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Optimization of Seed Potato Specific Density, Starch and Dry Matter Contents and Tuberization Capacity of Resultant Plants Through Integrated Irrigation, Nitrogen and Phosphorus Management

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Abstract: A study was conducted in a Rainshelter (RTrial) at the Horticultural Research and Teaching Farm of Egerton University to determine the effect of integrated application of irrigation water, nitrogen (N) and phosphorus (P) on seed potato physiological quality and performance of plants resulting from them. The treatments arranged in a split-split plot in a completely randomized 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 with experiment replicated three times and repeated once. After harvest seed specific density, starch and dry matter contents were determined after which 15 seed tubers per treatment were stored for 90 days under diffuse-light sprouting conditions for postharvest (PTrial) evaluation. Later, three potato tubers were selected per treatment and planted to study growth vigour and tuberization capacity of resultant potato plants both in PTrials I and II. Data collected were subjected to analysis of variance and significantly different means were separated using Tukey's Studentized Range Test at P=0.05. Specific density, starch and dry matter contents increased from 40% to 65% irrigation water. Application of irrigation water beyond 65% reduced the specific density, starch and dry matter contents by 0.03, 2.6%, 3.7% and 0.04, 3.7%, 5.2% in RTrials I and II, respectively. The 100% compared to 65% irrigation rate reduced post-treatment evaluation stem number, density and height at 57 DAP by 1.3 and 1.1, 15.1 and 12.6, and 13.4 cm and 10.3 cm, and tuberization capacity in resultant plants by 5 and 8.7 tubers, in PTrials I and II, respectively. Application of N and P significantly increased seed potato specific density, starch and dry matter contents but application of N and P beyond 112.5 kg N/ha and 75.9 kg P/ha respectively reduced the same both in RTrials I and II, respectively. In postharvest evaluation integration of N at 0 to 112.5 kg N/ha with 65% irrigation rate increased the number of tubers produced by the resultant plants by 3.4 and 5.4, while high P rate at 75.9 kg P/ha increased tuberization by 8.4 and 10.7, in RTrials I and II, respectively. Integration of 65% irrigation rate, 112.5 kg N/ha and 75.9 kg P/ha rates optimized potato growth, and vigour of resulting potato plants.

Keywords: Potato, Irrigation, Nitrogen, Phosphorus, Seed Quality, Resultant Plants, Tuberization

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]. Therefore, it has overtime generated special importance in most parts of Kenya as a means of strengthening food security and increasing revenues for farmers due to its best potential for yield increases. Potato produces high yield, more edible energy and protein per unit area and time than many other crops, fits well into multiple-cropping systems, its cultivation is profitable and it provides employment hence it cultivation is expanding rapidly in developing countries [3]. However, due limited supply of pest-free planting materials, low quality in terms of content and size, lack of sufficient irrigation, fertilization, low technical and postharvest handling know-how among farmers, local production rarely meets the market demand.

Kenya needs 300,000 tonnes of certified potato seed per year [4], but only 2,640 tonnes [5] are available from research institutions and certified seed producers and therefore 96% of the farmers use their own harvest for replanting [6]. It is therefore very difficult for farmers in most parts of the country to get good quality seed potato for planting. What farmers are forced to do in most cases is that at the time of planting, they use the available potatoes in their seed store, regardless of their quality which lead to poor yields [5]. To meet the increasing demand of seed tubers, production efficiency in the informal seed production sector must therefore be improved. The seed potato tubers produced must present good physiological characteristics such as specific density, starch and dry matter contents which are crucial in improving the vigour of seedlings and tuberization capacity of the resultant plants. Formal potato production sector's high-quality and more productive seed potato tubers are expensive and remain largely unavailable to smallholder farmers in sub-Saharan Africa. Compared to the formal seed sector which involves a long certification process according to the Seed and Plant Varieties Act Cap 326 the informal seed production system needs much less time to avail the seed to the farmers and therefore should be supported as it is the only sustainable method to alleviate the problem of seed shortage [7].

