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Determination Of Optimum Phosphorus And Potassium Application Rates For Higher Potato Seed Tuber Production

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Abstract: Obtaining adequate high-quality potato seed tuber is the major challenge in potato production. However, phosphorous (P) and potassium (K) management are prudent techniques for the regulation of the yield and tuber quality. The study aimed to assess the economically optimum amount of P, K, and PK required for higher seed tuber production. The experiment had four levels of P and K fertilizers below the recommended dose of ware potatoes applied on three potato varieties in a factorial split-plot design with three replications. Results showed the absence of statistically significant interaction effects ($p>0.05$) of variety by fertility management. However, the cultivar, P, K, and combined application of P and K altered some growth, yield, and quality characteristics of the varieties. Application P affected seed tuber yield and the economic benefit of the varieties substantially and a quarter of the recommended P for ware potato gave maximum standard seed tuber yield (20.51t) equivalent to the recommended level (23.51t). It enhanced the economic benefit of medium-sized and total seed tuber by 385 and 362%. Therefore, a quarter of the P fertilizer required for ware potato production seems optimal to produce potato seed tuber while there was no yield and economic advantage of K application.

Keywords: potato varieties; nutrient management; growth; seed tuber yield; seed tuber quality; economic benefit

1. Introduction

In potato seed-tuber production, nutrient management is one of the variable inputs that drive up production costs of quality seed tubers. However, small-scale potato seed growers and cooperatives are applying high amounts of P_2O_5 fertilizers up to 138 kg ha^{-1}, suggested for ware potato[1], with the belief that both seed and ware potato production require the same nutrient level. Thus, they produce more undesirable-sized tubers and a lesser amount of seed-size tuber yield, which drives up the price of standard seed tuber beyond the purchasing power of small-scale growers. Consequently, small-scale potato growers are using substandard seeds that diminish productivity and challenge sustainable production.

Nevertheless, seed and ware potato production differ in plant spacing, anticipated tuber size, and quality standards, highlighting that they have different nutrient needs. Several nutrient management studies indicated that applying NPK below the advised level increases the yield of seed-sized tubers at the expense of large and small-sized tubers in the production of ware potatoes [2]–[5]. Accordingly [6] reported that adequate phosphorus management affects early tuber development and maturity in ware potato production, which may control the size of tubers in seed tuber production. Furthermore, [7], and [8] pointed out that phosphorus management could have the ability to improve the carbohydrate content and shelf life of potatoes in ware potato production, indicating that special phosphorus management is essential for the production of high-quality seed tuber. Besides this, appropriate K management also lessens physiological aging and seed tuber weight losses after harvest, extending the shelf life of both ware and seed tubers [9], [10]. Optimal potassium (K) management, however, increases the tuber size and yield of potatoes in K-deficient soils [11].

Despite this, there were no nutrient management studies or recommendations for seed tuber production in most developing countries like Ethiopia. Still, there has not yet been a full investigation into how newly released potato varieties respond to varied applications of P, K, and combined P and K in terms of seed tuber yield and quality. Therefore, the present study evaluated the yield, seed tuber quality, and economic return of the three potato varieties under different P, K, and combined applications of P and K levels.

2. Materials and Methods

2.1. Description of the study area

The field experiment was carried out at Debre Birehane Agricultural Research Center, located between 09º 35' 45'' and 09º 36' 45'' N latitude and 39o 29' 40' to 39o 31' 30' E longitude at an altitude of 2878 meters above sea level during the main rainy season. The area has 6.5 °C - 19.9 °C temperature and about 897.8 mm mean rainfalls on average each year. The soil is mesotrophic vertisol, 1- 2 m deep, with loam to clay loam texture and pH that range between 5.5-5.8 (H2O 1:1.25) and 4.0- 4.3 (KCl 1:1.25). The total nitrogen content of the topsoil ranged between 0.18 to 0.21%; the extractable K levels ranged from 28.2 to 50.7 ppm and P values lie between 7.54 to 8.44 ppm.

2.2. Description of the experimental materials

The varieties used as the test martial were Gera (KP-90134.2), Shenkolla (KP-90134.5), and Belete (CIP-393371.58) because they are adaptable and dominantly grown in the country. The sources of the fertilizers were urea, Di-Ammonium Phosphate (DAP - 46 % P_2O_5), and Potash (KCl - 60 % K_2O).

