988426	27.87	<0.0045	6062.106157	3031.053079	27.92	<0.0045
N	3	5466.673611	1822.224537	54.49	<0.0001	5392.840255	1797.613418	50.79	<0.0001
P	3	7278.229167	2426.076389	85.69	<0.0001	8013.927847	2671.309282	119.02	<0.0001
Rep. * Water	4	436.120370	109.030093	2.14	0.0753	434.173426	108.543356	2.07	0.0844
Water * N	6	114.652778	19.108796	0.57	0.7479	160.338843	26.723140	0.76	0.6138
Rep. * Water * N	18	601.902778	33.439043	0.66	0.8531	637.046528	35.391474	0.67	0.8366
Water * P	6	108.708333	18.118056	0.64	0.6979	28.626806	4.771134	0.21	0.9717
N * P	9	312.057870	34.673097	1.22	0.2938	319.911690	35.545743	1.58	0.1365
Water * N * P	18	385.032407	21.390689	0.76	0.7426	312.393380	17.355188	0.77	0.7233
Rep.* Water* N * P	72	2038.555556	28.313272	0.50	0.9997	1615.992778	22.444344	0.37	1.0000
Error	288	16294.66667	56.57870			17276.92667	59.98933		
Corrected Total	431	39377.55324				40569.05831			

Appendix 6: ANOVA table for plant height (cm) at 59 DAP in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				RTrial II			
Rep.	2	1245.42130	622.71065	12.60	<0.0001	1399.69019	699.84509	12.92	<0.0001
Water	2	16369.92130	8184.96065	127.09	<0.0002	18291.47005	9145.73502	128.09	<0.0002
N	3	10021.02546	3340.34182	42.68	<0.0001	11034.24192	3678.08064	40.42	<0.0001
P	3	10993.96991	3664.65664	139.81	<0.0001	12038.33840	4012.77947	139.96	<0.0001
Rep. * Water	4	257.62037	64.40509	1.30	0.2684	285.61148	71.40287	1.32	0.2628
Water * N	6	137.24537	22.87423	0.29	0.9328	190.15162	31.69194	0.35	0.9017
Rep. * Water * N	18	1408.79167	78.26620	1.58	0.0615	1637.83500	90.99083	1.68	0.0408
Water * P	6	237.85648	39.64275	1.51	0.1864	419.94292	69.99049	2.44	0.0332
N * P	9	148.92824	16.54758	0.63	0.7667	266.91447	29.65716	1.03	0.4216
Water * N * P	18	829.05093	46.05838	1.76	0.486	880.78505	48.93250	1.71	0.0579
Rep. * Water * N * P	72	1887.27778	26.21219	0.47	0.9999	2064.25000	28.67014	0.47	0.9999
Error	288	15906.00000	55.22917			17439.82000	60.55493		
Corrected Total	431	59443.10880				65949.05109			

Appendix 7: ANOVA table for plant height (cm) at 73 DAP in RTrials I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	2343.36574	1171.68287	20.64	<0.0001	2672.64292	1336.32146	21.52	<0.0001
Water	2	35114.08796	17557.04398	112.92	<0.0003	37881.63167	18940.81583	141.83	<0.0002
N	3	9839.35880	3279.78627	89.57	<0.0001	10503.05935	3501.01978	81.90	<0.0001
P	3	15569.96991	5189.98997	114.84	<0.0001	17267.71046	5755.90349	123.35	<0.0001
Rep. * Water	4	621.92593	155.48148	2.74	0.0286	534.20083	133.55021	2.15	0.0742
Water * N	6	293.68981	48.94830	1.34	0.2920	263.75426	43.95904	1.03	0.4390
Rep. * Water * N	18	659.09722	36.61651	0.65	0.8633	769.43014	42.74612	0.69	0.8232
Water * P	6	839.41204	139.90201	3.10	0.0094	915.87704	152.64617	3.27	0.0067
N * P	9	413.15046	45.90561	1.02	0.4358	633.48491	70.38721	1.51	0.1614
Water * N * P	18	414.21759	23.01209	0.51	0.9454	709.71037	39.42835	0.84	0.6430
Rep. * Water * N * P	72	3253.83333	45.19213	0.76	0.9205	18998.70000	65.96771	0.71	0.9602
Error	288	17180.66667	59.65509			3359.63722	46.66163		
Corrected Total	431	86542.77546				94509.83917			

Appendix 8: ANOVA table for plant height at 94 DAP in RTrials I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	3618.17130	1809.08565	22.03	<0.0001	4165.08847	2082.54424	23.44	<0.0001
Water	2	47076.47685	23538.23843	112.57	<0.0003	50071.24056	25035.62028	105.27	<0.0003
N	3	10421.80324	3473.93441	34.74	<0.0001	13490.29306	4496.76435	63.55	<0.0001
P	3	24238.91435	8079.63812	136.86	<0.0001	25183.69713	8394.56571	136.67	<0.0001
Rep. * Water	4	836.42593	209.10648	2.55	0.0392	951.26181	237.81545	2.68	0.0317
Water * N	6	355.13426	59.18904	0.59	0.7327	367.38056	61.23009	0.87	0.5385
Rep. * Water * N	18	1799.79167	99.98843	1.22	0.2434	1273.63972	70.75776	0.80	0.7048
Water * P	6	1248.18981	208.03164	3.52	0.0041	1934.95315	322.49219	5.25	0.0002
N * P	9	1730.61343	192.29038	3.26	0.0023	1604.21787	178.24643	2.90	0.0055
Water * N * P	18	1355.31019	75.29501	1.28	0.2301	1373.61241	76.31180	1.24	0.2528
Rep. * Water * N * P	72	4250.72222	59.03781	0.67	0.9777	4422.24111	61.42002	0.64	0.9872
Error	288	25306.6667	87.8704			27560.1533	95.6950		
Corrected Total	431	122238.2199				132397.7792			

Appendix 9: ANOVA table for plant height at 108 DAP in RTrials I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	8088.11574	4044.05787	31.49	<0.0001	8028.35574	4014.17787	33.92	<0.0001
Water	2	76714.39352	38357.19676	47.61	<0.0016	82466.73282	41233.36641	42.63	<0.0020
N	3	20076.78472	6692.26157	27.27	<0.0001	20873.10796	6957.70265	31.63	<0.0001
P	3	34569.96991	11523.32330	112.88	<0.0001	35509.04315	11836.34772	111.23	<0.0001
Rep. * Water	4	3222.59259	805.64815	6.27	<0.0001	3869.18787	967.29697	8.17	<0.0001
Water * N	6	3042.40278	507.06713	2.07	0.1088	3728.08384	621.34731	2.83	<0.0407
Rep. * Water * N	18	4416.62500	245.36806	1.91	0.0142	3958.95694	219.94205	1.86	0.0182
Water * P	6	4449.21759	741.53627	7.26	<0.0001	4917.41532	819.56922	7.70	<0.0001
N * P	9	3337.00231	370.77803	3.63	0.0009	3205.80074	356.20008	3.35	0.0018
Water * N * P	18	4485.83796	249.21322	2.44	0.0040	5190.15690	288.34205	2.71	0.0015
Rep. * Water * N * P	72	7350.22222	102.08642	0.76	0.921	7661.97056	106.41626	0.88	0.7443
Error	288	38878.0000	134.9931			34947.0933	121.3441		
Corrected Total	431	208631.1644				214355.9052			

Appendix 10: ANOVA table for leaf stomatal conductivity at 59 DAP in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				**RTrial II**			
Rep.	2	2843537.290	1421768.645	7727.97	<0.0001	3322982.706	1661491.353	7215.40	<0.0001
Water	2	78921.925	39460.962	3.90	<0.1150	88172.367	44086.184	3.99	<0.1113
N	3	39685.289	13228.430	7.52	<0.0018	34987.811	11662.604	10.03	<0.0004
P	3	33449.047	11149.682	37.52	<0.0001	41852.840	13950.947	38.52	<0.0001
Rep. * Water	4	40500.900	10125.225	55.04	<0.0001	44148.588	11037.147	47.93	<0.0001
Water * N	6	1326.271	221.045	0.13	0.9916	1931.602	321.934	0.28	0.9405
Rep. * Water * N	18	31654.539	1758.586	9.56	<0.0001	20927.752	1162.653	5.05	<0.0001
Water * P	6	548.303	91.384	0.31	0.9311	1440.797	240.133	0.66	0.6796
N * P	9	2439.896	271.100	0.91	0.5197	2307.454	256.384	0.71	0.6997
Water * N * P	18	3322.216	184.568	0.62	0.8716	2824.568	156.920	0.43	0.9755
Rep. * Water * N * P	72	21398.571	297.202	1.91	0.0001	26075.619	362.161	1.84	0.0002
Error	288	44833.147	155.671			56821.673	197.297		
Corrected Total	431	3141617.393				3644473.777			