Potato seed is usually the most expensive single input to potato cultivation accounting for 40 to 50% of production cost and shortage of good quality seed is recognized as the most important factor inhibiting potato production [3]. Availability of quality potato planting materials in adequate quantities is a major issue and although efforts to strengthen the formal seed system are critical, there is need to consider effective integration with the informal seed system to close the availability gap. However, many informal seed potato farmers in Kenya still use ware potato production technology for producing seed tubers. Consequently, seed tubers available through the informal system are of poor quality. Though potato yields are affected by several factors, seed quality is the basic factor. Most potato growers do not apply integrated management practices during seed tuber production. Potato growth depends on a supply of plant nutrients, such as nitrogen (N), phosphorus (P) and potassium (K), each with a specific function for plant growth and lack of them results in retarded growth processes and reduced yields [8]. In Kenya, low application of N and P under continuous cultivation is a major constraint that leads to poor potato growth and productivity and therefore, use of these fertilizers nutrients has not been effective due to isolated application practices.

Another factor that has limited seed potato production in many parts of Kenya is unreliable rainfall. Potato is sensitive to soil water deficit [9 10]. Water deficit is a common stress in potato production, which leads to decrease in tuber quality and yield [11]. Water, which is the most important component of life, is rapidly becoming a critically scarce commodity for humans and crop production, and its limited supply is one of the major abiotic factors that adversely affect agricultural crop production worldwide in many ways [12]. Irrigation and fertilization has been reported as two critical inputs in potato production and increased production depends on their efficient use throughout the growth period [13]. Proper nutrition is the basic need of every living organism as the nutrients are not only required for better plant growth and development, but they are also helpful to alleviate different kinds of abiotic stresses like drought stress. However, recent trends indicate that productivity and fertility of soils are globally declining due to degradation and intensive use of soils without consideration of proper soil management practices [14, 15]. Irrigation has been increasingly employed to curtail effects of drought [16] in parts of the world, but in Kenya potato farmers rarely use this practice due to cost and lack of knowledge, among other factors. Knowledge on performance of potato under different irrigation regimes will help predict the expected seed tuber quality characteristics in environments characterized by varied rainfall amounts.

There is need to develop strategies to provide potato growers with good quality seed tubers at affordable price. Study of tolerance of potato to varying irrigation water and mineral nutrient supply rates will assist farmers in the informal seed potato sector in predicting seed potato tuber quality characteristics and expected performance of resultant plants 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, Tigoni variety were planted to determine the effect of irrigation water, nitrogen (N) and phosphorus (P) application rates on potato specific density, starch and dry matter contents, and performance of resultant plants. 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. Seed Potato Specific Density, Starch, and Dry Matter (DM) Contents

Starch content and DM of a 5 kg sample of tubers per treatment were determined at harvest on the principle of a linear relationship between specific gravity with starch and/or DM. Specific gravity is a measurement of density and in tubers it is the weight of the tuber compared to the weight of the same volume of water. It was computed by weighing five (5) kg tuber sample in a sturdy wire basket both in air (Wa) and in water (Ww) using a spring balance. The weight measured is the difference between the weight of the sample, and the weight of an equal volume of water. The two weights were then applied to the equation and the specific gravity of different treatments calculated as: Specific gravity = Wa/(Wa-Ww). A high correlation occurs between the specific gravity of the tuber and the starch content and also the percentage of dry matter or total solids. This contributes to higher recovery rate and better quality of the processed product [17]. Starch content = 112.1x - 106.4, while percentage DM = 158.3x - 142; where x = specific gravity [18]. Starch content indicates accumulated food reserves that are later used by tubers in initial growth after planting. The sample of potato selected per treatment was free of any dirt. Specific density is dimensionless while starch content and DM are expressed as percentage.

