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Improving Seed Potato Leaf Area Index, Stomatal Conductance and Chlorophyll Accumulation Efficiency through Irrigation Water, Nitrogen and Phosphorus Nutrient Management

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Abstract

A study was conducted in a Rainshelter (RTrial) at Horticultural Research and Teaching Farm, Egerton University to determine the effect of integration of irrigation water, nitrogen (N) and phosphorus (P) application on seed potato leaf area index (LAI), stomatal conductance and chlorophyll content. The treatments arranged in a split-split plot layout in a completely randomised block design, consisted of three irrigation water 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. During the growth leaf area, stomatal conductance, and chlorophyll content were measured. Data collected were subjected to analysis of variance and significantly different means separated using Tukey's Studentized Range Test at $P \leq 0.05$. 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 days after planting (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. Subjecting potato to 100% compared to 40%

irrigation rate increased stomatal conductance at 87 days after planting (DAP) by 32.82 and 31.99 mmol$m^{-2}s^{-1}$; 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, in RTrials I and II respectively. Irrespective of N and P rates LAI, stomatal conductance and chlorophyll content were significantly greater with high irrigation water at 100% followed by 65% and was lowest with 40% irrigation water rate.

Keywords: Potato, Irrigation, Nitrogen, Phosphorus, Leaf, Conductance, Chlorophyll

1. Introduction

Plant growth and development and consequently yields are influenced by many stress factors, such as low or high temperatures, water deficit, excessive radiation within the photosynthetically active range, mechanical injuries, gaseous contamination, phytotoxins, herbicides applied, or intensive fertilization (Sawicka *et al.*, 2015). 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). 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. Mineral nutrients are essential for healthy plant growth, optimum yield, and better economic returns. Potato plants have a high demand on soil nutrients and their proper management is one of the most important factors required to obtain maximum tuber yield (Braun *et al.*, 2015).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. 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) and is often considered as a drought sensitive crop and its sustainable production is threatened due to frequent drought episodes (Obidiegwu *et al.*, 2015). 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).

Effective management and proper coordination of N, P and irrigation water 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. 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. 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 influences potato leaf area expansion, stomatal conductance, chlorophyll content, seed potato yield and quality, as well as market and consumer values. Conductance of the diffusion and the transport of CO_2 play a major role in determining CO_2:O_2 ratio (Biman *et al.*, 2014) which is crucial in determining photosynthetic rates. The lower stomatal conductance inhibits water losses, thus helping the plants to cope with the drought in better way (Naveed *et al.*, 2012) although it inhibits the CO_2 fixation, resulting in lower productivity (Cornic 2000; Chaves *et al.*, 2002). Nitrogen is an important nutrient since it has a positive effect on chlorophyll concentration, photosynthetic rate, plant height and dry matter accumulation and higher potato tuber yields (Sinfield *et al.*, 2010; Tremblay *et al.*, 2011). Chlorophyll is one of the most photochemically active compounds in photosynthesis and its determination provides useful information concerning the photosynthetic status (Yadav *et al.*, 2010)

Where fertilization is done, farmers do not supply irrigation water to the crop to enable it utilize the nutrients efficiently and realize better returns. 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). 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 production remains sustainable. 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).

There is therefore need to evaluate, document and disseminate comprehensive management packages and knowledge on leaf expansion capacities, stomatal conductance and chlorophyll content in environments characterized by varied rainfall and nutrient amounts. The ability of leaves to expand, stomatal conductance and the chlorophyll concentration determined by water and nutrient supply forms critical determinants of leaf photosynthetic capacities which influences the photoassimilates available for plant growth and consequent yield. Study of tolerance of seed potato to varying irrigation water and mineral nutrient supply rates will assist producers in predicting expected potato growth and tuber yields under their prevailing agro-ecological conditions.

2. Materials and Methods

2.1 Potato Growth in the Field

Potatoes were planted in a rainshelter at the Horticultural Research and Teaching Farm of Egerton University, Njoro between 19th August and 19th December 2011 (RTrial I) and the trial was repeated between 5th April and 6th August 2012 (RTrial II). Potatoes were planted to determine the effect of irrigation water, nitrogen (N) and phosphorus (P) application rates on leaf area index, stomatal conductance, and chlorophyll content of seed potato. The three factors were tested in a split-split plot design with the irrigation water rate assigned to main plots, N to subplots and P to sub-subplots. The treatments were replicated three times. The treatments consisted of three irrigation water (W) rates (40%, 65% and 100% field capacity [FC]), 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 WaterScout (Model SM 100 Sensor) connected to 2475 Plant Growth Station (Watch Dog Model, Spectrum Technologies, Plainfield, IL 60585, USA), which is applicable between 0% to saturation was used to indicate the need for irrigation.