Appendix 11: ANOVA table for leaf stomatal conductivity at 73 DAP in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				**RTrial II**			
Rep.	2	3547048.911	1773524.455	6795.16	<0.0001	3777697.584	1888848.792	6987.71	<0.0001
Water	2	95193.317	47596.658	4.12	<0.1069	77234.049	38617.025	3.71	<0.1227
N	3	44270.193	14756.731	8.45	<0.0010	47107.521	15702.507	8.10	<0.0013
P	3	48077.867	16025.956	32.05	<0.0001	48924.664	16308.221	35.53	<0.0001
Rep. * Water	4	46250.309	11562.577	44.30	<0.0001	41638.459	10409.615	38.51	<0.0001
Water * N	6	4528.253	754.709	0.43	0.8478	3576.275	596.046	0.31	0.9249
Rep. * Water * N	18	31433.194	1746.289	6.69	<0.0001	34898.367	1938.798	7.17	<0.0001
Water * P	6	1731.464	288.577	0.67	0.6763	1277.097	212.849	0.46	0.8329
N * P	9	4519.519	502.169	1.16	0.3330	5267.322	585.258	1.27	0.2654
Water * N * P	18	6256.373	347.576	0.80	0.1645	5128.782	284.932	0.62	0.8718
Rep. * Water * N * P	72	31142.270	432.532	1.98	<0.0001	33050.995	459.042	2.06	<0.0001
Error	288	62817.027	218.115			64260.600	223.127		
Corrected Total	431	3923268.696				4140061.716			

Appendix 12: ANOVA table for leaf stomatal conductivity at 87 DAP in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				**RTrial II**			
Rep.	2	2346402.208	1173201.104	5307.62	<0.0001	2209647.753	1104823.877	7276.86	<0.0001
Water	2	80235.819	40117.909	3.75	<0.1208	82410.792	41205.396	3.28	<0.1433
N	3	40282.511	13427.504	9.29	<0.0006	35148.038	11716.013	8.69	<0.0009
P	3	31575.271	10525.090	32.22	<0.0001	43300.518	14433.506	31.31	<0.0001
Rep. * Water	4	42738.547	10684.637	48.34	<0.0001	50212.118	12553.030	82.68	<0.0001
Water * N	6	3096.495	516.082	0.36	0.8963	1325.499	220.917	0.16	0.9833
Rep. * Water * N	18	26005.271	1444.737	6.54	<0.0001	24279.695	1348.872	8.88	<0.0001
Water * P	6	590.441	98.407	0.30	0.9343	1784.201	297.367	0.64	0.6939
N * P	9	2703.843	300.427	0.92	0.5134	2926.074	325.119	0.71	0.7022
Water * N * P	18	1547.156	85.953	0.26	0.9987	5119.560	284.420	0.62	0.8749
Rep. * Water * N * P	72	23520.521	326.674	1.68	0.0016	33195.494	461.049	6.19	<0.0001
Error	288	56054.233	194.633			21462.200	74.522		
Corrected Total	431	2654752.315				2510811.942			

Appendix 13: ANOVA table for leaf Chlorophyll Content Index at 59 DAP in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				**RTrial II**			
Rep.	2	56.78804	28.39402	0.94	0.3916	7.23267	3.61634	0.12	0.8833
Water	2	6356.47192	3178.23596	46.28	<0.0017	5330.57517	2665.28759	141.77	<0.0002
N	3	5141.30868	1713.76956	28.39	<0.0001	2439.93991	813.31330	11.60	<0.0002
P	3	12504.95842	4168.31947	153.11	<0.0001	11549.62991	3849.87664	92.21	<0.0001
Rep. * Water	4	274.71077	68.67769	2.27	0.0598	75.20051	18.80013	0.64	0.6305
Water * N	6	599.64142	99.94024	1.66	0.1895	893.78617	148.96436	2.13	<0.1005
Rep. * Water * N	18	1086.61192	60.36733	1.99	0.0079	1261.50122	70.08340	2.40	0.0009
Water * P	6	378.29994	63.04999	2.32	0.0422	676.33047	112.72174	2.70	0.0202
N * P	9	621.59438	69.06604	2.54	0.0137	369.87658	41.09740	0.98	0.4605
Water * N * P	18	748.98399	41.61022	1.53	0.1052	804.98403	44.72134	1.07	0.3978
Rep. * Water * N * P	72	1960.11368	27.22380	0.89	0.7226	3006.21564	41.75300	1.47	0.0075
Error	1152	35081.41520	30.45262			32675.86409	28.36447		
Corrected Total	1295	64810.89836				59091.13638			

Appendix 14: ANOVA table for leaf Chlorophyll Content Index at 73 DAP in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				**RTrial II**			
Rep.	2	1984.57514	992.28757	17.69	<0.0001	359.09242	179.54621	2.77	0.0628
Water	2	7494.20227	3747.10113	9.78	<0.0288	8436.88807	4218.44404	49.08	<0.0015
N	3	14664.24873	4888.08291	15.61	<0.0001	10620.42799	3540.14266	24.19	<0.0001
P	3	22184.39459	7394.79820	83.80	<0.0001	20177.66428	6725.88809	87.37	<0.0001
Rep. * Water	4	1531.79801	382.94950	6.83	<0.0001	343.81304	85.95326	1.33	0.2573
Water * N	6	353.62069	58.93678	0.19	0.9763	329.26051	54.87675	0.37	0.8854
Rep. * Water * N	18	5636.07037	313.11502	5.58	<0.0001	2634.58935	146.36608	2.26	0.0019
Water * P	6	1242.80465	207.13411	2.35	0.0398	2095.67144	349.27857	4.54	<0.0006
N * P	9	1335.71242	148.41249	1.68	0.1092	1043.23766	115.91530	1.51	0.1624
Water * N * P	18	1239.81437	68.87858	0.78	0.7153	2538.41579	141.02310	1.83	0.0374
Rep. * Water * N * P	72	6353.52759	88.24344	1.63	0.0009	5542.74222	76.98253	1.20	0.1231
Error	1152	62304.7311	54.0840			73662.3244	63.9430		
Corrected Total	1295	126325.4999				127784.1272			

Appendix 15: ANOVA table for leaf Chlorophyll Content Index at 87 DAP in RTrials I and II

Source	**DF**	**SS**	**Mean Square**	**F Value**	**Pr > F**	**SS**	**Mean Square**	**F Value**	**Pr > F**
		RTrial I				**RTrial II**			
Rep.	2	50.75816	25.37908	0.91	0.4024	120.383997	60.191998	2.21	0.1106
Water	2	2514.99835	1257.49917	13.49	<0.0167	6590.458812	3295.229406	27.77	<0.0045
N	3	6591.12064	2197.04021	15.24	<0.0001	3921.813395	1307.271132	15.85	<0.0001
P	3	11338.73743	3779.57914	101.30	<0.0001	8770.176173	2923.392058	95.44	<0.0001
Rep. * Water	4	372.77957	93.19489	3.34	0.0098	474.618549	118.654637	4.35	0.0017
Water * N	6	798.28202	133.04700	0.92	<0.5019	971.340633	161.890105	1.96	<0.1251
Rep. * Water * N	18	2595.70338	144.20574	5.18	<0.0001	1484.870972	82.492832	3.02	<0.0001
Water * P	6	719.26060	119.87677	3.21	0.0075	1098.071559	183.011926	5.97	<0.0001
N * P	9	777.13593	86.34844	2.31	0.0239	606.931420	67.436824	2.20	0.0316
Water * N * P	18	1645.20742	91.40041	2.45	<0.0039	1890.649738	105.036097	3.43	<0.0001
Rep. * Water * N * P	72	2686.34111	37.31029	1.37	0.0250	2205.338333	30.629699	1.13	0.2180
Error	1152	31415.68889	27.27056			31201.37333	27.08453		
Corrected Total	1295	61506.01351				59336.02691			

Appendix 16: ANOVA table for LAI at 51 DAP in RTrials I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	0.03378472	0.01689236	4.31	0.0142	0.00418380	0.00209190	0.69	0.5000
Water	2	53.60250417	26.80125208	363.06	<0.0001	10.53672407	5.26836204	224.55	<0.0001
N	3	19.69795069	6.56598356	507.52	<0.0001	4.44548588	1.48182863	326.11	<0.0001
P	3	32.76436736	10.92145579	725.46	<0.0001	3.42453588	1.14151196	269.22	<0.0001
Rep. * Water	4	0.29528194	0.07382049	18.82	<0.0001	0.09384676	0.02346169	7.79	<0.0001
Water * N	6	4.13402917	0.68900486	53.26	<0.0001	0.77647037	0.12941173	28.48	<0.0001
Rep. * Water * N	18	0.23287222	0.01293735	3.30	<0.0001	0.08179167	0.00454398	1.51	0.0837
Water * P	6	2.57846250	0.42974375	28.55	<0.0001	0.09008704	0.01501451	3.54	<0.0040
N * P	9	0.25896134	0.02877348	1.91	<0.0638	0.06470949	0.00718994	1.70	0.1058
Water * N * P	18	1.13998935	0.06333274	4.21	<0.0001	0.26557037	0.01475391	3.48	<0.0001
Rep. * Water * N * P	72	1.08392778	0.01505455	13.20	<0.0001	0.30528889	0.00424012	1.57	0.0054
Error	288	0.3284000	0.0011403			0.77913333	0.00270532		
Corrected Total	431	116.1505313				20.86782755			