2.3. Postharvest Field Performance Evaluation

After harvest endodormancy was determined by transferring 15 seed tubers per treatment to diffuse-light sprouting conditions. Wiersema [19] stated that storage conditions that favour apical dominance limit the number of sprouts, and pre-sprouting in diffuse light allows sprouts to become well developed and firm. The tubers were kept in diffuse light conditions in paper punch perforated and stapled at the top "Mafuco® khaki" paper bags of size No. 16 for 90 days after harvesting. Perforation was done to allow free air movement. After withdrawal from storage, three potato tubers were later selected per treatment and planted to study the growth vigour (number of stems, plant height) and tuberization capacity under the prevailing farmer conditions. The three sprouted tubers per treatment were planted under prevailing (outdoor) farmer conditions to determine the treatments with the highest vigour and tuberization. The emerging plants were allowed to grow for a period of 8 weeks in both PTrials I and II.

2.3.1. Number of Stems and Plant Height

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

The number of stems was recorded 22 DAP and used to calculate stem density as the number of main stems or aboveground stems per plant. A main potato stem was considered as the one that originates from the tuber. The number of main stems/m^2 was calculated using the formula: Stem density = total stem number/[total row length * row spacing] [19]). Total stems/m^2 were determined by multiplying the number of stems by the number of plants per equivalent area which is equal to eight. The total row length and width in a m^2 is 0.9 by 0.75m respectively. Stem density assists determine expected yield of seed tubers obtained from various treatments. Plant height was determined at 22, 36, 50 to 57 DAP.

2.3.2. Tuberization

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

2.4. Data Analysis

Data collected was subjected to analysis of variance using the SAS system for windows V8 1999-2001 by SAS Institute Inc., Cary, NC, USA and significantly different means separated using Tukey's Studentized Range Test at $P = 0.05$. The data for the two seasons were analyzed separately.

3. Results

3.1. Seed Potato Specific Density, Starch and Dry Matter Contents

The specific gravity, starch content and DM of seed potato significantly depended on irrigation water, N and P rates in RTrials I and II. Irrigation water rate significantly decreased seed potato specific density, starch and dry matter contents of potato tubers (Table 1).The specific density, starch and dry matter contents increased from 40% to 65% and decreased by 0.03, 2.6%, 3.7% and 0.04, 3.7%, 5.2% in RTrials I and II, respectively. Lowest specific density, starch and dry matter contents were observed with 100% followed by 40% and the highest was recorded with 65% irrigation water rate (Table 1).Application of N and P significantly increased seed potato specific density, starch and dry matter contents. Higher rates of N and P led to higher levels of seed potato specific density, starch and dry matter contents in RTrials I and II. Specific density, starch and dry matter contents significantly increased with N rate up to 112.5 kg N/ha, after which they non-significantly reduced. Application of 150 kg N/ha compared to 112.5 kg N/ha reduced the specific density, starch and dry matter contents by 0.01, 0.7%, 0.9% and 0.01, 0.7%, 0.9% in RTrials I and II, respectively (Table 1).

Table 1. *Effect of irrigation water, N and P rates on seed potato specific gravity, starch and dry matter contents.*

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

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

Similarly P application significantly increased the seed potato specific density, starch and dry matter content up to 75.9 kg P/ha beyond which there was no significant increase at 101.2 kg P/ha. Overall, the lowest seed potato specific density, starch and dry matter content was 1.1, 12.5%, and 25.8% recorded with the lowest P application at 0 kg P/ha and the highest was 1.1, 17.2%, and 32.5% with 65% irrigation water (Table 1). Unlike high N and P application rates which were positively correlated to specific density, starch and dry matter content, a strong negative relationship was observed with 100% irrigation water.

