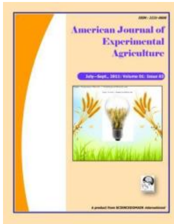

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Optimizing Seed Potato (*Solanum tuberosum* L.) Tuber Yield and Size Distribution through Integrated Irrigation Water, Nitrogen and Phosphorus Mineral Nutrient Application

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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.

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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 19th 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

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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 potato sizes I and II. The 100% irrigation water increased the ware-sized seed potato tubers and reduced the quantity of chats. Therefore, integration of moderate irrigation water and high rates of N and P is recommended for optimizing seed potato tuber grades.

Keywords: Potato; irrigation; Nitrogen; Phosphorus; Seed; Yield; Size.

1. INTRODUCTION

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 [1,2]. It is a staple diet in many households, a source of diverse essential nutrients and is available all year-round [3]. Potato is a source of sustenance for people from the high Andes to the plains of East Africa. Because it can be stored to provide food during food scarcity times, it is part of both commercial and subsistence agriculture [4]. Kenya requires 60,000 tons of certified seed potato per year, but only 600 tons are availed, forcing 96% of the farmers to replant their own harvested seed potato tubers [5]. The formal seed sector therefore only provides 1-4%. The informal system, which includes unlicensed potato growers and suppliers mainly in immediate localities, entails farmer-to-farmer distribution that supplies upto 99% of the seed potato tubers required annually [6]. However, potato productivity and industry expansion have been constrained by the poor quality and inadequate seed tubers being produced, especially in the informal system. Poor seed arises from inadequate supply of initial planting materials, improper fertilizer application practices and irregular rainfall patterns. To meet the increasing demand of seed potato tubers, production efficiency must be improved. Many informal seed potato sector farmers rely on ware potato irrigation water, N and P nutrient application rates, which are not economical or appropriate agronomically for producing seed potato tubers. Consequently, seed potato tubers available through the informal system are of poor quality that increases the cost of production. Furthermore, most potato growers do not integrate irrigation water and nutrient management practices during seed potato tuber production.

Plant needs of water and nutrients are interdependent, as good water supply improves the nutritional status of crops, and adequate nutrient supply saves water [7]. There exists potential of increasing yield and improving the seed potato tuber size through integration of irrigation water, N and P application. However, there is limited information on the effects of integrating irrigation water, N and P rates on seed potato tuber yield and size distribution and this scarcity can constrain the seed potato production system. The present study determined the effects of integrating irrigation water, N and P application rates on yield and size distribution of seed potato tubers.

2. MATERIALS AND METHODS

2.1 Potato Growth in Field

Potatoes were planted in a rain shelter at the Horticultural Research and Teaching Farm of Egerton University, Njoro from 19th August to 19th December 2011 (Trial I) and the trial was repeated from 5th April to 6th August 2012 (Trial II) to determine the effects of integrating irrigation water, nitrogen (N) and phosphorus (P) rates on seed potato tuber yield and size distribution. The three factors were tested in a split-split plot design. The irrigation water was assigned to main plots, N to subplots and P to sub-subplots. The treatments were replicated three times. Three irrigation rates (40%, 65% and 100% field capacity) were tested. The irrigation water was applied throughout the potato growth period to the root zone only using drip tube lines, 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 0% and 100% (saturation) was used to signal the need for resuming irrigation. Four rates of N (0, 75, 112.5 and 150 kg N/ha) were supplied as urea (46% N), each in two splits, the first half at planting and the second 5 weeks after planting. Four rates of phosphorus (0, 115, 172.5 and 230 kg /ha P_2O_5, which translated to 0, 50.6, 75.9, 101.2 kg P/ha) were supplied at planting time as triple superphosphate (46% P_2O_5). Each plot measured 1.8 m x 2.25 m. Each experimental unit consisted of seven rows and each of them had seven plants. Seed potato from 10 randomly selected plants per treatment were harvested 115 days after planting, placed in "PIL®" polythene paper bags and labelled for yield and tuber size distribution determination.

2.2 Number of Tubers and Yield

After harvesting, the harvested 10 plants per treatment were placed separately on the ground to facilitate determination of tuber numbers per individual plant within the treatment. Swollen tubers produced per plant were counted and recorded to determine the treatment effects. After counting of the tuber numbers per plant, all the tubers from the 10 plants per treatment were combined together and placed in one "PIL®" polythene paper bags and weighed using a spring balance to determine the yield per plot. The result was converted to ton/ha.