Appendix 17: ANOVA table for LAI at 64 DAP in RTrials I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	0.05547269	0.02773634	3.61	0.0279	0.03895741	0.01947870	1.61	0.2018
Water	2	96.80819491	48.40409745	385.75	<0.0001	71.60345741	35.80172870	375.25	<0.0001
N	3	35.95066111	11.98355370	512.81	<0.0001	26.24263032	8.74754344	481.87	<0.0001
P	3	58.38710370	19.46236790	708.31	<0.0001	43.55211921	14.51737307	708.80	<0.0001
Rep. * Water	4	0.50192593	0.12548148	16.35	<0.0001	0.38163009	0.09540752	7.87	<0.0001
Water * N	6	7.57022917	1.26170486	53.99	<0.0001	5.52693148	0.92115525	50.74	<0.0001
Rep. * Water * N	18	0.42063472	0.02336860	3.05	<0.0001	0.32675694	0.01815316	1.50	0.0873
Water * P	6	4.58220880	0.76370147	27.79	<0.0001	3.39429259	0.56571543	27.62	<0.0001
N * P	9	0.48849815	0.05427757	1.98	<0.0547	0.35126505	0.03902945	1.91	0.0646
Water * N * P	18	2.04138935	0.11341052	4.13	<0.0001	1.50203704	0.08344650	4.07	<0.0001
Rep. * Water * N * P	72	1.97836667	0.02747731	10.09	<0.0001	1.47467778	0.02048164	2.04	<0.0001
Error	288	0.7840000	0.0027222			2.8871333	0.0100248		
Corrected Total	431	209.5686852				157.2818887			

Appendix 18: ANOVA table for days to 50% flowering in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				**RTrial II**			
Rep.	2	57.555556	28.777778	19.58	<0.0001	68.097222	34.048611	26.08	<0.0001
Water	2	5341.430556	2670.715278	1816.93	<0.0001	5577.555556	2788.777778	2136.09	<0.0001
N	3	2734.409722	911.469907	620.09	<0.0001	706.909722	902.303241	691.13	<0.0001
P	3	442.187500	147.395833	100.28	<0.0001	335.409722	111.803241	85.64	<0.0001
Rep. * Water	4	68.819444	17.204861	11.70	<0.0001	80.361111	20.090278	15.39	<0.0001
Water * N	6	30.902778	5.150463	3.50	0.0043	19.777778	3.296296	2.52	0.0283
Rep. * Water * N	18	169.125000	9.395833	6.39	<0.0001	202.875000	11.270833	8.63	<0.0001
Water * P	6	13.458333	2.243056	1.53	0.1820	2.111111	0.351852	0.27	0.9494
N * P	9	52.951389	5.883488	4.00	0.0004	30.673611	3.408179	2.61	0.0114
Water * N * P	18	17.319444	0.962191	0.65	0.8429	12.555556	0.697531	0.53	0.9320
Error	72	105.833333	1.469907			94.000000	1.305556		
Corrected Total	143	9033.993056				9130.326389			

Appendix 19: ANOVA table for days to physiological maturity in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				RTrial II			
Rep.	2	54.500000	27.250000	8.37	0.0005	30.125000	15.062500	4.95	0.0097
Water	2	1421.791667	710.895833	218.43	<0.0001	1426.041667	713.020833	234.42	<0.0001
N	3	8116.722222	2705.574074	831.30	<0.0001	8794.465278	2931.488426	963.78	<0.0001
P	3	2926.722222	975.574074	299.75	<0.0001	2929.243056	976.414352	321.01	<0.0001
Rep. * Water	4	84.958333	21.239583	6.53	0.0002	65.958333	16.489583	5.42	0.0007
Water * N	6	7.986111	1.331019	0.41	0.8708	7.680556	1.280093	0.42	0.8628
Rep. * Water * N	18	35.541667	1.974537	0.61	0.8830	48.916667	2.717593	0.89	0.5878
Water * P	6	113.486111	18.914352	5.81	<0.0001	112.736111	18.789352	6.18	<0.0001
N * P	9	16.555556	1.839506	0.57	0.8211	13.395833	1.488426	0.49	0.8772
Water * N * P	18	15.402778	0.855710	0.26	0.9987	8.875000	0.493056	0.16	1.0000
Error	72	234.33333	3.25463			219.00000	3.04167		
Corrected Total	143	13028.00000				13656.43750			

Appendix 20: ANOVA table for total dry biomass at harvest in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				**RTrial II**			
Rep.	2	76.6392	38.3196	0.14	0.8720	240.8589	120.4295	0.52	0.5930
Water	2	204492.6613	102246.3306	365.74	<0.0001	377421.7572	188710.8786	819.92	<0.0001
N	3	179570.6230	59856.8743	214.11	<0.0001	321475.2717	107158.4239	465.59	<0.0001
P	3	202981.6316	67660.5439	242.02	<0.0001	372328.9133	124109.6378	539.24	<0.0001
Rep. * Water	4	63955.2977	15988.8244	57.19	<0.0001	132926.4715	33231.6179	144.39	<0.0001
Water * N	6	6077.1427	1012.8571	3.62	<0.0017	16234.7731	2705.7955	11.76	<0.0001
Rep. * Water * N	18	10174.1684	565.2316	2.09	0.0083	11450.9084	636.1616	2.76	0.0002
Water * P	6	3503.1595	583.8599	2.09	0.0539	20463.3856	3410.5643	14.82	<0.0001
N * P	9	11685.2451	1298.3606	4.64	<0.0001	26407.6702	2934.1856	12.75	<0.0001
Water * N * P	18	6503.2036	361.2891	1.29	0.1892	17777.7147	987.6508	4.29	<0.0001
Error	360	100642.0420	279.5612			82856.759	230.158		
Corrected Total	431	789661.8140				1379584.484			

Appendix 21: ANOVA table for number of tubers per plant at harvest in RTrial Is and II

Source	**DF**	**SS**	**Mean Square**	**F Value**	**Pr > F**	**SS**	**Mean Square**	**F Value**	**Pr > F**
		RTrial I				**RTrial II**			
Rep.	2	9.418056	4.709028	5.94	0.0027	20.251389	10.125694	7.42	0.0006
Water	2	1031.726389	515.863194	651.12	<0.0001	1433.151389	716.575694	525.25	<0.0001
N	3	461.147222	153.715741	194.02	<0.0001	701.496528	233.832176	171.40	<0.0001
P	3	242.469444	80.823148	102.01	<0.0001	429.468750	143.156250	104.93	<0.0001
Rep. * Water	4	3.644444	0.911111	1.15	0.3314	4.090278	1.022569	0.75	0.5583
Water * N	6	37.873611	6.312269	7.97	<0.0001	24.743056	4.123843	3.02	0.0061
Rep. * Water * N	18	17.104167	0.950231	1.20	0.2528	35.041667	1.946759	1.43	0.1094
Water * P	6	49.268056	8.211343	10.36	<0.0001	75.537500	12.589583	9.23	<0.0001
N * P	9	21.069444	2.341049	2.95	0.0018	22.661806	2.517978	1.85	0.0562
Water * N * P	18	12.109722	0.672762	0.85	0.6421	23.990278	1.332793	0.98	0.4840
Error	1368	1083.833333	0.792276			1866.316667	1.364267		
Corrected Total	1439	2969.663889				4636.749306			

Appendix 22: ANOVA table for tuber yield (t/ha) in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				**RTrial II**			
Rep.	2	42.346876	21.173438	4.21	0.0187	116.784085	58.392042	14.37	<0.0001
Water	2	2841.486485	1420.743242	282.44	<0.0001	3253.490518	1626.745259	400.33	<0.0001
N	3	3934.971406	1311.657135	260.75	<0.0001	5752.720483	1917.573494	471.90	<0.0001
P	3	2855.639000	951.879667	189.23	<0.0001	3674.045789	1224.681930	301.38	<0.0001
Rep. * Water	4	134.523207	33.630802	6.69	0.0001	52.139411	13.034853	3.21	0.0176
Water * N	6	231.243249	38.540541	7.66	<0.0001	217.877104	36.312851	8.94	<0.0001
Rep. * Water * N	18	133.793633	7.432980	1.48	0.1240	137.640388	7.646688	1.88	0.0313
Water * P	6	183.685371	30.614228	6.09	<0.0001	123.018965	20.503161	5.05	0.0002
N * P	9	136.564461	15.173829	3.02	0.0041	284.814983	31.646109	7.79	<0.0001
Water * N * P	18	65.544851	3.641381	0.72	0.7759	51.101146	2.838953	0.70	0.8013
Error	72	362.18142	5.03030			292.57352	4.06352		
Corrected Total	143	10921.97996				13956.20639			

Appendix 23: ANOVA table for ware potato (t/ha) in RTrials I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	2.0109722	1.0054861	0.58	0.5652	9.8082292	4.9041146	6.02	0.0038
Water	2	478.7662847	239.3831424	136.92	<0.0001	682.5596375	341.2798188	419.08	<0.0001
N	3	547.4299687	182.4766562	104.37	<0.0001	681.8851611	227.2950537	279.11	<0.0001
P	3	434.1939243	144.7313081	82.78	<0.0001	421.8996167	140.6332056	172.69	<0.0001
Rep. * Water	4	8.0268444	2.0067111	1.15	0.3412	1.1050958	0.2762740	0.34	0.8506
Water * N	6	29.9784542	4.9964090	2.86	0.0149	32.9702514	5.4950419	6.75	<0.0001
Rep. * Water * N	18	35.0780333	1.9487796	1.11	0.3567	33.9156250	1.8842014	2.31	0.0065
Water * P	6	52.1715319	8.6952553	4.97	0.0003	39.1079292	6.5179882	8.00	<0.0001
N * P	9	20.2550674	2.2505630	1.29	0.2588	16.7011111	1.8556790	2.28	0.0261
Water * N * P	18	16.9298181	0.9405454	0.54	0.9298	12.7874264	0.7104126	0.87	0.6118
Error	72	125.880883	1.748346			58.633117	0.814349		
Corrected Total	143	1750.721783				1991.373200			

