

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

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Abstract

Potato has overtime generated special importance in most parts of Kenya and the world as a means of strengthening food security and increasing revenue for farmers. However, potato productivity and industry expansion have been constrained by the poor quality seed tubers being produced in the informal seed sector due to inadequate supply of initial planting materials, improper fertilizer management practices and irregular rainfall patterns. A study was done at the Horticultural Research and Teaching Farm of Egerton University to determine the effect of integration of irrigation water, nitrogen and phosphorus rates on seed tuber relative weight loss and sprouting characteristics after storage. The three factors were tested in a split-split plot design where irrigation water supply was assigned to main plots, N to subplots and P to sub-subplots. The treatments were replicated three times and the trial repeated once. The treatments consisted of three irrigation water rates (40%, 65% and 100% field capacity), applied throughout the potato growth period through drip tube lines. Nitrogen was supplied as urea (46% N) at four equivalent rates of 0, 75, 112.5 and 150 kg N/ha, while phosphorus was supplied at planting time as triple superphosphate (46% P₂O₅) at four rates of 0, 115, 172.5 and 230 kg/ha P₂O₅, which translated into 0, 50.6, 75.9, 101.2 kg P/ha. Data collected included relative percentage weight loss, number of sprouts and sprouting percentage. Data collected was subjected to analysis of variance and significantly different means separated using Tukey's Studentized Range Test at $p \leq 0.05$. The 100% compared to 65% and 40% irrigation water rates resulted in relatively high weight loss, sprout length and reduced the number of sprouts and sprouting percentage of seed tubers. N and P rates generally decreased the relative weight loss, improved the number of sprouts and sprouting percentage. It is recommended to apply low to intermediate irrigation water, intermediate to high N and P rates to reduce the percentage relative weight loss and sprouting characteristics.

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

1. Introduction

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

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

physiological age (Struik et al., 2006). The purpose of potato storage is to maintain tuber quality and provide a uniform flow of seed tubers to farmers. Seed potato with good storageability should prevent excessive dehydration due to water loss, decay and sprouting. Sprouting, weight loss, rotting and low temperature sweetening are the major problems during storage. The factors contributing to qualitative and quantitative deterioration of potato could be grouped into physical, physiological, microbiological, and entomological factors (Rezaee et al., 2011). The physiological status of seed potato has a great impact on sprouting, and may depend on the water and nutrient management of the crop in the field. Effective sprout control is a major component of managing stored potato quality as sprouting causes increased weight loss resulting in significant reduction of tuber quality (Frazier et al., 2004). Control of seed tuber quality through proper irrigation water and mineral nutrient management is an essential element in the sustainability of the seed industry as it is the basis of increased yield at the farm level.

Conditions under which potatoes are grown including irrigation water and mineral nutrient supply are some of the most important factors affecting seed potato storageability. The physiological status of seed potato after varied irrigation and mineral nutrient supply may affect the quality of the tubers after storage, which may influence the growth and development of resultant potato crop and consequently affecting their productivity. Potato growth depends on a supply of plant nutrients, such as nitrogen (N), phosphorus (P) and potassium (K), each with has a specific function in plant growth and lack of them results in retarded growth processes and reduced yield (Vander Zaag, 1981). 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).

Selection of the right potato planting material is one of the most challenging tasks a farmer undertakes to obtain good yields. Small-scale potato farmers are constrained by limited access to both seed potato tuber quantity and quality. Although there exists potential of increasing potato productivity through increased irrigation water, N and P application there is limited knowledge on the effects of integrated N, P and irrigation rates on seed potato relative weight loss and subsequent sprouting following storage. Knowledge of the effect of integrated water and nutrient management on relative weight loss and sprouting quality of seed potato tubers will help to strengthen the seed potato production system. This study determined the interactive effects of rate of irrigation water, N and P application on seed potato relative weight loss and sproutability after storage.

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 after which seed potato tubers were stored for 90 days between December 2011 and April 2012 (Trial I). The trial was repeated between 5th April and 6th August 2012 and the seed potato tubers stored for 90 days between August and November 2012 (Trial II).

Potatoes were planted to determine the effect of irrigation water, nitrogen (N) and phosphorus (P) application rates on relative weight loss and tuber sprouting characteristics after 90 days storage. 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% P₂O₅) at four rates (0, 115, 172.5 and 230 kg/ha P₂O₅, which translated into 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. Seed potato from 10 randomly selected plants per treatment were harvested 115 days after planting, labelled and placed in plastic bags for testing weight loss and sproutability after storage.