2.3 Tuber Grading and Size Distribution

After yield determination, the tubers per treatment were graded into small size (25-35 mm), seed size I (35 - 45 mm) and seed size II (45 - 60 mm) [8], using grading scales (graders) obtained from the Kenya Agricultural Research Institute (KARI) at Tigoni Marindas Sub centre. Each grade was weighed separately using a spring balance to determine weight per plot which was converted to tons per ha. Too small or large tubers, measuring less than 25 mm in diameter (chats) and greater than 60 mm (ware), were discarded. Grading was done to facilitate determination of the economic benefit of different treatments and only seed sizes I and II were considered.

2.4. Statistical Analysis

Data collected in both trials were analyzed using the SAS statistical program (SAS Institute, 2002-2003). The analysis of variance (ANOVA) was performed using PROC ANOVA. Means were separated using Tukey's Studentized Range Test at $P = 0.05$.

3. RESULTS

3.1 Number of Tubers

Tubers were significantly affected by all the treatments in both trials I and II. The tubers also significantly depended on integration of irrigation water with either N or P (Table 1).

Generally, 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 1.15 and 1.3 in trials I and II respectively (Table 1). Application of lower irrigation water rate at 40% also greatly reduced tubers compared with 100% irrigation water rate. Also tubers increased with application of N regardless of the amount of irrigation water supplied until 122.5 kg N/ha when it reduced with high N rate of 150 kg N/ha. Tubers increased with P application from 0 kg P/ha to 101.2 kg P/ha with 65% irrigation water, but tubers decreased after 75.9 kg P/ha both with 40% and 100% irrigation water. Higher P rates, regardless of irrigation water, increased the tubers by 1.05 and 1.35 in both trials I and II, respectively. Unlike P, high N application rates beyond 112.5 kg N/ha significantly depressed the number of tubers. However, high compared to low N rate increased the number of tubers by 1.03 and 1.44 in both trials I and II, respectively (Table 1). Generally, plants in trial I had less number of tubers than those in trial II.

3.2 Tuber Yields

The seed potato tuber yield (t/ha) significantly differed among the rates of irrigation water, N and P application in both trials. Tuber yield significantly depended on the integration of irrigation water either with N or P and also integration of N and P. Irrigation water application increased seed potato tuber yield. The highest yield was recorded with 65% followed by 100% and 40% irrigation water rates. Intermediate irrigation water rate at 65% significantly increased the yield to 32.49 and 38.42 t/ha compared to 22.12 and 27.12 t/ha recorded with 40% irrigation water irrespective of N or P rate. This translated to an increase by 10.37 and 11.26 t/ha although irrigation water supply beyond 65% reduced the yield by 2.33 and 3.08 t/ha both in trials I and II respectively. However, integration of irrigation water and N application significantly improved the seed potato tuber yields (Table 2).

The 65% irrigation rate together with high N rate of 150 kg N/ha increased the yield to 40.5 and 44.93 t/ha compared to 17.17 and 20.29 t/ha when 0 kg N/ha was applied together with the lowest irrigation rate of 40% in trials I and II, respectively. However, irrespective of the irrigation rate the seed potato tuber yields significantly increased with N application rate from 0 kg N/ha to 150 kg N/ha in trial I and 0 kg N/ha to 112.5 kg N/ha in trial II after which there was no significant increase. High compared to low N rate increased the yield by 13.69 and 15.04 t/ha in trials I and II respectively. Similarly, integration of irrigation water with P significantly increased seed potato tuber yield. Where 65% irrigation water was applied together with 0 kg P/ha compared to 101.2 kg P/ha, yield increased from 25.35 and 30.21 to 38.43 and 44.57 t/ha in trials I and II respectively. With 40% irrigation water, the seed potato yield increased from 17.98 and 21.67 to 25.12 and 30.85 t/ha when 0 kg P/ha and 101.2 kg P/ha were applied in trials I and II respectively (Table 2).

Combination of N and P significantly increased seed potato tuber yield. However, P rates beyond 75.9 kg P/ha with low rate 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 the low P rate (Table 3). Seed potato tubers increased by 11.39 and 12.41 t/ha when high P rate was applied compared to low P rate. Higher increases were observed where 75.9 kg P/ha and 101.2 kg P/ha were supplied with high N rates. Seed potato tuber yield increased from 15.90 and 18.34 to 24.50 and 26.81 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 26.58 and 30.44 to 41.25 and 46.12 t/ha for 150 kg N/ha by 0 kg P/ha, and 150 kg N/ha by 101.2 kg P/ha in trials I and II, respectively (Table 3).