Appendix 24: ANOVA table for seed size II (t/ha) RTrials I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	21.7733931	10.8866965	13.83	<0.0001	38.0862764	19.0431382	13.63	<0.0001
Water	2	559.7586764	279.8793382	355.52	<0.0001	679.7508931	339.8754465	243.22	<0.0001
N	3	763.5594243	254.5198081	323.31	<0.0001	924.5921694	308.1973898	220.55	<0.0001
P	3	430.8928021	143.6309340	182.45	<0.0001	570.1208028	190.0402676	135.99	<0.0001
Rep. * Water	4	42.6341111	10.6585278	13.54	<0.0001	55.6145194	13.9036299	9.95	<0.0001
Water * N	6	66.6868236	11.1144706	14.12	<0.0001	69.9476514	11.6579419	8.34	<0.0001
Rep. * Water * N	18	37.3047958	2.0724887	2.63	0.0020	61.5920042	3.4217780	2.45	0.0039
Water * P	6	9.1941458	1.5323576	1.95	0.0848	32.7286014	5.4547669	3.90	0.0020
N * P	9	63.5739563	7.0637729	8.97	<0.0001	91.0225361	10.1136151	7.24	<0.0001
Water * N * P	18	19.5079542	1.0837752	1.38	0.1702	43.4444097	2.4135783	1.73	0.0539
Error	72	56.680767	0.787233			100.614200	1.397419		
Corrected Total	143	2071.566849				2667.514064			

Appendix 25: ANOVA table for seed size I (t/ha) in both RTrials I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	0.9780847	0.4890424	0.19	0.8268	3.2303931	1.6151965	0.76	0.4703
Water	2	312.1710764	156.0855382	60.87	<0.0001	311.6791681	155.8395840	73.54	<0.0001
N	3	308.4833611	102.8277870	40.10	<0.0001	595.9090910	198.6363637	93.74	<0.0001
P	3	327.8323889	109.2774630	42.61	<0.0001	548.2435521	182.7478507	86.24	<0.0001
Rep. * Water	4	17.5404986	4.3851247	1.71	0.1571	12.5704944	3.1426236	1.48	0.2163
Water * N	6	33.5019681	5.5836613	2.18	0.0550	11.7313819	1.9552303	0.92	0.4839
Rep. * Water * N	18	23.1543333	1.2863519	0.50	0.9491	21.8830958	1.2157275	0.57	0.9071
Water * P	6	14.4717236	2.4119539	0.94	0.4716	6.0460375	1.0076729	0.48	0.8244
N * P	9	10.9820167	1.2202241	0.48	0.8862	34.6042174	3.8449130	1.81	0.0802
Water * N * P	18	27.0882542	1.5049030	0.59	0.8979	28.4999014	1.5833279	0.75	0.7514
Error	72	184.630417	2.564311			152.568017	2.119000		
Corrected Total	143	1260.834122				1726.965349			

Appendix 26: ANOVA table for Chata (small sized tubers) (t/ha) in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				RTrial II			
Rep.	2	1.31962917	0.65981458	7.45	0.0011	2.25759306	1.12879653	10.52	<0.0001
Water	2	10.13011667	5.06505833	57.21	<0.0001	14.94621806	7.47310903	69.66	<0.0001
N	3	15.01791875	5.00597292	56.54	<0.0001	20.46425833	6.82141944	63.58	<0.0001
P	3	17.85381875	5.95127292	67.22	<0.0001	23.43700278	7.81233426	72.82	<0.0001
Rep. * Water	4	1.32797917	0.33199479	3.75	0.0079	0.79063611	0.19765903	1.84	0.1301
Water * N	6	2.09565000	0.34927500	3.94	0.0018	1.98645417	0.33107569	3.09	0.0096
Rep. * Water * N	18	2.13762500	0.11875694	1.34	0.1894	3.54103750	0.19672431	1.83	0.0371
Water * P	6	1.17336667	0.19556111	2.21	0.0518	0.86870972	0.14478495	1.35	0.2468
N * P	9	1.10906736	0.12322971	1.39	0.2080	0.92371389	0.10263488	0.96	0.4827
Water * N * P	18	1.69682222	0.09426790	1.06	0.4040	1.55777361	0.08654298	0.81	0.6862
Error	72	6.37470000	0.08853750			7.72420000	0.10728056		
Corrected Total	143	60.23669375				78.49759722			

Appendix 27: ANOVA table for Harvest Index (%) in RTrials I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	47.0130597	23.5065299	7.66	0.0010	44.0306542	22.0153271	10.90	<0.0001
Water	2	795.7001931	397.8500965	129.66	<0.0001	601.5810125	300.7905063	148.90	<0.0001
N	3	616.6975722	205.5658574	66.99	<0.0001	650.5636250	216.8545417	107.35	<0.0001
P	3	237.4243056	79.1414352	25.79	<0.0001	170.1623417	56.7207806	28.08	<0.0001
Rep. * Water	4	72.4097903	18.1024476	5.9	0.0004	9.9767958	2.4941990	1.23	0.3039
Water * N	6	38.9223736	6.4870623	2.11	0.0620	21.2578542	3.5429757	1.75	0.1210
Rep. * Water * N	18	75.9340167	4.2185565	1.37	0.1711	51.2922333	2.8495685	1.41	0.1533
Water * P	6	18.1845403	3.0307567	0.99	0.4401	11.6875542	1.9479257	0.96	0.4556
N * P	9	47.9759111	5.3306568	1.74	0.0961	67.0993194	7.4554799	3.69	0.0008
Water * N * P	18	68.9984264	3.8332459	1.25	0.248	52.1552681	2.8975149	1.43	0.1423
Error	72	220.927867	3.068443			145.449317	2.020129		
Corrected Total	143	2240.188056				1825.255975			

Appendix 28: ANOVA table for weight in water (5 kg) and specific density of seed tubers in RTrials I and II

Weight of tubers	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
Source		**RTrial I**				**RTrial II**			
Water	2	0.10791667	0.05395833	28.08	<0.0001	0.15791667	0.07895833	57.81	<0.0001
N	3	0.07895833	0.02631944	13.70	<0.0001	0.07229167	0.02409722	17.64	<0.0001
P	3	0.08229167	0.02743056	14.28	<0.0001	0.07062500	0.02354167	17.24	<0.0001
Water * N	6	0.00541667	0.00090278	0.47	0.8217	0.00375000	0.00062500	0.46	0.8303
Water * P	6	0.01208333	0.00201389	1.05	0.4279	0.00708333	0.00118056	0.86	0.5392
N * P	9	0.02354167	0.00261574	1.36	0.2752	0.03354167	0.00372685	2.73	0.0334
Error	18	0.03458333	0.00192130			0.02458333	0.00136574		
Total	47	0.34479167				0.36979167			

Specific density of seed tubers

Water	2	0.00702917	0.00351458	27.36	<0.0001	0.01052917	0.00526458	55.34	<0.0001
N	3	0.00481667	0.00160556	12.50	0.0001	0.00457500	0.00152500	16.03	<0.0001
P	3	0.00541667	0.00180556	14.05	<0.0001	0.00434167	0.00144722	15.21	<0.0001
Water * N	6	0.00027083	0.00004514	0.35	0.8999	0.00028750	0.00004792	0.50	0.7975
Water * P	6	0.00092083	0.00015347	1.19	0.3532	0.00047083	0.00007847	0.82	0.5655
N * P	9	0.00140000	0.00015556	1.21	0.3472	0.00187500	0.00020833	2.19	0.0750
Error	18	0.00231250	0.00012847			0.00171250	0.00009514		
Total	47	0.02216667				0.02379167			

Appendix 29: ANOVA table for starch and dry matter contents of seed potato tubers in RTrials I and II

Starch content	**DF**	**SS**	**Mean Square**	**F Value**	**Pr > F**	**SS**	**Mean Square**	**F Value**	**Pr > F**
Source (%)		**RTrial I**				**RTrial II**			
Water	2	74.67780417	37.33890208	28.47	<0.0001	110.7172042	55.3586021	56.11	<0.0001
N	3	54.89910625	18.29970208	13.95	<0.0001	49.6986896	16.5662299	16.79	<0.0001
P	3	56.67037292	18.89012431	14.40	<0.0001	51.5231396	17.1743799	17.41	<0.0001
Water * N	6	4.23016250	0.70502708	0.54	0.7729	2.3983792	0.3997299	0.41	0.8660
Water * P	6	8.68639583	1.44773264	1.10	0.3980	5.5395792	0.9232632	0.94	0.4937
N * P	9	16.90278542	1.87808727	1.43	0.2465	24.3968188	2.7107576	2.75	0.0325
Error	18	23.6077708	1.3115428			17.7602375	0.9866799		
Corrected Total	47	239.6743979				262.0340479			

Dry matter content of seed tubers (%)