Nitrogen (N) 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 (P) was supplied at planting time as triple superphosphate (46% P_2O_5) at four rates (0, 50.6, 75.9, 101.2 kg P/ha). Each plot measured 1.8 m x 2.25 m. Each experimental unit consisted of seven rows each with seven tubers planted. 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.

2.2 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).

2.3 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).

2.4 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).

2.5. 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 (SAS, 2011) and significantly different means separated using Tukey's Studentized Range Test at $P \leq 0.05$.

3. Results

3.1. Leaf area index (LAI)

Leaf area index significantly differed among the treatments at 51 and 64 DAP. 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 1).

3.2. Leaf stomatal conductance (mmol$m^{-2}s^{-1}$)

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. 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 2). 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 $mmolm^{-2}s^{-1}$ with high compared to 21 and 33.9 $mmolm^{-2}s^{-1}$ 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 2).

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 (Table 3).

Table 1. Effect of irrigation water, N and P application rate treatments on potato LAI

RTrial 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 (% FC) 100%	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%	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%	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			
RTrial II									
Irrigation water 100 %	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 %	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
	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
40%	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. FC = Field Capacity, DAP = Days after Planting, MSD = Minimum Significant Difference. Mean separation was done within each season.

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 3).

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 ($P \leq 0.05$).

Table 2. 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, DAP = Days after Planting, MSD = Minimum Significant Difference. Mean separation was done within each season.

3.2 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 (Table 4). Interactions between irrigation water, N and P rates resulted to significant differences in leaf chlorophyll content

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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.

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 (Table 4).

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 4).

Table 3. 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	75	112.5	150	0	75	112.5	150	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

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rates are not significantly different at $P \leq 0.05$ according to Tukey's Studentized Range Test. Some interactions were not significant. DAP = Days after Planting, MSD = Minimum Significant Difference. Mean separation was done within each season.

Table 4. Effect of irrigation water, N and P rates on potato leaf chlorophyll content index

RTrial 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 (% FC)	100%	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%	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%	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			
RTrial II														
Irrigation water rate (% FC)	100%	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%	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%	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. FC = Field Capacity, DAP = Days after Planting, MSD = Minimum Significant Difference. Mean separation was done within each season.

4. Discussion

In Kenya, farmers grow seed potato during the rainy season using fertilizer rates of commercial potato production. In this study, 100% irrigation water rate represented a normal rainy season, and fertilizer rates were varied from zero to recommended commercial potato production rates. In the present study, potato plants supplied with high irrigation water, N and P rates had larger LAI, higher leaf stomatal conductance and chlorophyll content index. 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 and water stress within the potato plant, which possibly resulted in low LAI, stomatal conductance and chlorophyll content index and consequently reduced photosynthetic activity. Plants under water stress have been reported to show a decrease in leaf conductance (Obidiegwu *et al.,* 2015), total area of leaves (Albiski *et al.,* 2012), reduced plant chlorophyll content (Anithakumari *et al.,* 2012), and the photosynthesis rate (Li *et al.,* 2015).

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 lower stomatal conductance, chlorophyll content and consequently reduced total dry matter (biomass) accumulation as indicated by the least LAI.

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 leaf stomatal conductance and chlorophyll accumulation. Chlorophyll traps light and transfers energy for driving photochemical reactions (Yadav *et al.,* 2010) and photosynthetic activity is related to the content of the photosynthetic pigment, chlorophyll (Maclntyre *et al.,* 2002; Huang et al., 2014). Therefore, 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 a large LAI that is durable through the reproductive phase. This was achieved through high irrigation water, N and P rates. 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.

Stalham and Allison (2012) reported that RUE was increased by irrigating and that this was also associated with significant increase in total dry matter 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). 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. 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 LAI 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 LAI. 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.* (2011) 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 utilization 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. Najm *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.

5. Conclusion and Recommendations

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 leaf expansion capacities, stomatal conductance and chlorophyll content. Integration of high irrigation water at 100%, N and P rates at 150 kg N/ha and 101.2 kg P/ha increases potato physiological activities that enhances greater growth and development rates. It is recommended to avoid low irrigation water rates at 40% FC and low N and P rates at 0 kg N/ha and 0 kg P/ha due to their potential negative effects on seed potato growth and development.

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