3.3 Tuber Grades

The tuber grades significantly depended on irrigation water, N and P rates in both trials. Integration of irrigation water and N significantly affected the potato grades of ware, seed size II and chats. Integration of irrigation water and P, as well as N and P affected the ware and seed size II, respectively in both trials. Ware potato tubers increased from 40% to 65% and were highest with 100% irrigation water (Table 4).

Table 1. 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)**			
Irrigation (% FC)	**0**	**75**	**112.5**	**150**	**0**	**50.6**	**75.9**	**101.2**
100	5.12d	5.69c	6.48a	6.06b	5.35c	5.70b	6.16a	6.13a
65	6.02d	6.63c	8.10a	7.21b	6.08d	6.71c	7.35b	7.82a
40	4.33c	4.66b	5.42a	5.28a	4.51c	4.89b	5.17a	5.12a
MSD (N)	0.17							
MSD (P)	0.17							
MSD (W)	0.13							
CV (%)	15.05							
Trial II								
100	6.84d	7.65c	8.46a	8.08b	7.22c	7.49b	8.19a	8.13a
65	7.88d	8.64c	10.07a	9.67b	7.93d	8.59c	9.58b	10.14a
40	5.76d	6.28c	7.39a	7.06b	6.06c	6.48b	6.96a	6.99a
MSD (N)	0.22							
MSD (P)	0.22							
MSD (W)	0.18							
CV (%)	14.95							

Means followed by the same letter(s) along the row for different N and P rates by irrigation rate are not significantly different at P≤0.05 according to Tukey's Studentized Range Test. MSD =Minimum Significant Difference

High compared to low irrigation water increased the ware potato by 4.34 and 5.06 t/ha in trials I and II, respectively. While the ware potato increased with increase in irrigation water rate, the seed size II, size I and chats decreased beyond 65% irrigation water rate. Increased application of irrigation water beyond 65% reduced the seed size II yield by 2.45 and 2.88 t/ha, seed size I by 1.62 and 2.1 t/ha, and chats by 0.65 and 0.78 t/ha in trials I and II respectively (Table 4).

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. The yield of chats increased with low irrigation water application at 40% compared to 100% (Table 4).

Integration of irrigation with N increased yield of seed potato per grade. Application of N from 0 to 150 kg N/ha increased the yield of ware, seed potato sizes II and I by 5.29 and 5.54 t/ha, 6.32 and 6.36 t/ha, and 3.78 and 5.38 t/ha, while the yield of chats reduced by 0.84 and 1.0 t/ha, irrespective of irrigation rate in trials I and II, respectively. However, application of N beyond 112.5 kg N/ha with 100% and 40% irrigation water reduced seed size I (Table 4). Integration of irrigation water with P significantly increased yield of all grades. Increased P resulted in significant yield increases per size distribution. The yield of ware, sizes II and I tubers increased with P rate from 0 to 101.2 kg P/ha with 65% followed by 100% and 40% irrigation water, respectively. However, P rates beyond 75.9 kg P/ha reduced or stagnated seed size I, resulting in more of seed size II. In addition, the higher P rate from 0 kg P/ha to 101.2 kg P/ha reduced chats regardless of the irrigation water rate. Application of P from 0 kg P/ha to 101.2 kg P/ha increased the yield of ware, sizes II and I by 4.72 and 4.59 t/ha, 4.69 and 5.33 t/ha, and 3.9 and 5.16 t/ha, while chats reduced by 0.94 and 1.1 t/ha, irrespective of irrigation water rate in trials I and II respectively (Table 5). Generally, integration of N and P rates did not significantly affect yield of ware, seed sizes II and I, and the chats in both trials.

Table 2. Effect of irrigation water, N and P rates on seed potato tuber yield

Trial I	**N rate (kg N/ha)**				**P rate (kg P/ha)**			
% FC	**0**	**75**	**112.5**	**150**	**0**	**50.6**	**75.9**	**101.2**
100	21.61d	28.17c	34.17b	36.70a	22.64d	27.54c	33.88b	36.58a
65	23.45d	30.36c	35.66b	40.50a	25.35d	30.48c	35.72b	38.43a
40	17.17c	20.40b	24.83a	26.10a	17.98c	20.80b	24.60a	25.12a
MSD (N)	1.39							
MSD (P)	1.39							
MSD (W)	1.10							
CV (%)	7.94							
Trial II								
100	24.82c	33.43b	41.76a	41.34a	27.60d	32.54c	39.93b	41.29a
65	27.44c	35.80b	45.53a	44.93a	30.21d	35.73c	43.19b	44.57a
40	20.29c	25.57b	31.31a	31.47a	21.67c	25.65b	30.47a	30.85a
MSD (N)	1.25							
MSD (P)	1.25							
MSD (W)	0.98							
CV (%)	5.99							