Water	2	149.8887500	74.9443750	28.49	<0.0001	222.0929167	111.0464583	56.48	<0.0001
N	3	109.8606250	36.6202083	13.92	<0.0001	99.5139583	33.1713194	16.87	<0.0001
P	3	113.8022917	37.9340972	14.42	<0.0001	102.7472917	34.2490972	17.42	<0.0001
Water * N	6	8.3212500	1.3868750	0.53	0.7804	4.8654167	0.8109028	0.41	0.8611
Water * P	6	17.5045833	2.9174306	1.11	0.3953	10.9520833	1.8253472	0.93	0.4982
N * P	9	33.7102083	3.7455787	1.42	0.2496	48.4835417	5.3870602	2.74	0.0328
Error	18	47.3454167	2.6303009			35.3895833	1.9660880		
Total	47	480.4331250				524.0447917			

Appendix 30: ANOVA table for tuber tissue N content (%) at harvest in RTrials I and I

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				RTrial II			
Rep.	2	0.90462222	0.45231111	128.66	<0.0001	0.16751667	0.08375833	15.74	<0.0001
Water	2	10.10381806	5.05190903	1437.03	<0.0001	6.61848750	3.30924375	622.05	<0.0001
N	3	15.84595208	5.28198403	1502.48	<0.0001	39.03290000	13.01096667	2445.71	<0.0001
P	3	1.30380764	0.43460255	123.62	<0.0001	3.24452778	1.08150926	203.29	<0.0001
Rep. * Water	4	0.34338194	0.08584549	24.42	<0.0001	0.55183333	0.13795833	25.93	<0.0001
Water * N	6	0.05062083	0.00843681	2.40	0.0360	0.67931250	0.11321875	21.28	<0.0001
Rep. * Water * N	18	0.68074583	0.03781921	10.76	<0.0001	0.87415000	0.04856389	9.13	<0.0001
Water * P	6	0.01304861	0.00217477	0.62	0.7147	0.04978472	0.00829745	1.56	0.1715
N * P	9	0.00388403	0.00043156	0.12	0.9990	0.12366111	0.01374012	2.58	0.0123
Water * N * P	18	0.04146806	0.00230378	0.66	0.8422	0.07599306	0.00422184	0.79	0.7009
Error	72	0.25311667	0.00351551			0.38303333	0.00531991		
Corrected Total	143	29.54446597				51.80120000			

Appendix 31: ANOVA table for tuber tissue P (%) content at harvest in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				**RTrial II**			
Rep.	2	0.00491806	0.00245903	11.12	<0.0001	0.00061250	0.00030625	2.30	0.1079
Water	2	0.15682222	0.07841111	354.70	<0.0001	0.10151250	0.05075625	380.67	<0.0001
N	3	0.54932986	0.18310995	828.31	<0.0001	0.45480833	0.15160278	1137.02	<0.0001
P	3	0.05571875	0.01857292	84.02	<0.0001	0.04449722	0.01483241	111.24	<0.0001
Rep. * Water	4	0.02182778	0.00545694	24.68	<0.0001	0.01033750	0.00258438	19.38	<0.0001
Water * N	6	0.00512222	0.00085370	3.86	0.0021	0.00937083	0.00156181	11.71	<0.0001
Rep. * Water * N	18	0.01840417	0.00102245	4.63	<0.0001	0.00698333	0.00038796	2.91	0.0007
Water * P	6	0.00038333	0.00006389	0.29	0.9404	0.00118194	0.00019699	1.48	0.1981
N * P	9	0.00255625	0.00028403	1.28	0.2601	0.00153611	0.00017068	1.28	0.2627
Water * N * P	18	0.00365000	0.00020278	0.92	0.5609	0.00173472	0.00009637	0.72	0.7770
Error	72	0.01591667	0.00022106			0.00960000	0.00013333		
Corrected Total	143	0.8346493				0.64217500			

Appendix 32: ANOVA table for WUE (kg/m³) RTrials I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	20.130060	10.065030	6.43	0.0027	41.420560	20.710280	13.73	<0.0001
Water	2	1182.546168	591.273084	377.98	<0.0001	1905.697106	952.848553	631.77	<0.0001
N	3	1043.173914	347.724638	222.29	<0.0001	1556.992697	518.997566	344.11	<0.0001
P	3	733.866625	244.622208	156.38	<0.0001	997.860230	332.620077	220.54	<0.0001
Rep. * Water	4	48.907769	12.226942	7.82	<0.0001	23.784986	5.946247	3.94	0.0060
Water * N	6	40.919449	6.819908	4.36	0.0008	50.801006	8.466834	5.61	<0.0001
Rep. * Water * N	18	32.162337	1.786797	1.14	0.3322	37.890304	2.105017	1.40	0.1605
Water * P	6	13.086587	2.181098	1.39	0.2287	30.874806	5.145801	3.41	0.0051
N * P	9	30.199325	3.355481	2.15	0.0363	83.811478	9.312386	6.17	<0.0001
Water * N * P	18	10.584263	0.588015	0.38	0.9887	19.714061	1.095226	0.73	0.7735
Error	72	112.629900	1.564304			108.592550	1.508230		
Corrected Total	143	3268.206397				4857.439783			

Appendix 33: ANOVA table for NUE (kg/kg) in RTrials I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	2.0406380	1.0203190	2.04	0.1373	1.9950147	0.9975073	1.73	0.1846
Water	2	48.9731493	24.4865747	48.99	<0.0001	40.5541203	20.2770602	35.16	<0.0001
N	3	653.4811015	217.8270338	435.82	<0.0001	887.4226090	295.8075363	512.95	<0.0001
P	3	10.1483530	3.3827843	6.77	0.0004	22.5298747	7.5099582	13.02	<0.0001
Rep. * Water	4	9.6472360	2.4118090	4.83	0.0017	11.1142462	2.7785616	4.82	0.0017
Water * N	6	18.3331525	3.0555254	6.11	<0.0001	14.9468040	2.4911340	4.32	0.0009
Rep. * Water * N	18	12.4456952	0.6914275	1.38	0.1667	14.8071754	0.8226209	1.43	0.1459
Water * P	6	9.1870554	1.5311759	3.06	0.0100	2.1752555	0.3625426	0.63	0.7068
N * P	9	7.1439275	0.7937697	1.59	0.1352	12.4846220	1.3871802	2.41	0.0191
Water * N * P	18	4.9223228	0.2734624	0.55	0.9244	4.8358276	0.2686571	0.47	0.9645
Error	72	35.9864103	0.4998113			41.520907	0.576679		
Corrected Total	143	812.3090416				1054.386456			

Appendix 34: ANOVA table for PUE (kg/kg) in RTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		RTrial I				**RTrial II**			
Rep.	2	39.050516	19.525258	8.03	0.0007	16.469820	8.234910	5.30	0.0071
Water	2	147.000597	73.500299	30.24	<0.0001	74.951005	37.475503	24.13	<0.0001
N	3	73.879696	24.626565	10.13	<0.0001	46.048046	15.349349	9.88	<0.0001
P	3	2285.793094	761.931031	313.53	<0.0001	2745.261236	915.087079	589.11	<0.0001
Rep. * Water	4	63.809056	15.952264	6.56	0.0001	8.395812	2.098953	1.35	0.2595
Water * N	6	28.659058	4.776510	1.97	0.0819	24.198583	4.033097	2.60	0.0247
Rep. * Water * N	18	69.875848	3.881992	1.60	0.0838	81.997789	4.555433	2.93	0.0006
Water * P	6	51.221393	8.536899	3.51	0.0042	27.646612	4.607769	2.97	0.0121
N * P	9	29.653397	3.294822	1.36	0.2245	70.038710	7.782079	5.01	<0.0001
Water * N * P	18	30.320442	1.684469	0.69	0.8067	16.863495	0.936861	0.60	0.8857
Error	72	174.972746	2.430177			111.840840	1.553345		
Corrected Total	143	2994.235843				3223.711949			

Appendix 35: ANOVA table for economic benefit (Ksh) per hectare in RTrials I and II

Source	DF	SS RTrial I	Mean Square	F Value	Pr > F	SS RTrial II	Mean Square	F Value	Pr > F
Rep.	2	26040234833	13020117417	3.75	0.0283	51801360699	25900680349	7.35	0.0012
Water	2	1.3876935E12	693846774093	199.78	<0.0001	1.7067213E12	853360651750	242.28	<0.0001
N	3	1.4768603E12	492286754105	141.75	<0.0001	2.514259E12	838086349901	237.95	<0.0001
P	3	1.3246023E12	441534116221	127.13	<0.0001	1.9950589E12	665019627372	188.81	<0.0001
Rep. * Water	4	86611360298	21652840074	6.23	0.0002	26487736589	6621934147.2	1.88	0.1232
Water * N	6	164556806376	27426134396	7.90	<0.0001	116684536455	19447422743	5.52	<0.0001
Rep. * Water * N	18	46946690099	7824448349.8	2.25	0.0476	84148888790	4674938266.1	1.33	0.1975
Water * P	6	46946690099	7824448349.8	2.25	0.0476	28526416238	4754402706.3	1.35	0.2467
N * P	9	50816912174	5646323574.9	1.63	0.1241	169878959729	18875439970	5.36	<0.0001
Water * N * P	18	44451653277	2469536293.2	0.71	0.7889	44023956775	2445775376.4	0.69	0.8055
Error	72	250054060185	3472973058.1			253594801012	3522150014.1		
Corrected Total	143	4.9344985E12				6.9911859E12			

Appendix 36: ANOVA table for percentage weight loss of seed tubers at 90 DAS in PTrials I and II (15 tubers/treatment)