2.3. Experimental design and treatments

The experimental design of the field experiment was split-plot with a factorial combination of the two mineral types as the main plot factor; the three varieties as the subplot factor replicated trice. It is an efficient and suitable design to accommodate a large set of full factorial treatments and appropriately test interactions [12]. The experiment had sixteen factorial treatment combinations of phosphorus (Control, 8.5, 17, and 34 kg ha^{-1}P) and potassium levels (Control, 85, 170, and 340 kg ha^{-1} K) in the main plots, and the three potato varieties in the sub-plots designed to test the effect of individual factors and their interactions. The fertilizer levels were set up below the recommendation suggested for ware potato production in the experimental area, as a quarter, half, and complete dosage of recommended P and K. The experimental plots had 4 rows 60 cm apart and 12 plants with 25 cm spacing within the rows as recommended for seed tuber production [22]. Therefore, the sample size was 20 plants.

2.4. Data collection

2.4.1. Yield data collection

At harvest, tubers collected from central rows of each experimental unit were categorized into undersize (< 35mm); small size (35-45mm); medium (45-55mm); and large (>55mm) based on East African seed potato specification[13] to explore the effects of treatments on tuber size distribution. Accordingly, medium-sized (standard seed tuber), total marketable seed tuber (medium and small), and marketable (large, medium, and small) and unmarketable (under size, rote and diseased) tuber yield (t ha^{-1}) were determined as yield tone per hectare. The sum of the marketable and unmarketable tuber weight was used to calculate the total tuber yield (t ha^{-1}). The harvest index (%) was calculated as the ratio of the total tuber yield and total biomass, as suggested by [14].

2.4.2. Tuber quality data collection

To evaluate the impact of nutrient management on tuber size distribution, and physical and chemical quality characteristics, sample tubers from the small, medium, and big size categories were sampled. Then, the strength of the tuber periderm layer (kg/cm^2) was determined from five randomly chosen sample tubers. The weight of thirty tubers from all size groups was measured in air and water to compute the specific gravity using the formula SG=Wa/(Wa-Ww), where SG= specific gravity, Wa= weight in air, and Ww= weight in water. Next, using the formula starch % =17.546+199.07(SG-1.0988) (Talburt and Smith 1959 as refereed in [15], the starch content was calculated functionally from the specific gravity. Traditional plant-tissue analysis procedures [16], digital Kjeldahl instruments (Kjeltec TM 8400nuclear magnetic resonance spectroscopy (R-R-SMZ-A1-UV-1900), and flame photometry (Flame photometer PFP7-JANEWAY Ltd.) were used to estimate the N, P, and K content of tubers. Eventually, all data acquired from the experimental units were coded and analyzed to test the proposed hypothesis.

2.5. Data analysis

All data collected from the experiment were cleaned and tested for normality using the powerful test model the Shapiro-Wilk model[17]. Analysis of variance (ANOVA) was conducted using the General Linear Model (GLM) function of SAS Statistics 9.4 for Windows' free University edition. When an ANOVA revealed significant findings, the means were compared using the Tukey post hoc test. In the presence of significant economic yield, the partial budget analysis was carried out using the CIMMIT partial budget analysis procedure[18].

3. Results

The ANOVA showed no significant (P>0.05) interaction effects of variety and nutrient management on growth, tuber yield, and quality responses. However, there was an interaction effect of P and K on some agronomic traits and individual factors variety, P and K fertilizer management significantly affected growth, tuber size distribution, yield, and quality performances (Table 1 and Table 2).

Table 1. Yield response of potato varieties to different P and K fertilizer application levels based on seed tuber category.