Means followed by the same letter(s) along the row for different N and P rates by irrigation rate are not significantly different at P≤0.05 according to Tukey's Studentized Range Test. MSD =Minimum Significant Difference. FC = Field Capacity

Table 3. Effect of N and P rates on seed potato tuber yield

	N rate (kg N/ha) in trial I				**N rate (kg N/ha) in trial II**			
P rate (kg P/ha)	**0**	**75**	**112.5**	**150**	**0**	**75**	**112.5**	**150**
0	15.90c	21.13c	24.35d	26.58d	18.34d	25.31c	31.89d	30.44d
50.6	19.28b	24.66b	29.27c	31.88c	23.16c	30.54b	35.67c	35.83c
75.9	23.28a	29.27a	35.03b	38.02b	28.42a	35.08a	43.36b	44.60b
101.2	24.50a	30.19a	37.56a	41.25a	26.81b	35.46a	47.21a	46.12a
MSD (P)	1.39				1.25			
MSD (N)	1.39				1.25			
CV (%)	7.94				5.99			

Means followed by the same letter(s) along the column for different N by P rates are not significantly different at P≤0.05 according to Tukey's Studentized Range Test. MSD =Minimum Significant Difference

Table 4. Effect of irrigation water and N rates on seed potato size distribution

N rate	Irrigation rate (100% FC)				Irrigation rate (65% FC)				Irrigation rate (40% FC)				Mean			
(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
Trial I																
0	5.36d	5.93d	9.04d	1.27a	4.21d	7.20d	10.14c	1.90a	2.36d	4.78d	7.78c	2.25a	3.97	5.97	8.99	1.80
75	8.18c	8.07c	10.72c	1.21a	6.11c	10.72c	11.93b	1.61b	4.26c	6.05c	8.18c	1.90b	6.18	8.28	10.27	1.57
112.5	9.68b	10.20b	13.25a	1.04a	7.78b	12.51b	14.17a	1.21c	5.13b	7.37b	10.89a	1.44c	7.70	9.85	12.77	1.23
150	12.22a	12.27a	11.41b	0.81b	9.22a	15.84a	14.69a	0.75d	6.34a	8.76a	9.68b	1.32c	9.26	12.29	11.93	0.96
MSD (N)	0.82	0.55	0.99	0.18												
MSD(W)	0.65	0.43	0.78	0.15												
CV (%)	19.5	9.75	14.57	21.4												
Trial II																
0	6.44d	6.99d	9.87d	1.53a	5.06d	8.51c	11.70d	2.18a	2.78c	5.75d	9.01d	2.76a	4.76	7.08	10.19	2.16
75	9.90c	9.67c	12.31c	1.55a	7.38c	12.43b	14.14c	1.85b	5.02b	7.50c	10.83c	2.20b	7.43	9.87	12.43	1.87
112.5	12.12b	12.81b	15.60a	1.23b	9.73b	16.72a	17.66a	1.43c	6.53a	9.57b	13.45a	1.76c	9.69	12.80	15.57	1.47
150	13.07a	13.45a	13.94b	0.88c	10.50a	16.79a	16.63b	1.02d	6.95a	10.47a	12.46b	1.60c	10.30	13.44	14.34	1.16
MSD (N)	0.56	0.73	0.90	0.20												
MSD(W)	0.44	0.58	0.71	0.16												
CV (%)	11.22	10.95	11.08	19.67												

Means followed by the same letter(s) along the column 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. FC = Field Capacity

Table 5. Effect of irrigation water and P rates on seed potato size distribution (t/ha)

P rate	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
Trial I																
0	5.59d	6.63d	8.93c	1.50a	4.44d	8.76d	10.43c	1.73a	3.28c	4.73d	7.60c	2.36a	4.44	6.70	8.99	1.86
50.6	8.07c	8.18c	10.08b	1.21b	6.22c	10.95c	11.81b	1.50b	3.98bc	6.22c	8.64b	1.96b	6.09	8.45	10.18	1.55
75.9	9.85b	9.97b	13.13a	0.92c	7.55b	12.27b	14.63a	1.27c	4.78b	7.43b	10.89a	1.50c	7.43	9.85	12.89	1.23
101.2	11.29a	12.33a	12.27a	0.69d	9.10a	14.29a	14.06a	0.98d	6.05a	8.58a	9.39b	1.09d	9.16	11.39	11.91	0.92
MSD (P)	0.82	0.55	0.99	0.18												
MSD(W)	0.44	0.58	0.71	0.16												
CV (%)	19.5	9.75	14.57	21.4												
Trial II																
0	7.38d	7.62d	10.69d	1.91a	5.67d	10.41d	12.09d	2.04a	3.84d	6.30d	8.85d	2.69a	5.63	8.11	10.54	2.21
50.6	9.45c	9.75c	11.94c	1.40b	7.51c	12.30c	14.20c	1.72b	4.97c	7.99c	10.35c	2.32b	7.41	9.92	12.16	1.81
75.9	11.47b	12.04b	15.32a	1.10c	8.93b	14.81b	17.89a	1.56c	5.77b	8.92b	13.89a	1.90c	8.91	11.73	15.70	1.52
101.2	13.33a	13.42a	13.77b	0.77d	10.55a	16.92a	15.95b	1.16d	6.69a	10.06a	12.68b	1.41d	10.22	13.44	14.13	1.11
MSD (P)	0.56	0.73	0.90	0.20												
MSD(W)	0.44	0.58	0.71	0.16												
CV (%)	11.22	10.95	11.08	19.67												