2.2 Seed Potato Tuber Relative Weight Loss

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

2.3 Seed Potato Tuber Sprouting Characteristics

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

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

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

2.4 Data Analysis

Data collected were subjected to analysis of variance using the SAS system for windows V8 1999-2001 by SAS Institute Inc., Cary, NC, USA and significantly different means separated using Tukey's Studentized Range Test at $p \leq 0.05$.

3. Results

3.1 Seed Potato Tuber Relative Weight Loss

The relative weight loss (%) of seed potato at 90 days after storage (90 DAS) significantly depended on irrigation water, N and P rates. Integration of irrigation water with either N or P also significantly influenced the percentage relative weight loss of the seed potato tubers. Slight differences were also observed from combination of N and P rates both in Trials I and II (Table 1).

Low irrigation water rate at 40% decreased the relative weight loss of seed potato tubers in storage. A lower relative weight loss was observed with low irrigation water rate at 40% compared to 65% and 100%. A relative weight loss of 12.37% and 10.51% was observed with high compared with 7.51% and 5.87% recorded with low irrigation water rate both in Trials I and II, respectively. The 100% compared to 40% irrigation water rate together with low N rate of 0 kg N/ha increased the relative weight loss in seed potato tubers at 90 DAS. Nitrogen decreased the relative weight loss of seed potato tubers regardless of the irrigation water rate (Table 1).

Weight loss decreased from 12.37% and 10.51% with low N rate of 0 kg N/ha to 9.90% and 7.82% with high N rate of 150 kg N/ha, when supplied with 100% irrigation water rate in Trials I and II, respectively. With low irrigation water rate, weight loss reduced from 7.51% and 5.87% to 7.11% and 5.44% both with the low and high N rates of 0 and 150 kg N/ha, respectively. Greater reduction in weight loss resulted with high compared to low irrigation water rate when high N rate of 150 kg N/ha was supplied. However, significant decrease in weight loss was only evident where high irrigation water rate was supplied. Application of high N rate did not significantly decrease the relative weight loss of seed potato tubers where 40% and 65% irrigation water rates were supplied (Table 1).

Table 1. Effect of irrigation water, N and P application rates on percentage weight loss of seed potato at 90 DAS

Trial I	N rate (kg N/ha)					P rate (kg P/ha)					
	0	75	112.5	150	Mean	0	50.6	75.9	101.2	Mean	
Irrigation (% FC)	100	12.37a*	11.26ab	10.73bc	9.90c	11.06	12.66a	11.15b	10.63c	9.81d	11.07
	65	9.34a	9.19a	8.80a	8.65a	8.99	9.36a	8.91b	8.90b	8.82b	8.99
	40	7.51a	7.36a	7.11a	7.11a	7.27	7.60a	7.40a	7.11b	6.97b	7.27
Mean	9.74	9.27	8.88	8.55		9.88	9.15	8.88	8.53		
MSD (N)	1.36										
MSD (P)	0.45										
MSD(W)	1.05										
CV (%)	3.73										
Trial II											
Irrigation (% FC)	100	10.51a	9.29ab	8.65bc	7.82c	9.07	11.06a	9.11b	8.26c	7.85c	9.07
	65	7.27a	6.81a	6.46a	6.41a	6.74	7.46a	6.81b	6.57b	6.10c	6.74
	40	5.87a	5.63a	5.49a	5.44a	5.61	6.81a	5.26b	5.23b	5.13b	5.61
Mean	7.88	7.24	6.87	6.56		8.44	7.06	6.69	6.36		
MSD (N)	1.42										
MSD (P)	0.48										
MSD (W)	1.09										
CV (%)	5.90										

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

Similarly, P application decreased the relative weight loss of seed tubers regardless of the irrigation water rate. The relative weight loss of seed tubers decreased with increases in P rate. However, significant differences between the P rates were only evident with 100% irrigation water rate. With 40% and 65% irrigation water rates, significant decrease was only evident up to 50.6 kg P/ha after which high rate of P up to 75.9 and 101.2 kg P/ha did not significantly decrease the relative weight loss of seed potato tubers. Like N application, greater reduction in relative weight loss was observed when high P was combined with high irrigation water rate (Table 1).

3.2 Seed Potato Tuber Sprouting Characteristics

After 90 days of storage, the sprouting capacity of seed potato tubers which was expressed as a percentage significantly depended on the individual effects of irrigation water, N and P application rates and it was not affected by their combinations. The sprout length other than being significantly dependent on irrigation, N and P application rates was also affected by the integration of irrigation water rate and P application (Table 2).