Treatment	LTY (t ha^{1})	MTY (t ha^{1})	STY (t ha^{1})	VSTY (t ha^{1})	R&D (t ha^{1})	MY (t ha^{1})	UMY (t ha^{1})	TSY (t ha^{1})	TY (t ha^{1})
P levels									
P_0	4.6^{b}	18.1^{b}	9.6	2.7^{ab}	2.0^{b}	31.1^{b}	4.7^{b}	27.17^{c}	34.3^{c}
P_1	7.3^{a}	20.3^{ab}	9.9	2.5^{b}	2.4^{b}	37.5^{a}	4.9^{b}	30.35^{b}	41.7^{ab}
P_2	4.9^{b}	19.9^{ab}	10.1	2.9^{ab}	2.7^{ab}	34.1^{b}	5.7^{ab}	30.11^{b}	39.8^{b}
P_3	5.7^{ab}	23.1^{a}	10.8	3.3^{a}	3.5^{a}	39.7^{a}	6.8^{a}	34.55^{a}	45.1^{a}
K levels									
K_0	5.8	18.4^{b}	10.9	3.0	2.6	34.5	5.6	29.48	40.1
K_1	5.0	20.5^{ab}	9.3	3.0	3.1	34.6	6.1	30.39	39.5
K_2	5.4	21.1^{ab}	10.4	2.5	2.6	36.1	5.2	31.62	40.7
K_3	6.7	21.5^{a}	9.9	2.9	2.3	37.0	5.2	30.74	40.9
Variety									
Gera	6.6^{a}	21.3	7.3^{c}	1.8^{c}	2.8^{a}	34.9	4.64^{b}	28.97^{c}	38.6^{b}
Shenkolla	6.5^{a}	20.4	10^{b}	2.8^{b}	1.9^{b}	35.9	4.70^{b}	30.47^{b}	40.2^{ab}
Belete	3.9^{b}	19.5	12.9^{a}	4.0^{a}	3.3^{a}	34.9	7.25^{a}	32.28^{a}	42.2^{a}
CV%	19.6	4.6	13.87	11.76	18.2	17.9	12.2	18.5	14.9
Mean	5.72	19.96	10.12	2.85	2.67	35.5	5.53	30.56	40.3

LTY- large size tuber yield, MTY- medium size tuber yield, STY- small size tuber yield, VSTY- very small size tuber yield, R&D-rote, and diseased tuber yield, MY- marketable tuber yield, UMY-unmarketable tuber yield, TSY-total seed tuber yield, TY-total tuber yield, superscript letters abc – means with the same letters are not significantly different.

Table 2. Tuber quality responses to variety, P and K levels.

Treatment	NEPT	TPDS	ATW	SG	Starch (%)	TDMC (%)	TN (%)	TP (%)	TK (%)
P levels									
P_0	5.50	3.28	46.92	1.084	14.73	19.62	0.88	0.075	2.284
P_1	5.48	3.26	50.81	1.089	14.82	20.11	0.90	0.073	2.194
P_2	5.52	3.25	48.33	1.085	14.76	19.52	0.89	0.077	2.153
P_3	5.54	3.26	47.62	1.085	14.77	19.43	0.92	0.078	2.255
K levels									
K_0	5.63	3.27	48.24	1.087[a]	15.15[a]	19.59	0.95[a]	0.074	2.202
K_1	5.41	3.23	46.79	1.085[b]	14.83[b]	19.62	0,90[a]	0.076	2.070
K_2	5.57	3.27	49.95	1.084[bc]	14.66[bc]	19.92	0.93[a]	0.075	2.294
K_3	5.43	3.29	48.68	1.083[c]	14.42[c]	19.57	0.82[b]	0.077	2.326
V									
Gera	5.40[b]	3.26	49.52[a]	1.078[c]	13.42[c]	18.84[b]	0.90	0.078[a]	2.064[b]
Shenkolla	5.38[b]	3.30	51.69[a]	1.086[b]	15.04[b]	19.86[a]	0.92	0.078[a]	2.002[b]
Belete	5.74[a]	3.23	44.05[b]	1.090[a]	15.84[a]	20.31[a]	0.88	0.070[b]	2.592[a]
CV	9,08	5.07	14.13	0.29	4.37	9.42	17.19	16.06	25.44
Mean	5.51	3.26	48.42	1.085	14.77	19.67	0.89	0.076	2.222

NEPT-Number of eyes, TPDS-tuber periderm strength, ATW-Average tuber weight, SG-specific gravity, TDMC-tuber dry matter content, TN-tuber nitrogen, TP-tuber phosphorus, TK-tuber potassium, superscript letters abc –means with the same letters are not significantly different.