3.2. Seed Potato Tuber Field Performance Evaluation

3.2.1. Number of Stems and Plant Height

In the postharvest evaluation the number of stems, stem density, and plant height at 22, 36, 50 and 57 DAP significantly depended on individual effects of irrigation water, N and P rates (Table 2). The different irrigation water rates during the growth of the potato crop at production stage significantly affected the growth pattern of the resultant potato plants in the field. The resultant stem number, stem density and height significantly depended on the amount of irrigation water supplied earlier on. Seed generated from potatoes that received high irrigation water rate at 100% had the least number of stems, stem density and height compared to 40% and intermediate 65% irrigation water rates. The 65% irrigation water resulted in seed potato which generated more vigorous plants which had greater stem numbers, stem density and stems with greater height. However, regardless of the amount of initial irrigation water supplied the height of the resultant plants increased throughout the growth period but higher increases were observed with plants from seed which were generated using low irrigation water. The stem numbers, density and height in resultant plants increased from those generated from potato seed grown with 40% and were highest with 65% after which they reduced with 100% irrigation water rate. For example 100% compared with 65%

irrigation water rate reduced the stem numbers, density and height 57 DAP by 1.3 and 1.1, 15.1 and 12.6, and 13.4 cm and 10.3 cm in PTrials I and II respectively (Table 2).

Table 2. *Effect of irrigation water, N and P rates on post-treatment performance evaluation of stem number and density and plant height.*

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

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

Unlike high irrigation water application which did not favour the fast growth of the resultant potato plants, N and P application led to production of seed potato whose resultant plants were very vigorous. Low N rate of 0 and 75 kg N/ha non-significantly increased the resultant potato plants stem numbers and stem density until after 112.5 kg N/ha application. Resultant plants of potato seed that had received 112.5 kg N/ha had more stems and higher stem density. However, 150 kg N/ha potato seeds did not express in the field significantly different from the 112.5 kg N/ha generated ones. Plant height was similarly affected by N application. There were non-significant increases in plant height up to 112.5 kg N/ha from 22 to 50 DAP after which there was a significant decrease in plant height 57 DAP with 150 kg N/ha generated plants (Table 2).

Generally, the stem numbers and density increased from low N rate at 0 kg N/ha to 112.5 kg N/ha after which there was a decrease. High application of N at 150 kg N/ha compared with 112.5 kg N/ha in potatoes produced seed which led to decrease in the stem numbers and density of resultant plants by 0.1 and 0.2, and 1.7 and 2.6 while the plant height increased at all growth stages in PTrials I and II, respectively. Furthermore, application of P in potato crop field produced seed potato whose resultant plants expressed significant differences in stem numbers and density, and including plant height.

However, for stem numbers significant differences were observed from P rate, 50.6 kg P/ha after which there were non-significant increases beyond 75.9 kg P/ha. In most of the growth stages plant height progressively increased with increase in P rate both in PTrials I and II (Table 2).

3.2.2. Tuberization Capacity

The number of tubers harvested from plants established from seed potato that was produced with different irrigation water, N and P application rates significantly varied between the different potato plants evaluated (Table 3). Number of tubers per plant increased from potato seed that had received low irrigation water at 40% together with 0 kg N/ha and 0 kg P/ha to those that was raised under intermediate irrigation water rate at 65% together with 112.5 kg N/ha and 75.9 kg P/ha both in PTrials I and II, respectively (Table 3). Seed that received low irrigation water application at 40% significantly produced more tubers per plant compared to those that received 100% but not better than 65% irrigation water.

Table 3. *Effect of irrigation water, N and P rates on post-treatment performance evaluation of tuberization capacity.*

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

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

Application of 100% compared with 65% irrigation water to seed potatoes regardless of N and P application rates led to decrease in tuber numbers (tuberization capacity) in resultant plants. The highest number of tubers per resultant plant was 16.7 and 22 observed with seed potato that was raised with 65% FC together with 112.5 kg N/ha and 75.9 kg P/ha both in PTrials I and II. The lowest number of tubers per resultant plant was 4.3 and 8.3 observed with seed potato that was raised with 100% FC together with 0 kg N/ha and 0 kg P/ha. When high irrigation water at 100% FC was integrated with 112.5 kg N/ha and 75.9 kg P/ha the resultant plants produced 11.7 and 13.3 tubers compared with 16.7 and 22 tubers observed with seed potato that was raised with 65% irrigation water which was an equivalent decrease of 5 and 8.7 tubers in PTrials I and II, respectively. Therefore, increasing irrigation water beyond 65% FC reduced the postharvest tuberization capacity of seed potato tubers.