Irrigation water rate significantly decreased the number of sprouts and percentage sprouting. High irrigation rate at 100% reduced the number of sprouts to 3.77 and 4.65 compared to intermediate irrigation water rate at 65%, which increased them to 4.71 and 5.71 in Trials I and II, respectively. Irrigation water rate at 100% had 58.87% and 66.37% sprouting compared to intermediate irrigation water rate at 65%, which had 67.26% and 81.55% sprouting in Trials I and II, respectively. Compared to irrigation water rate, N application significantly increased the number of sprouts and the percentage sprouting of seed potato tubers (Table 2).

Application of N from 0 to 150 kg N/ha significantly increased the number of sprouts from 3.83 and 4.64 to 4.81 and 5.5, and sprouting from 54.76% and 66.27% to 68.65% and 78.57% in Trials I and II, respectively. However, non-significant increases were observed between 0 and 75 kg N/ha, and between 112.5 and 150 kg N/ha in both Trials. Increase of P rate from 0 to 101.2 kg P/ha also significantly increased the number of sprouts and the percentage sprouting of seed potato tubers. The number of sprouts increased from 3.75 and 4.53 to 4.75 and 5.69, and sprouting from 53.57% and 64.68% to 67.86% and 81.35% with 0 and 101.2 kg P/ha in both Trials (Table 2).

Comparatively, higher sprout numbers and a better percentage sprouting were observed in Trial II compared to Trial I, regardless of irrigation, N and P rates (Table 2).

Table 2. Effect of irrigation water, N and P application rates on seed potato sprouts and percentage sprouting

Irrigation water rate (% FC)	Number of sprouts		Percentage sprouting	
	Trial I	Trial II	Trial I	Trial II
100	3.77a*	4.65a	53.87a	66.37a
65	4.71c	5.71c	67.26c	81.55c
40	4.29b	5.06b	61.31b	72.32b
MSD (W)	0.20	0.21	2.85	2.97
N rate (kg/ha)				
0	3.83a	4.64a	54.76a	66.27a
75	4.06a	5.06b	57.94a	72.22b
112.5	4.33b	5.36c	61.90b	76.59c
150	4.81c	5.50c	68.65c	78.57c
MSD (N)	0.25	0.26	3.62	3.76
P rate (kg/ha)				
0	3.75a	4.53a	53.57a	64.68a
50.6	4.05b	5.00b	58.33b	71.43b
75.9	4.44c	5.33c	63.49c	76.19c
101.2	4.75d	5.69d	67.86d	81.35d
MSD (P)	0.25	0.26	3.62	3.76
CV (%)	9.59	8.27	9.59	8.27

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

Increasing N rate from 0 to 150 kg N/ha significantly increased the seed potato sprout length from 7.83 and 3.17 cm with 0 kg N/ha to 12.0 and 5.63 cm with high N rate at 150 kg N/ha in both Trials (Figure 1). However, higher sprout length was observed in Trial I compared to Trial II regardless of irrigation, N or P rates. Overall, lower number of sprouts and percentage sprouting were observed with high irrigation water rate when coupled with lower rates of both N and P in both Trials I and II, respectively ($p \leq 0.05$).

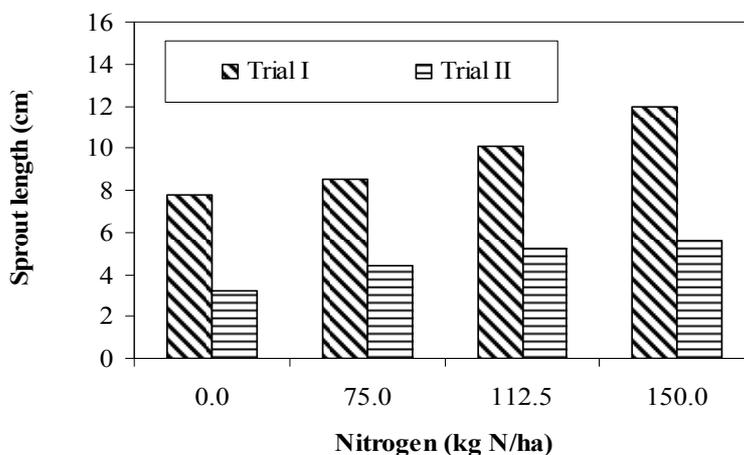


Figure 1. Effect of nitrogen rate on seed potato sprout length

The sprout length at 90 DAS also significantly depended on irrigation water and P rates. Low irrigation water rate at 40% together with low P rate of 0 kg P/ha reduced the sprout length to 4.7 and 3.2 cm compared to 9.85 and 4.13 cm recorded for high irrigation water rate of 100% with the same P rate of 0 kg P/ha in both Trials. However, application of high P rate at 101.2 kg P/ha significantly increased the sprout length to 8.9 and 4.4 cm with 40% irrigation water rate compared to 16.18 and 7.38 cm observed with 100% irrigation water rate in both Trials. Low compared to high irrigation water rate decreased the sprout length, whereas higher rates of P increased the sprout length (Table 3).