	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
Source		**PTrial I**				**PTrial II**			
Water	2	113.9662500	56.9831250	375.54	<0.0001	98.67541667	49.33770833	279.09	<0.0001
N	3	9.0756250	3.0252083	19.94	<0.0001	11.41416667	3.80472222	21.52	<0.0001
P	3	11.6456250	3.8818750	25.58	<0.0001	27.49750000	9.16583333	51.85	<0.0001
Water * N	6	5.5687500	0.9281250	6.12	0.0012	6.05958333	1.00993056	5.71	0.0018
Water * P	6	7.4137500	1.2356250	8.14	0.0002	8.63625000	1.43937500	8.14	0.0002
N * P	9	2.2468750	0.2496528	1.65	0.1761	3.43416667	0.38157407	2.16	0.0787
Error	18	2.7312500	0.1517361			3.1820833	0.1767824		
Corrected Total	47	152.6481250				158.8991667			

Appendix 37: ANOVA table for firmness (kgf) at harvest in PTrials I and II

Source	DF	SS PTrial I	Mean Square	F Value	Pr > F	SS PTrial II	Mean Square	F Value	Pr > F
Rep.	2	0.85541667	0.42770833	2.14	0.1255	1.39291667	0.69645833	6.31	0.0030
Water	2	34.47791667	17.23895833	86.13	<0.0001	38.76541667	19.38270833	175.58	<0.0001
N	3	6.67916667	2.22638889	11.12	<0.0001	17.49576389	5.83192130	52.83	<0.0001
P	3	42.34083333	14.11361111	70.51	<0.0001	48.92687500	16.30895833	147.73	<0.0001
Rep. * Water	4	0.11666667	0.02916667	0.15	0.9643	0.21791667	0.05447917	0.49	0.7405
Water * N	6	1.42875000	0.23812500	1.19	0.3216	0.44902778	0.07483796	0.68	0.6679
Rep. * Water * N	18	10.24958333	0.56942130	2.84	0.0009	2.40083333	0.13337963	1.21	0.2782
Water * P	6	0.38041667	0.06340278	0.32	0.9263	1.35625000	0.22604167	2.05	0.0702
N * P	9	2.23083333	0.24787037	1.24	0.2859	3.60451389	0.40050154	3.63	0.0009
Water * N * P	18	5.20625000	0.28923611	1.45	0.1376	6.61152778	0.36730710	3.33	0.0001
Error	72	14.4116667	0.2001620			7.9483333	0.1103935		
Corrected Total	143	118.3775000				129.1693750			

Appendix 38: ANOVA table for firmness (kgf) at 90 DAS in PTrials I and II

Source	**DF**	**SS** PTrial I	**Mean Square**	**F Value**	**Pr > F**	**SS** PTrial II	**Mean Square**	**F Value**	**Pr > F**
Rep.	2	0.14291667	0.07145833	2.02	0.1404	0.45500000	0.22750000	2.91	0.0609
Water	2	12.16541667	6.08270833	171.75	<0.0001	50.92125000	25.46062500	325.70	<0.0001
N	3	0.74854167	0.24951389	7.05	0.0003	75.92805556	25.30935185	323.77	<0.0001
P	3	29.93298611	9.97766204	281.72	<0.0001	63.43027778	21.14342593	270.48	<0.0001
Rep. * Water	4	0.04166667	0.01041667	0.29	0.8809	0.10250000	0.02562500	0.33	0.8584
Water * N	6	1.08791667	0.18131944	5.12	0.0002	0.38652778	0.06442130	0.82	0.5550
Rep. * Water * N	18	2.26541667	0.12585648	3.55	<0.0001	1.11416667	0.06189815	0.79	0.7028
Water * P	6	0.18513889	0.03085648	0.87	0.5204	1.03597222	0.17266204	2.21	0.0518
N * P	9	0.77340278	0.08593364	2.43	0.0181	3.63472222	0.40385802	5.17	<0.0001
Water * N * P	18	0.82597222	0.04588735	1.30	0.2169	4.88069444	0.27114969	3.47	<0.0001
Error	72	2.55000000	0.03541667			5.6283333	0.0781713		
Corrected Total	143	50.71937500				207.5175000			

Appendix 39: ANOVA table for total soluble solids (%) at harvest before storage in PTrials I and II

Source	DF	SS PTrial I	Mean Square	F Value	Pr > F	SS PTrial II	Mean Square	F Value	Pr > F
Rep.	2	0.93875000	0.46937500	8.71	0.0004	0.30013889	0.15006944	6.70	0.0021
Water	2	1.79541667	0.89770833	16.67	<0.0001	1.72722222	0.86361111	38.58	<0.0001
N	3	7.00083333	2.33361111	43.32	<0.0001	12.36250000	4.12083333	184.10	<0.0001
P	3	15.77583333	5.25861111	97.62	<0.0001	12.76805556	4.25601852	190.13	<0.0001
Rep. * Water	4	0.02583333	0.00645833	0.12	0.9750	0.20944444	0.05236111	2.34	0.0632
Water * N	6	0.87625000	0.14604167	2.71	0.0198	1.04000000	0.17333333	7.74	<0.0001
Rep. * Water * N	18	1.69041667	0.09391204	1.74	0.0510	0.67875000	0.03770833	1.68	0.0624
Water * P	6	2.49958333	0.41659722	7.73	<0.0001	1.19611111	0.19935185	8.91	<0.0001
N * P	9	1.48972222	0.16552469	3.07	0.0036	2.46027778	0.27336420	12.21	<0.0001
Water * N * P	18	1.22652778	0.06814043	1.27	0.2370	2.21888889	0.12327160	5.51	<0.0001
Error	72	3.87833333	0.05386574			1.61166667	0.02238426		
Corrected Total	143	37.19750000				36.57305556			

Appendix 40: ANOVA table for total soluble solids (%) at 90 DAS in PTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		PTrial I				**PTrial II**			
Rep.	2	0.40541667	0.20270833	7.35	0.0012	0.35013889	0.17506944	11.76	<0.0001
Water	2	28.86000000	14.43000000	523.41	<0.0001	25.01097222	12.50548611	840.18	<0.0001
N	3	9.45631944	3.15210648	114.33	<0.0001	7.06409722	2.35469907	158.20	<0.0001
P	3	13.27020833	4.42340278	160.45	<0.0001	7.62854167	2.54284722	170.84	<0.0001
Rep. * Water	4	0.07833333	0.01958333	0.71	0.5875	0.21194444	0.05298611	3.56	0.0105
Water * N	6	0.18722222	0.03120370	1.13	0.3528	0.05569444	0.00928241	0.62	0.7108
Rep. * Water * N	18	1.08458333	0.06025463	2.19	0.0104	0.51958333	0.02886574	1.94	0.0255
Water * P	6	1.41500000	0.23583333	8.55	<0.0001	0.10458333	0.01743056	1.17	0.3314
N * P	9	0.08618056	0.00957562	0.35	0.9555	0.10173611	0.01130401	0.76	0.6537
Water * N * P	18	0.27111111	0.01506173	0.55	0.9249	0.21097222	0.01172068	0.79	0.7077
Error	72	1.98500000	0.02756944			1.07166667	0.01488426		
Corrected Total	143	57.09937500				42.32993056			

Appendix 41: ANOVA table for sprouting (%) at 90 DAS in PTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		PTrial I				**PTrial II**			
Rep.	2	1040.202950	520.101475	15.29	<0.0001	11.348643	5.674322	0.15	0.8575
Water	2	4322.199554	2161.099777	63.54	<0.0001	5613.363226	2806.681613	76.18	<0.0001
N	3	3870.078814	1290.026271	37.93	<0.0001	3208.843574	1069.614525	29.03	<0.0001
P	3	4153.854314	1384.618105	40.71	<0.0001	5430.422913	1810.140971	49.13	<0.0001
Rep. * Water	4	822.081971	205.520493	6.04	0.0003	56.713449	14.178362	0.38	0.8188
Water * N	6	189.797107	31.632851	0.93	0.4788	201.120007	33.520001	0. 91	0.4929
Rep. * Water * N	18	722.586029	40.143668	1.18	0.3002	952.220325	52.901129	1.44	0.1416
Water * P	6	246.647424	41.107904	1.21	0.3119	597.826335	99.637722	2.70	0.0200
N * P	9	126.187692	14.020855	0.41	0.9246	907.303895	100.811544	2.74	0.0083
Water * N * P	18	320.276804	17.793156	0.52	0.9382	614.974432	34.165246	0.93	0.5496
Error	72	2448.83032	34.01153			2652.53425	36.84075		
Corrected Total	143	18262.74298				20246.67105			

Appendix 42: ANOVA table for sprouts length (cm) at 90 DAS in PTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		PTrial I				**PTrial II**			
Rep.	2	46.0172222	23.0086111	16.87	<0.0001	3.0605556	1.5302778	3.01	0.0558
Water	2	900.4143056	450.2071528	330.18	<0.0001	74.9059722	37.4529861	73.55	<0.0001
N	3	374.5035417	124.8345139	91.55	<0.0001	125.0018750	41.6672917	81.83	<0.0001
P	3	643.7446528	214.5815509	157.37	<0.0001	94.5885417	31.5295139	61.92	<0.0001
Rep. * Water	4	9.1219444	2.2804861	1.67	0.1658	1.3461111	0.3365278	0.66	0.6212
Water * N	6	26.1529167	4.3588194	3.20	0.0077	2.2912500	0.3818750	0.75	0.6115
Rep. * Water * N	18	20.7141667	1.1507870	0.84	0.6441	10.0900000	0.5605556	1.10	0.3695
Water * P	6	17.9584722	2.9930787	2.20	0.0532	14.9745833	2.4957639	4.90	0.0003
N * P	9	29.6756250	3.2972917	2.42	0.0185	2.6011806	0.2890201	0.57	0.8192
Water * N * P	18	10.6854167	0.5936343	0.44	0.9748	11.9148611	0.6619367	1.30	0.2142
Error	72	98.173333	1.363519			36.6633333	0.5092130		
Corrected Total	143	2177.161597				377.4382639			