Furthermore, N and P application affected the postharvest field performance of seed potato produced. Production of seed potato through application of N from 0 to 112.5 kg N/ha together with 65% irrigation water led to increased number of tubers produced by the resultant plants from 8.3 and 11.3 to 11.7 and 16.7, which was an equivalent increase of 3.4 and 5.4 tubers in both PTrials I and II, respectively. Therefore, increase in N application from 0 kg N/ha to 112.5 kg N/ha during seed production increased tuberization capacity of the resultant plants. However, increase in N application to 150 kg N/ha in the field produced seed potato whose resultant plants were characterized by significantly low number of tubers than those produced by 112.5 kg N/ha generated seeds (Table 3).

Unlike N, seed potato where P was applied from 0 to 101.2 kg P/ha resulted in significantly higher number of tuber production per resultant plant.

Higher number of tubers was observed with plants whose seed potato was from field plants where high P rates were applied. When integrated with 65% irrigation water and 112.5 kg N/ha seed potato from where low P rate of 0 kg P/ha was applied resulted in plants that produced fewer tubers amounting to 8.3 and 11.3, compared to 16.7 and 22 produced by plants from seed potato supplied with 75.9 kg P/ha in the field which was an equivalent increase of 8.4 and 10.7 (Table 3). Overall, low to intermediate irrigation water, high N and P application rates at 112.5 kg N and 75.9 kg P/ha resulted in seed potato which when established in the field the resultant plants produced more tubers (greater tuberization).

4. Discussion

In Kenya, farmers grow seed potato during the rainy season using fertiliser rates of commercial potato production.

In this study, specific density, starch and dry matter contents increased with irrigation water, N and P application rates. However, they decreased with over application of both irrigation water and N. One of the most important qualities of seed potato is high starch and dry matter contents, which are determined by specific gravity. As the specific gravity increased, the starch and dry matter content of seed potato increased. Therefore, there was a correlation between specific gravity, starch and dry matter contents. The 100% compared to 40% and 65% irrigation rates led to a decrease in seed potato specific density and consequently starch and dry matter contents. Fernando [20] reported that excessive water, whether from rainfall or irrigation, and a general increase in soil fertility results in tubers with low dry matter.

The potato plants supplied with high irrigation water could have experienced a high rate of growth and development in terms of height, total biomass. Therefore, most of the photoassimilates were used in maintenance of high growth and development. This vegetative growth may have affected the physiological state of tubers, which in turn influenced the specific density, starch and DM contents. Conversely, low to moderate irrigation water probably decreased potato growth and development, causing photoassimilates to be translocated for storage in the seed potato tubers that ended up having high specific density, starch and dry matter contents. Makaraviciute [21] reported that dry matter, starch, protein and sugar contents in potato tubers increase or decrease, depending on the mineral fertilizer forms, rates and their correlations. Where 40% or 100% irrigation rates were applied with either low or high N and P rates, seed potato had low specific density, starch and dry matter contents. This suggested that if potato growth and development is either poor or massive due to low or high irrigation water, N and P rates, the specific density, starch and dry matter contents of the tubers will not be high. Balanced potato growth and development as a result of 65% irrigation water together with intermediate N and P rates lead to high specific density, starch and dry matter contents, compared to the two extremes.

According to this study, low N and P rates had the least specific density, starch and dry matter contents. However, high N and P rates did not greatly improve the specific density, starch and dry matter contents, compared to intermediate application rates. This result indicates that high N or P rates promoted potato growth and development at the expense of accumulation of dry matter and starch in the seed potato tubers. Very low levels of N and P decrease starch and dry matter probably by reducing the photosynthetic rate. The potato plant has been reported as being basically a starch factory and over 90% of the dry weight of a potato tuber is a direct result of photosynthetic process [22]. The high irrigation water, N and P rates probably increased growth rates, prompting solids accumulated through photosynthesis to be rapidly utilized for growth and development as they were formed, resulting in low specific density, starch and dry matter contents.

