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Effects of Irrigation Water and Mineral Nutrients Application Rates on Tissue Contents and Use Efficiencies in Seed Potato Tuber Production

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Authors' contributions

This work was carried out in collaboration between all authors. All the authors conducted and managed the literature searches, and designed the study. All the authors wrote, supervised and reviewed the study, the statistical analysis, and the first draft of the manuscript. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Soil fertility and unreliable rainfall have become important in seed potato (*Solanum tuberosum* L.) production in Kenya. Knowledge on water and mineral nutrient use efficiencies will help predict the best application rates for optimal seed potato production. A study was conducted at Egerton University, Horticultural Research and Teaching Farm to determine the effect of integration of irrigation water, nitrogen (N) and phosphorus (P) nutrient on water, N and P use efficiencies and tissue content. In a split-split plot, the irrigation water supply (40%, 65% and 100% field capacity) was assigned to main plots, N (0, 75, 112.5 and 150kg N/ha) to subplots and P (0, 50.6, 75.9, 101.2kg P/ha) to sub-subplots, each treatment replicated three times and trial repeated once. Irrigation water was drip applied throughout the potato growth period, with N supplied as urea (46% N) in two splits, and P as triple superphosphate (46% P_2O_5) at planting time. Data on seed potato yield collected from each treatment at harvest was used to calculate water, N and P use efficiencies. Oven dried ground tubers were used to determine N and P contents. Analysis of variance was done and significantly different means separated using Tukey's Studentized Range Test at $P \leq 0.05$. High irrigation water at 100% compared to 65 and 40% rate resulted in relatively high N and P use efficiencies, but decreased water use efficiency. High (100%) compared to 40% irrigation rate when integrated with high

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compared with low N and P application rates reduced the WUE by 6.1 and 8.1kg/m^3, increased NUE by 14.4 and 13.3kg/kg, and PUE by 73.4 and 69.5kg/kg, in Trials I and II respectively. Application of intermediate to high N and P nutrient increased the water, N and P use efficiencies. Regardless of irrigation water rate tuber tissue N and P contents increased with N and P application rate. Application of low to intermediate irrigation water, intermediate to high N and P will increase their use efficiencies and tissue contents during seed potato production.

Keywords: Potato; nitrogen; phosphorus; water; tissue contents; use efficiency.

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) has overtime generated special importance in most parts of Kenya as a means of strengthening food security and increasing revenues for farmers. There is, therefore, increased need to boost output and improve cropping systems to increase profits. However, many soils in areas where potato is grown are deficient in one or more of the essential nutrients needed to support healthy plants. Therefore, addition of fertilizers and/or amendments has become extremely important in correcting declining soil fertility, seed tuber yields and quality. However, use of these fertilizers has not been effective due to isolated application practices. 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 to groundwater or surface water [1]. Estimates of overall efficiency of applied fertilizer have been reported to be about or lower than 50% for N, less than 10% for P, and about 40% for K [2]. Ability of potato plant to absorb and utilize nutrients greatly enhance the efficiency of applied fertilizers, reducing cost of inputs, and preventing losses of nutrients to ecosystems. Variation for plant growth and nutrient use efficiency may be modified by quantities of nutrients applied.

Another factor that has limited seed potato production in many parts of Kenya is unreliable rainfall. Water deficit is a common stress in potato production, which leads to decrease in tuber quality and yield [3]. Irrigation has been increasingly employed to curtail effects of drought [4] in other countries, but in Kenya potato farmers rarely use this practice due to cost and lack of knowledge, among other factors. Knowledge on water, mineral nutrient use efficiencies on potato grown under different irrigation regimes, nitrogen and phosphorus will help predict the best application rates for optimal seed potato production and yield. 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 [5].

Potato is particularly sensitive to soil water stress [4], which affects physiology, bulking, grade, specific gravity, processing quality and yield of tubers [6]. A visible shift from rain-fed to irrigation-fed seed production could unlock the perennial seed shortage and guarantee food security through increased potato productivity. There is dramatic decrease of water resources due to prolonged drought periods in many potato growing areas coupled with increased fertilizer nutrient costs. Therefore proper water and nutrient utilization is a constant concern to increase on their use efficiency for improved seed potato production in the informal sector. Farmers in informal seed production sector generally lack knowledge on aspects of water and nutrient management that increase their use efficiency, productivity and quality of seed potato.

Water-use efficiency (WUE) is a quantitative measurement of how much biomass or yield is produced over a growing season, normalized 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 rain-fed plant production can be increased per unit water used, resulting in "more crop per drop" [7]. Nitrogen uptake efficiency (NUE) is a measure of the capacity of the plant to recover applied N [8]. This applies also to water and phosphorus.