Means followed by the same letter(s) along the column for different irrigation water with P rates are not significantly different at P≤0.05 according to Tukey's Studentized Range Test. MSD =Minimum Significant Difference. FC = Field Capacity

4. DISCUSSION

The growth, development, and consequently yield of crops are highly influenced by available soil moisture [9]. In the present study, high irrigation water, N and P rates increased tuber yield and improved the seed size distribution. The number of tubers and seed yield 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 highest 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 [9]. Therefore, low irrigation water rate could have resulted in water stress during tuber set and early bulking stages and hence the greatest reduction in tuber yields while high irrigation water favoured vegetative at expense of reproductive growth.

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 [11]. Kleinkopf [12] 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, as well as their subsequent 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 [13] reported that there is a general relationship between stem number and tuber number whereby an increase in stem number often indicates an increase in tuber number. It is possible that potato plants supplied with low irrigation water, N and P rates experienced water and nutrient deficiency stresses due to imbalance in optimum growth conditions which resulted in fewer stems, 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 that helps in better nutrient uptake by the crop, resulting in assimilation of photosynthates into sinks [14,15,16]. 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 potato 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 [17]. 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 [18]. After initiation and maintenance, tubers must also increase in size during the bulking that determines ultimate weight. The total yield depends on the length of the tuber growing period and the average growth of the tubers per day [19]. At the bulking stage, photoassimilates generated through photosynthesis in the vegetative phase become critical for expansion of the tubers. Increased leaf area index (LAI) due to irrigation water, N and P integration 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 the final tuber yield [20]. The high number of seed potato tubers with greater size led to high yields in plots that received high irrigation water, N and P rates probably due to the greater LAI that favoured production of more photoassimilates. Potato plants need P only during the vegetative growth and tuber initiation stages, while N is required up to tuber bulking stage [16]. Phosphorus sometimes affects tuber set and therefore is seen as an element contributing to tuber quality in this respect [21].

The present study showed that integration of irrigation water, N and P fertilizer positively increased potato tuber yield. Application of 65% irrigation water followed by 100% produced 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 integration 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 rather 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. Huang [22] 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 [23,24,25] and can delay tuber initiation and bulking [26,27]. 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 both number and bulking capacity of tubers resulted in increase in photoassimilates production. The high tuber weight 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 reduces. Potatoes that received 100% irrigation water rate were intermediate in seed potato tuber yields. High seed tuber yields where intermediate irrigation water, high N and P rates were applied could have possibly been that their high quantities increased the use efficiency of other nutrients in the soil at the time including like potassium which are very critical in tuber production.

Increasing irrigation water, N and P rates greatly influenced the seed potato size distribution. In the present study highest 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 [28] 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 stress conditions due to low irrigation water together with the low N and P rates restricted the seed potato forming processes. El-Ghamry [29] 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 plants, 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 [12] 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 which represents the plant environment probably led to establishment of high LAI, which increased photosynthetic capacity, photoassimilates production, tuber bulking capacity and proportion of ware and size II 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 size II and I resulted 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.

5. CONCLUSION AND RECOMMENDATION

Integration of highest irrigation water, N and P rates can enhance overall potato tuber yield and yield components and hence may not be suitable for optimizing seed potato tuber yield. Lower irrigation water supply, N and P rates decreased seed potato tuber numbers and yield and increase the number of chats which are not suitable for use as seed. The results obtained indicate that intermediate irrigation water supply, N and P rates increase seed potato production as they contribute high seed potato yield. These intermediate rates increase the quantity of seed sizes II and I that are ideal for use as seed. Therefore, to obtain adequate seed potato tubers, proper irrigation water, N and P mineral nutrient integration should be adopted.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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