Appendix 43: ANOVA table for number of stems in PTrials I and II

Source	DF	SS PTrial I	Mean Square	F Value	Pr > F	SS PTrial II	Mean Square	F Value	Pr > F
Rep.	2	0.22222222	0.11111111	0.18	0.8391	0.79166667	0.39583333	0.80	0.4520
Water	2	38.84722222	19.42361111	30.74	<0.0001	27.37500000	13.68750000	27.76	<0.0001
N	3	16.13888889	5.37962963	8.51	<0.0001	26.97222222	8.99074074	18.23	<0.0001
P	3	52.97222222	17.65740741	27.94	<0.0001	57.47222222	19.15740741	38.85	<0.0001
Rep. * Water	4	2.86111111	0.71527778	1.13	0.3484	2.83333333	0.70833333	1.44	0.2307
Water * N	6	0.48611111	0.08101852	0.13	0.9924	3.06944444	0.51157407	1.04	0.4083
Rep. * Water * N	18	6.75000000	0.37500000	0.59	0.8931	8.20833333	0.45601852	0.92	0.5524
Water * P	6	2.15277778	0.35879630	0.57	0.7546	1.40277778	0.23379630	0.47	0.8254
N * P	9	1.75000000	0.19444444	0.31	0.9700	4.63888889	0.51543210	1.05	0.4134
Water * N * P	18	5.62500000	0.31250000	0.49	0.9525	5.48611111	0.30478395	0.62	0.8739
Error	72	45.5000000	0.6319444			35.5000000	0.4930556		
Corrected Total	143	173.3055556				173.7500000			

Appendix 44: ANOVA table for stem density in PTrials I and II

Source	DF	SS PTrial I	Mean Square	F Value	Pr > F	SS PTrial II	Mean Square	F Value	Pr > F
Rep.	2	31.468889	15.734444	0.18	0.8380	110.723889	55.361944	0.80	0.4535
Water	2	5453.117639	2726.558819	30.71	<0.0001	3848.659306	1924.329653	27.79	<0.0001
N	3	2266.330764	755.443588	8.51	<0.0001	3783.231319	1261.077106	18.21	<0.0001
P	3	7436.584097	2478.861366	27.92	<0.0001	8071.841875	2690.613958	38.86	<0.0001
Rep. * Water	4	401.007778	100.251944	1.13	0.3497	399.150694	99.787674	1.44	0.2293
Water * N	6	68.197361	11.366227	0.13	0.9925	430.908472	71.818079	1.04	0.4086
Rep. * Water * N	18	949.345000	52.741389	0.59	0.8926	1149.637083	63.868727	0.92	0.5552
Water * P	6	302.432361	50.405394	0.57	0.7547	197.264583	32.877431	0.47	0.8249
N * P	9	246.605625	27.400625	0.31	0.9697	650.288403	72.254267	1.04	0.4148
Water * N * P	18	788.837083	43.824282	0.49	0.9529	770.367639	42.798202	0.62	0.8740
Error	72	6393.01833	88.79192			4985.63500	69.24493		
Corrected Total	143	24336.94493				24397.70826			

Appendix 45: ANOVA table for postharvest evaluation plant height (cm) at 22 DAP in PTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		PTrial I				**PTrial II**			
Rep.	2	8.6805556	4.3402778	3.10	0.0509	5.5416667	2.7708333	3.25	0.0444
Water	2	411.0555556	205.5277778	147.00	<0.0001	143.2916667	71.6458333	84.11	<0.0001
N	3	89.0000000	29.6666667	21.22	<0.0001	24.1875000	8.0625000	9.46	<0.0001
P	3	356.0555556	118.6851852	84.89	<0.0001	219.2430556	73.0810185	85.79	<0.0001
Rep. * Water	4	15.0277778	3.7569444	2.69	0.0379	0.1666667	0.0416667	0.05	0.9954
Water * N	6	23.0000000	3.8333333	2.74	0.0186	7.0416667	1.1736111	1.38	0.2353
Rep. * Water * N	18	3.6250000	0.2013889	0.14	1.0000	18.9583333	1.0532407	1.24	0.2571
Water * P	6	2.9444444	0.4907407	0.35	0.9071	7.9861111	1.3310185	1.56	0.1706
N * P	9	14.2777778	1.5864198	1.13	0.3502	5.8958333	0.6550926	0.77	0.6451
Water * N * P	18	32.5555556	1.8086420	1.29	0.2182	30.7916667	1.7106481	2.01	0.0199
Error	72	100.666667	1.398148			61.3333333	0.8518519		
Corrected Total	143	1056.888889				524.4375000			

Appendix 46: ANOVA table for postharvest evaluation plant height (cm) at 36 DAP in PTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		PTrial I				PTrial II			
Rep.	2	25.347222	12.673611	1.67	0.1953	3.2916667	1.6458333	0.41	0.6638
Water	2	1625.430556	812.715278	107.14	<0.0001	794.0000000	397.0000000	99.42	<0.0001
N	3	1391.805556	463.935185	61.16	<0.0001	559.3888889	186.4629630	46.70	<0.0001
P	3	969.361111	323.120370	42.60	<0.0001	348.2222222	116.0740741	29.07	<0.0001
Rep. * Water	4	6.527778	1.631944	0.22	0.9292	15.7083333	3.9270833	0.98	0.4221
Water * N	6	47.402778	7.900463	1.04	0.4059	22.1111111	3.6851852	0.92	0.4838
Rep. * Water * N	18	139.291667	7.738426	1.02	0.4490	59.5000000	3.3055556	0.83	0.6624
Water * P	6	82.180556	13.696759	1.81	0.1100	40.2777778	6.7129630	1.68	0.1380
N * P	9	61.472222	6.830247	0.90	0.5296	24.8333333	2.7592593	0.69	0.714
Water * N * P	18	136.319444	7.573302	1.00	0.4719	81.1666667	4.5092593	1.13	0.3436
Error	72	546.166667	7.585648			287.500000	3.993056		
Corrected Total	143	5031.305556				2236.000000			

Appendix 47: ANOVA table for postharvest evaluation plant height (cm) at 50 DAP in PTrials I and II

Source	DF	SS PTrial I	Mean Square	F Value	Pr > F	SS PTrial II	Mean Square	F Value	Pr > F
Rep.	2	14.388889	7.194444	0.29	0.7489	159.291667	79.645833	4.89	0.0102
Water	2	3812.763889	1906.381944	76.92	<0.0001	1519.291667	759.645833	46.59	<0.0001
N	3	2013.576389	671.192130	27.08	<0.0001	714.944444	238.314815	14.62	<0.0001
P	3	2383.243056	794.414352	32.05	<0.0001	1141.888889	380.629630	23.35	<0.0001
Rep. * Water	4	365.944444	91.486111	3.69	0.0086	114.791667	28.697917	1.76	0.1463
Water * N	6	310.402778	51.733796	2.09	0.0652	30.263889	5.043981	0.31	0.9301
Rep. * Water * N	18	517.833333	28.768519	1.16	0.3164	133.416667	7.412037	0.45	0.9686
Water * P	6	65.236111	10.872685	0.44	0.8506	41.819444	6.969907	0.43	0.8583
N * P	9	190.784722	21.198302	0.86	0.5686	61.722222	6.858025	0.42	0.9200
Water * N * P	18	322.486111	17.915895	0.72	0.7769	301.736111	16.763117	1.03	0.4407
Error	72	1784.50000	24.78472			1173.833333	16.303241		
Corrected Total	143	11781.15972				5393.000000			

Appendix 48: ANOVA table for postharvest evaluation plant height (cm at 57 DAP in PTrials I and II

Source	**DF**	**SS**	**Mean Square**	**F Value**	**Pr > F**	**SS**	**Mean Square**	**F Value**	**Pr > F**
		PTrial I				**PTrial II**			
Rep.	2	51.097222	25.548611	0.29	0.7508	65.041667	32.520833	1.51	0.2280
Water	2	4282.930556	2141.465278	24.12	<0.0001	2531.791667	1265.895833	58.74	<0.0001
N	3	2945.055556	981.685185	11.06	<0.0001	1390.027778	463.342593	21.50	<0.0001
P	3	8795.277778	2931.759259	33.02	<0.0001	2420.972222	806.990741	37.45	<0.0001
Rep. * Water	4	471.652778	117.913194	1.33	0.2678	260.166667	65.041667	3.02	0.0233
Water * N	6	53.569444	8.928241	0.10	0.9961	94.430556	15.738426	0.73	0.6267
Rep. * Water * N	18	1435.750000	79.763889	0.90	0.5823	235.791667	13.099537	0.61	0.8821
Water * P	6	317.180556	52.863426	0.60	0.7330	83.819444	13.969907	0.65	0.6913
N * P	9	1368.111111	152.012345	1.71	0.1018	114.750000	12.750000	0.59	0.7998
Water * N * P	18	2002.097222	111.227623	1.25	0.2455	273.291667	15.182870	0.70	0.7955
Error	72	6392.83333	88.78935			1551.666667	21.550926		
Corrected Total	143	28115.55556				9021.750000			