However, currently there are no recommendations for the combined irrigation water supply, N and P nutrient application rates for seed potato tuber producers in the informal sector to adopt, that leads to their high use efficiencies leaving the sector to rely on management practices for commercial or subsistence potato production. As the need for food production increases with an increasing population growth, it is important that strategies are developed to enhance the nutrient uptake and utilization efficiencies [9]. Efficient irrigation and nutrient management can maximize marketable seed yield and reduce production costs by conserving water, energy and nitrogen fertilizer.

The 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. The aim of the study was to establish the water and nutrient use efficiency of seed potato tubers produced using different rates of irrigation water, N and P application.

2. MATERIALS AND METHODS

2.1 Potato Growth in the Field

The potatoes were planted in a rainshelter at the Horticultural Research and Teaching Farm of Egerton University, Njoro between 19th August 2011 and 19th December 2011(Trial I) and repeated between 5th April and 6th August 2012 (Trial II). Three soil samples were randomly collected from the top 0 -15cm and 15 - 30cm 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 nitrogen was determined using the Kjeldahl method [10]. Olsen [11] 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 rain shelter, maximum and minimum temperatures were recorded daily from three minimum- maximum thermometers hanged in two extreme ends and the middle of the structure during the trial periods. The minimum temperature was recorded early in the morning and the maximum at midday.

Potatoes were planted to determine the effect of irrigation water supply, nitrogen (N) and phosphorus (P) application rate on water, N and P use efficiency. The three factors were tested in a split-split plot design with the irrigation water assigned to main plots, N to subplots and P to sub-subplots. The treatments were replicated three times. The treatments consisted of three irrigation rates (40%, 65% and 100% field capacity), applied throughout the potato growth period through drip tube lines. Water was supplied through irrigating only the root zone, leaving the inter-row spaces dry. A Water Scout (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.

Nitrogen was supplied as urea (46% N) at four rates (0, 75, 112.5 and 150kg 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% P_2O_5) at four rates (0, 115, 172.5 and 230kg/ha P_2O_5, which translated into 0, 50.6, 75.9, 101.2kg P/ha. Each plot measured 1.8m x 2.25m. Each experimental unit consisted of seven rows each with seven tubers. Routine field maintenance practices such as weeding and spraying against diseases and insect pests using appropriate fungicides and insecticides was done when necessary. Seed potato from ten randomly selected plants per treatment were harvested 115 days after planting, labeled and placed in plastic bags for yield determination and consequent calculation of water, N and P use efficiencies.

2.2 Tissue N and P contents

Total tuber tissue N content was determined by micro-Kjeldahl method [10] while [11] 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.

2.3 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, normalized 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 rain-fed 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 [8]. 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 [12] and [5].

2.3.1 Water use efficiency

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

2.3.2 Nitrogen and phosphorus use efficiency

Nitrogen or Phosphorus use efficiency = (Tubers (kg) of fertilized – of controls)/nitrogen or phosphorus fertilizer used (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.

2.4 Data Analysis

Data collected were 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 nitrogen and phosphorus use efficiencies were first 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 before analysis.

3. RESULTS AND DISCUSSION

3.1 Soil Analysis and Climatic Data

After analysis the soil at the site had 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 1-15cm, 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) Trial respectively. A total of 635 mm and 221.7 mm was received in the site and mean temperatures were 19.0ºC and 18.9ºC during Trials I (Apr-June 2012) and II (November 2012-Jan 2013), respectively (Table 1). In the rain shelter the mean temperatures were 20.7ºC and 20.5°C in Trials I and II, respectively (Table 2).

3.2 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. 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 0kg P/ha compared to high P rate of 101.2kg P/ha in Trials I and II, respectively. Therefore P rate from 0 kg P/ha compared to 101.2kg P/ha increased the tissue N and P contents by 0.26% and 0.05% in Trial I and 0.4% and 0.05% in Trial II (Table 3).

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 0kg N/ha in Trials 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 Trials I and II, respectively (Table 3).

Table 1. Climatic data from 2011 to January 2013 at Egerton University Meteorological Station (9035092)

	Year								
	2011			2012			2013		
Month	R (mm)	T(ºC)	RH (%)	R (mm)	T (ºC)	RH (%)	R (mm)	T (ºC)	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 2. Mean monthly temperature data in the Rainshelter for 2011 (Aug-Dec) and 2012 (Apr-Aug) seasons

Month	2011			2012		
	Maximum	Minimum	Mean	Maximum (ºC)	Minimum (ºC)	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

Increasing N from 0 to 150kg 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 0kg N/ha compared to 150kg N/ha the tissue N and P contents increased by 0.86% and 0.18% in Trial I and 1.51% and 0.17% in Trial II (Table 4). 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 0kg N/ha compared to high content, which resulted with 150kg N/ha rate within a given irrigation water rate (Table 4). Overall, the irrigation water, N and P application rates had significant effects on tuber N and P contents at harvest.