Table 3. Effect of irrigation water and P application rates on seed potato sprout length

Irrigation water (% FC)	P rate (kg P/ha) in Trial I					P rate (kg P/ha) in Trial II				
	0	50.6	75.9	101.2	Mean	0	50.6	75.9	101.2	Mean
100	9.85a*	11.19b	13.64c	16.18d	12.72	4.13a	5.12b	5.59c	7.38d	5.56
65	7.01a	8.13b	9.99c	12.93d	9.52	3.23a	4.05b	4.84c	5.48d	4.4
40	4.7a	5.23a	7.54b	8.9c	6.59	3.2a	3.68b	3.99bc	4.4c	3.82
Mean	7.19	8.18	10.39	12.67		3.52	4.28	4.81	5.75	
MSD (P)	0.72					0.44				
MSD (W)	0.57					0.35				
CV (%)	9.61					4.59				

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

4. Discussion

In Kenya, farmers grow seed potato during the rainy season using fertiliser rates of commercial potato production. In this study, 100% irrigation water rate represented a normal rainy season, and fertiliser rates were varied from zero to commercial potato production rates. Reduction in seed potato weight after storage can be an indication of deterioration of seed potato quality and was found to depend on potato growing conditions tested in this study. The seed potato tuber relative weight loss decreased with increase in irrigation water rate, and increased with increased in N and P application rates. The seed potato tubers from high compared to lowest and intermediate irrigation water rates had the greatest relative weight loss after storage. Chachin and Iwata (1981) reported that weight loss in stored potato may be due to higher respiration rate, increased membrane permeability and more sprout development. This probably suggests that potato supplied with high irrigation water rate absorbed more of it into the seed tubers which lead to more water being available for physiological processes such as transpiration and respiration within the seed and also promoted sprouting. This consequently, resulted to a greater weight loss. Sprouting has been reported to cause increased weight loss and is also associated with the conversion of starch to sugars (Frazier et al., 2004). This then suggests that the seed potato harvested from plants grown with low irrigation water rate were in a relatively inactive physiological state during storage compared to those harvested from plants supplied with high irrigation water rate, which were probably characterized by high metabolic activities. The seed water content has been reported to affect the rate of metabolic and deteriorative reactions (Vertucci & Roos, 1990).

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

The seed potato tubers from low or intermediate irrigation, high N and P rates had high starch and dry matter

content. Gold and Hay (2008) reported that the dry matter in starchy seeds attracts and holds water molecules. This probably explains why the seed potato tubers grown under both high irrigation, low N and P rates experienced greater weight loss at 90 DAS due to low dry matter and starch contents. The weight loss could also be contributed to physiological aging of tubers and water loss as seed potato equilibrates or maintains at a specific moisture level. Loss of moisture as observed with 100% irrigation water rate has been reported to lead to quality loss and finally to non-marketable produce (Kibar, 2012). When low to intermediate irrigation, high N and P rates were applied minimal weight loss was observed in storage. Probably N and P application improved the strength and integrity of seed potato membrane, and minimized the metabolic and deteriorative reactions that lead to weight loss.

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

Potatoes supplied with low irrigation water rate attained physiological maturity earlier and therefore their seed tubers were physiologically older than those from plants supplied with high irrigation water rate. However, though these seed potatoes from low irrigation water rate attained physiological maturity earlier, probably they contained less moisture content, and therefore were physiologically inactive in storage, resulting in late germination that led to less sprout length. The high moisture content in the seed potato tubers obtained from high irrigation water rate might have stimulated their enzymatic activity, enhancing rapid germination of the eyes, which shortened the sprouting period. The high moisture facilitated physiological processes leading to earlier sprouting and consequently produced longer, but fewer sprouts. The stimulated sprouting in the seed potato obtained from high irrigation water rate could have had a negative influence on the tubers as they lost energy, moisture and withered due to the high respiration.

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

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

5. Conclusion

It is possible that potatoes supplied with high irrigation, low N and P rates were physiologically disadvantaged, which impacted on their quality and consequently experienced reduced sprouting. Seed growing conditions of different irrigation, N and P application rates had an impact on the seed physiological age, which led to varied relative water loss and sprouting characteristics. In general, the most effective treatments to reduce weight loss of tubers and increase sprouting characteristics were integration of low to intermediate irrigation water rate with

high N and P rates. Farmers in the informal sector should, therefore, be made aware of these optimal conditions, under which to grow potatoes destined for use as seed.

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