Appendix 49: ANOVA table for postharvest evaluation number of tubers per plant in PTrials I and II

Source	DF	SS	Mean Square	F Value	Pr > F	SS	Mean Square	F Value	Pr > F
		PTrial I				**PTrial II**			
Rep.	2	7.5416667	3.7708333	1.59	0.2105	0.5416667	0.2708333	0.15	0.8645
Water	2	414.0416667	207.0208333	87.42	<0.0001	762.7916667	381.3958333	205.44	<0.0001
N	3	223.1666667	74.3888889	31.41	<0.0001	286.3541667	95.4513889	51.42	<0.0001
P	3	210.1111111	70.0370370	29.58	<0.0001	419.9652778	139.9884259	75.41	<0.0001
Rep. * Water	4	1.5416667	0.3854167	0.16	0.9565	5.6666667	1.4166667	0.76	0.5527
Water * N	6	19.7916667	3.2986111	1.39	0.2292	37.3750000	6.2291667	3.36	0.0057
Rep. * Water * N	18	54.4166667	3.0231481	1.28	0.2292	105.4583333	5.8587963	3.16	0.0003
Water * P	6	11.8472222	1.9745370	0.83	0.5478	17.9305556	2.9884259	1.61	0.1569
N * P	9	12.5000000	1.3888889	0.59	0.8040	12.2291667	1.3587963	0.73	0.6783
Water * N * P	18	40.5416667	2.2523148	0.95	0.5231	35.4583333	1.9699074	1.06	0.4076
Error	72	170.500000	2.368056			133.666667	1.856481		
Corrected Total	143	1166.000000				1817.437500			

Appendix 50: Abstract page of published paper No. 1.

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INTEGRATION OF IRRIGATION WATER AND MINERAL NUTRIENT SUPPLY EFFECTS ON FIRMNESS AND TOTAL SOLUBLE SOLIDS CONTENT OF SEED POTATO (*Solanum tuberosum* L.)

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ABSTRACT

Potato (*Solanum tuberosum L.*) is of significant economic and nutritional importance in many countries. Establishment of good fertility, proper nitrogen, phosphorus and potassium fertilisation together with adequate water supply is critical in improvement of seed potato quality. Trials were conducted from August 2011 on a Farm at Egerton University to determine the effects of irrigation water, nitrogen (N) and phosphorus (P) on quality of seed potatoes. The three factors were tested in a split-split plot design with irrigation water assigned to main plots, N to subplots and P to sub-subplots. The treatments were replicated three times and repeated once. The treatments consisted of three irrigation rates (40%, 65% and 100% field capacity), applied throughout the potato growth period in drip tube lines. Water was supplied to root zones only, leaving the inter-row spaces dry. Nitrogen was supplied as urea (46% N) at four rates (0, 75, 112.5 and 150 kg N/ha), each in two splits, with the first half at planting and the second at 5 weeks after planting. Phosphorus was supplied at planting time as triple superphosphate (46% P2O5) at four rates (0, 115, 172.5 and 230 kg P2O5/ha), translating to 0, 50.6, 75.9, 101.2 kg P/ha. Analysis of variance revealed significant differences in firmness and total soluble solids (TSS) as affected by irrigation water, N and P supply. High irrigation water resulted in relatively low firmness (9.23 and 10.17), compared to low irrigation water, which had high firmness (10.43 and 11.44) in both trials. The low N supply improved firmness (9.51 and 10.31), while the low P rate reduced firmness of the seed potatoes (9.07 and 9.98). While high irrigation water supply reduced TSS, high supply of both P and N increased TSS. The 100% irrigation water (5.48 and 5.52) and both low N by P supply (5.33 and 5.49) resulted in relatively low TSS, compared to 40% irrigation water (6.00 and 6.06) and high N by P supply (5.66 and 5.93) in both trials. It is recommended to apply low irrigation water and N but high P to increase firmness that reduces susceptibility of seed potatoes to mechanical injury and decay in storage, leading to low deterioration. In addition, low irrigation water plus high N and P should be supplied to increase TSS content that enhances seed potato tuber physiology and growth of resulting potato plants.

Key Words: Potato, water, mineral nutrients, firmness, total soluble solids

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Appendix 51: Abstract page of published paper No. 2.

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Influence of Irrigation Water, Nitrogen and Phosphorus Nutrient Rates on Relative Weight Loss and Sprouting Characteristics of Seed Potato Tubers After Storage

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Abstract

Potato has overtime generated special importance in most parts of Kenya and the world as a means of strengthening food security and increasing revenue for farmers. However, potato productivity and industry expansion have been constrained by the poor quality seed tubers being produced in the informal seed sector due to inadequate supply of initial planting materials, improper fertilizer management practices and irregular rainfall patterns. A study was done at the Horticultural Research and Teaching Farm of Egerton University to determine the effect of integration of irrigation water, nitrogen and phosphorus rates on seed tuber relative weight loss and sprouting characteristics after storage. The three factors were tested in a split-split plot design where irrigation water supply was assigned to main plots, N to subplots and P to sub-subplots. The treatments were replicated three times and the trial repeated once. The treatments consisted of three irrigation water rates (40%, 65% and 100% field capacity), applied throughout the potato growth period through drip tube lines. Nitrogen was supplied as urea (46% N) at four equivalent rates of 0, 75, 112.5 and 150 kg N/ha, while phosphorus was supplied at planting time as triple superphosphate (46% P_2O_5) at four rates of 0, 115, 172.5 and 230 kg/ha P_2O_5, which translated into 0, 50.6, 75.9, 101.2 kg P/ha. Data collected included relative percentage weight loss, number of sprouts and sprouting percentage. Data collected was subjected to analysis of variance and significantly different means separated using Tukey's Studentized Range Test at $p \leq 0.05$. The 100% compared to 65% and 40% irrigation water rates resulted in relatively high weight loss, sprout length and reduced the number of sprouts and sprouting percentage of seed tubers. N and P rates generally decreased the relative weight loss, improved the number of sprouts and sprouting percentage. It is recommended to apply low to intermediate irrigation water, intermediate to high N and P rates to reduce the percentage relative weight loss and sprouting characteristics.

Keywords: potato, irrigation water, nitrogen, phosphorus, seed, weight loss, sprouting

1. Introduction

Potato has overtime generated special importance in most parts of Kenya and other parts of the world as a means of strengthening food security and increasing revenue for farmers. Potato plays an important role in the Kenyan economy and is currently one of the most important food and cash crops. Potato productivity and industry expansion have been constrained by the poor quality seed tubers being produced in the informal seed sector. Poor seed arise from inadequate supply of initial planting materials, improper fertilizer management practices and irregular rainfall patterns. One of the main constraints is the cost of producing seed tubers since this can account for between 30% and 50% of the total production expense depending on the country or region (Correa, et al., 2009). The seed potato tubers must present good physiological characteristics such as minimal weight loss in storage, firmness, total soluble solids content, and sproutability, which are crucial in improving production at the farm level. Poor potato seed tuber quality, irrigation, mineral fertilization, insect pest and disease forecasting, as well as poor planting dates and storage conditions are some of the factors that hinder potato productivity (Walingo et al., 2004).

Potato yield is affected by seed quality characteristics, which include tuber size, shape, wounds, health and

Appendix 52: Abstract page of published paper No. 3

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Optimizing Seed Potato (*Solanum tuberosum* L.) Tuber Yield and Size Distribution through Integrated Irrigation Water, Nitrogen and Phosphorus Mineral Nutrient Application

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Authors' contributions

All the authors conducted and managed the literature searches, designed, wrote, supervised and reviewed the study, the statistical analysis, the protocol, the first draft of the manuscript, and read and approved the final manuscript.

Original Research Article

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ABSTRACT

Potato is the world's fourth important food crop after wheat, rice and maize because of its great yield potential and high nutritive value. In Kenya, potato is constrained by low seed tuber production in the informal sector. This is partly due to improper fertilizer regimes and irregular rainfall patterns. Therefore, a study was conducted in a rain shelter at the Horticultural Research Farm of Egerton University in Kenya from 18th August to 19th December 2011 (Trial I) and 5th April to 6th August 2012 (Trial II) to determine the effects of integrated irrigation water, nitrogen (N) and phosphorus (P) supply on tuber yield and size distribution. The layout was a split-split plot design with irrigation (40%, 65% and 100% field capacity) assigned to main plots, N (0, 75, 112.5 and 150 kg N/ha) to subplots and P (0, 115, 172.5 and 230 kg/ha P_2O_5, corresponding to 0, 50.6, 75.9, 101.2 kg P/ha) to sub-subplots. The treatments were replicated three times and repeated once. The irrigation water rates were applied in drip tube lines. Nitrogen was supplied as urea (46% N) in two equivalent splits, at planting time and at 5 weeks after planting. Phosphorus was supplied at planting time as triple superphosphate (46% P_2O_5). Data were collected on number, yield and size distribution of tubers at harvest and subjected to analysis of variance. Significantly different means were separated using Tukey's Studentized Range Test at $P = 0.05$. The 65% irrigation water and the high N and P rates resulted in relatively high number, yield and quantity of seed

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