Table 3. Effect of P application rate treatments on tuber tissue N and P contents

P rate (kg P/ha)	Trial I		Trial II	
	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≤0.05 according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.*

Table 4. Effect of irrigation water and N rates on tuber tissue N and P contents

Trial I	Tissue N				Tissue P			
	N rate (kg N/ha)				N rate (kg N/ha)			
Irrigation (% FC)	0	75	112.5	150	0	75	112.5	150
100	2.59d*	2.85c	3.21b	3.54a	0.18d	0.23c	0.27b	0.33a
65	3.24d	3.49c	3.78b	4.1a	0.25d	0.3c	0.36b	0.43a
40	3.14d	3.41c	3.69b	3.99a	0.21d	0.26c	0.31b	0.38a
MSD (N)	0.04				0.01			
MSD (W)	0.03				0.01			
CV (%)	1.73				5.1			
Trial II								
100	2.94d	3.27c	3.62b	4.09a	0.22d	0.25c	0.29b	0.35a
65	3.25d	3.67c	4.22b	4.76a	0.27d	0.31c	0.36b	0.44a
40	3.15d	3.59c	4.09b	4.67a	0.24d	0.29c	0.34b	0.39a
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≤0.05 according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.*

3.3 Water Use Efficiency

Water use efficiency (WUE) significantly depended on all tested factors. Integrating N with either irrigation or P significantly affected WUE. High irrigation water alone depressed WUE, which was 10.8 and 12.7kg/m^3 where 100% irrigation water was supplied compared to 16.9 and 20.8kg/m^3 obtained with low irrigation water in Trials 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 (Fig.1). Application of N irrespective of irrigation rate increased WUE from 0 to 150 kg N/ha both in Trials I and II, respectively. The higher WUE was recorded when either of the irrigation rate was combined with high N rate at 150kg 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 9.8kg/m^3 to 14.1 and 16.2kg/m^3 observed with low compared to high rates in Trials I and II, respectively (Table 5).

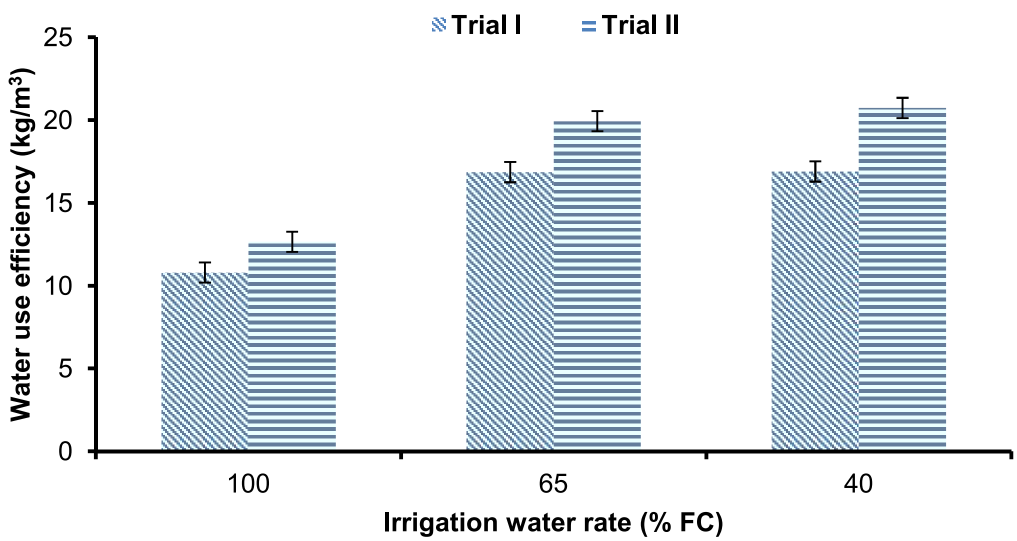

Fig. 1. Effect of irrigation water on potato water use efficiency

Nitrogen rate irrespective of P rate improved WUE. Increasing N from 0 to 150kg N/ha increased WUE from 11.1 and 12.9kg/m^3 to 18 and 20.7kg/m^3, which was equivalent to 7.1 and 7.9kg/m^3 in Trials I and II, respectively. Similarly, application of P from 0 to 101.2kg P/ha increased WUE irrespective of N rate from 11.7 and 14kg/m^3 to 17.4 and 20.5kg/m^3, which was equivalent to 5.8 and 6.5kg/m^3 in Trials I and II, respectively. WUE was greatly reduced by low N and P rates, while it was increased with integrated high rates (Table 5).

3.4 Nitrogen Use Efficiency

Irrigation water, N and P rates significantly affected Nitrogen Use Efficiency (NUE). Integrating N or P with irrigation water significantly affected NUE (Table 6). Application of irrigation water where low N rate of 0kg N/ha was supplied led to zero NUE. Nitrogen Use Efficiency 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 13.3kg/kg in Trials I and II, respectively (Table 6).