Fernando [20] reported that unlike P that increases DM, nitrogen has the most effect in promoting top growth, which if too lush can prolong the growing season causing tubers not to bulk but to have lower dry matter at harvest. DM mainly depends on maturity of the potato tuber, composition of the soil, and fertilization conditions [23, 24]. Therefore, low to intermediate N rates increase dry matter content of tubers, whereas high N rates produced the opposite effect.

The starch and dry matter contents directly influence seed potato quality and growth of the resultant potato crop. Potatoes with a high specific gravity have been reported to produce higher yields than potatoes with low specific gravity [25]. Information on specific density, starch and DM contents may help explain the different quality characteristics of seed potato tubers grown using different water and mineral nutrient supply conditions. The quality characteristics may affect subsequent commercial potato production. This information will help explain the qualities of seed potato and also their suitability for increased potato production. These quality characteristics are therefore important considerations when growing potato destined for seed use.

When the harvested seed potato tubers were planted in the field to evaluate their growth vigour, better performance was observed with seed potato tubers obtained from potatoes supplied with 65% (intermediate) followed by 40% irrigation water rates. Seed potato tubers from potato plants supplied with 100% irrigation water and lower rates of N and P showed the least growth vigour and performance. In storage, potato losses weight equally from respiration and evaporation [20], which impact on its physiological age. Olsen [26] reported that age is one of the most important physiological factors associated with seed potato performance, such that as a seed tuber ages it tends to have a short dormancy period, emerges early, produces multiple stems, initiates tubers early and produces more tubers, but of small size. In this study, it is possible that the seed growing conditions of different irrigation water, N and P rates had an impact on the seed physiological age, and consequently variation in post-treatment field performance.

The progress from physiologically young to physiologically mature tubers has been reported to affect yield parameters of the subsequent crop [27], which include date of emergence, stem number, canopy growth pattern, maturity date, total tuber yield and tuber size distribution [28]. It is possible that potatoes supplied with intermediate irrigation water (65%), high N and P rates experienced balanced growth and development that resulted in seed potato tubers which had better physiological maturity than those supplied with higher or lower irrigation water and similar N and P rates. These seed tubers probably had moisture and total soluble solids contents that enhanced germination of more eyes, sprout maintenance and sprouting percentage. These seed tubers possibly were physiologically better and resulted in better sprouting characteristics, which enabled them to perform better in the field under prevailing management conditions. Their better performance was due to high number of stems, stem density, plant height and the number of tubers on resultant plants. In this study, almost twice to thrice tuber numbers were obtained, compared to those obtained at the Rainshelter trial.

Kleinkopf [29] reported that initiated tubers not carried to harvest are re-adsorbed by the plant as it adapts to environmental conditions during growth. The number of tubers that actually reach maturity has also been reported to depend on available moisture and soil nutrients [1].Therefore, not all of the initiated tubers are carried to maturity due to the re-adsorption by the potato plant. This probably explains why the number of tubers decreases at potato maturity.

5. Conclusion and Recommendation

The overall combination of irrigation water, N and P rates affects soil moisture and nutrient content during the potato growing period. This result influences the physiological status of the potato plants, including growth and development status, and the subsequent quality characteristics of the seed potato tubers. The high rates of N and P improves the physiological quality of the seed potato tubers. High irrigation rate at 100% lowers physiological quality of seed potato tubers. It is recommended to avoid high irrigation water rates at 100% FC and low N and P rates at 0 kg N/ha and 0 kg P/ha due to their potential negative effects on the physiological characteristics of seed potato tubers which reduces the growth vigour and yields of resultant potato crop.

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