Irrespective of irrigation rate, N increased NUE up to 112.5kg N/ha beyond which it declined. Generally application of N beyond 112.5 to 150kg N/ha decreased NUE by 1.9 and 14.5kg/kg in Trials 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.

Table 5. Effect of N and P rates on potato water use efficiency

Trial 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						
Trial 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≤0.05 according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.*

Table 6. Effect of irrigation water, N and P rates on potato NUE

Trial I	Irrigation water (% FC)			P rate (kg P/ha)			
kg N/ha	**100**	**65**	**40**	**0**	**50.6**	**75.9**	**101.2**
0	0c*	0c	0c	0b	0c	0c	0c
75	35.1b	36.9b	17.3b	27.9a	28.8b	32.1b	30.4b
112.5	44.8a	43.6a	27.3a	30.2a	35.6a	41.9a	46.6a
150	40.4a	45.6a	23.9a	28.6a	33.7a	39.5a	44.8a
MSD	4.8 (N, P)	3.8 (W)					
CV (%)	15.2						
Trial II							
0	0c	0c	0c	0c	0c	0c	0d
75	46.1b	44.7b	28.3b	35.7b	37.3b	39.5b	46.3c
112.5	60.2a	64.6a	39.3a	44.7a	48.4a	53.3a	72.8a
150	44.2b	46.8b	29.9b	32.4b	33.9b	43.3b	51.7b
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≤0.05 according to Tukey's Studentized Range Test. MSD=Minimum Significant Difference. Mean separation was done within each season.*

Integration of high compared to low N and P rates improved NUE. Increasing P rate from 0 to 101.2kg P/ha regardless of N rate increased NUE from 21.7 and 28.2kg/kg to 30.5 and 42.7 kg/kg, which was equivalent to 8.8 and 14.5kg/kg in Trials I and II, respectively. The highest NUE was recorded when 112.5kg N/ha was integrated with 101.2kg P/ha. Regardless of P rate, high N rate of 150 kg N/ha reduced NUE in both Trials (Table 6).

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3.5 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 7). 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 133.3kg/kg, which was equivalent to 73.4 and 69.5 kg/kg in Trials I and II, respectively (Table 7). 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 0kg P/ha and 0 kg N/ha to 150.8 and 186.6kg/kg that resulted from combined application of 75.9kg P/ha and 150 kg N/ha in Trials I and II, respectively. Application of P increased PUE and regardless of N rate, low P at 0kg P/ha led to zero PUE. Phosphorus Use Efficiency increased with combined N and P rate from 0 to 75.9kg P/ha beyond which additional P to 101.2kg P/ha decreased PUE by 5.5 and 49.9 in Trials I and II, respectively (Table 7).

Table 7. Effect of irrigation water, N and P rates on potato PUE

Trial 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						
Trial 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≤0.05 according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each sea*

Table 8. Effect of irrigation water and P rates on potato PUE

Irrigation	P rate (kg P/ha) in Trial I				P rate (kg P/ha) in Trial 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≤0.05 according to Tukey's Studentized Range Test. MSD = Minimum Significant Difference. Mean separation was done within each season.*

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 0kg P/ha increased the PUE by 148 and 162.4 kg/kg. Irrespective of irrigation water rate, 0kg P/ha application resulted to zero PUE (Table 8)

4. DISCUSSION

Irrigation water, N and P rates significantly influenced 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 [13] 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 minimized 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, utilization 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 [14]. White [15] 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 utilization of photo assimilates that could have been stored in the seed tubers, resulting in low tuber tissue N and P contents.

The potato NUE and PUE 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 [16,17]. 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 utilization 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 [17] 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 utilize 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 [18]. 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 utilization 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 [19] 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 [20]. This aspect is particularly relevant for estimating WUE at different irrigation, N and P rates and consequently their impact in seed potato production.

The 0kg N/ha regardless of the irrigation water and P rates lead to zero NUE. This was similar to 0kg 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 [21]. High compared to low irrigation rates led to high NUE or PUE. Liu [9] 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 [22]. It is, therefore, crucial to understand that combining water and nutrient use efficiencies improves growth, yield and quality of seed potato tubers.

5. CONCLUSION AND RECOMMENDATION

Integration of irrigation water, N and P rates can improve water and mineral nutrient use efficiencies and hence optimize seed potato productivity. Lower irrigation water supply, N and P rates decreased WUE, NUE and PUE hence they are not suitable for use in potato production. The results obtained indicate that intermediate irrigation water supply, high N and P rates increased tissue N and P contents, WUE, NUE and PUE. Therefore, low to intermediate irrigation water, intermediate to high N and P application should be adopted to increase their use efficiencies and tissue contents during seed potato production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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