3.1. Effect of variety on tuber yield and quality traits

Varietal differences had a remarkable effect on tuber size distribution except for medium-sized and marketable tuber yield (Table 1). It had affected large-size tuber (LTY), small-size tuber (STY), very small-size tuber (VSTY), and rotted and disease (R&D) tuber distribution. Hence, variety altered UMY, TSY, and TY significantly. Belete scored the highest UMY, TSY, and TY, followed by Shenkolla and Gera. However, there was no statistical variation between the test varieties in major economic yield traits (MTY (standard seed size) and MY (ware potato yield) showing that they are nearly similar. The tuber quality assessment also showed that variety affected the number of eyes per tuber (NEPT), average tuber weight (ATW), Starch content, dry matter production (DMP), tuber phosphorus content (TP), and tuber potassium content (TK) (Table 2). Despite its lower ATW and TP content, Belete had more NEPT, SG, Starch, and TK than Gera and Shenkolla while Gera had lower DM content.

3.2. Effect of P on tuber size distribution and yield

The ANOVA result showed that P fertilization had a substantial impact on the tuber size distribution of the studied varieties except STY (Table 1). It increased both ware and seed tuber size distribution with advancing P levels. The mean separation result also showed that increasing the P fertilizer level from P_0 to P_1 could improve LTY by 37%; however, further increment had no significant effect. MTY increased with increasing P levels, and P_3 scored the highest record. However, MTY had no statistical change between P levels. Moreover, increasing P levels tended to increase undesirable tuber and remarkably lower VSTY and R&D found in P_1. Hence, P fertilizer levels significantly affected MY, UMTY, TSY, and TY (Table 1). Statistically higher MY and UMTY were produced in all P levels compared to the control showing that there was no substantial difference between P_1 and P_3 levels. Thus, P_1 and P_3 enhanced MY, TSY, and TY similarly, indicating that a quarter of the recommended P for ware potato has a similar effect with the recommended dose.

3.3. Effect of K on tuber yield and quality

The assessment of the yield traits indicated that K fertilizer utilization significantly influenced only the medium-sized tuber yield MTY (Table 1). MTY tended to increase with increasing K levels; though there was no statistical difference between the K treatment levels. Plots treated with K_3 produced remarkably higher medium-sized tuber yield compared to the control treatment. Thus, the application of K_3, K_2, and K_1 had 14.5, 12.8, and 10.2 % MTY increments over the control, respectively. Besides, analysis of tuber physical and chemical quality showed K fertilizer management affected only specific gravity (SG), starch, and TN contents (Table 2). Mean comparison results revealed that SG, starch, and N content of tubers decreased with increasing K fertilizer levels, and the control treatment significantly exceeded all K application levels. Therefore, K affected SG, starch, and N content undesirably.

3.4. Economic analysis

After the observation of significantly different yields, the cost-benefit analysis was carried out for phosphorus levels. The partial budget analysis result showed the highest marginal rate of return (MRR) on P1. The estimated value of standard quality seed tuber (MTY) and total seed tuber (TSY) had the highest (385 and 352 %) MRR. Furthermore, the total fresh marketable tuber yield (MY) obtained at P_1 scored the highest (210%) cost recovery for P fertilizer management (Table 3). The result indicated that P_1, which only required a fourth of the fertilizer cost needed to produce ware potatoes, increased the marginal rate of return compared to the control and other two scenarios (P_2 and P_3). The result indicated that the P fertilizer management below the recommended level of ware potatoes production could maximize the economic benefit of seed tuber production by recovering the cost incurred.

Table 3. Partial budget cost-benefit analysis.

Trt.	VC ($)	MSY (t ha^{-1})	GBMS (USD)	NBMS (USD)	MR (%)	TSY (t ha^{-1})	GB TS (USD)	NB TS (USD)	MR (%)	MY (t ha^{-1})	GB MY (USD)	NB (USD)	MR (%)
P_0	0	16.3	1636.1	1636.1		24.8	1982.6	1982.5		27.9	871	871	
P_1	58.1	18.3	1918.5	1860.4	3.8	26.9	2245.6	2187.4	3.5	33.7	1051	992.9	2.1
P_2	91.2	17.9	1846.3	1755.1	D	27.0	2207.9	2116.6	D	30.7	972.5	881.3	D
P_3	157	20.8	2103.8	1946.3	0.8	30.5	2476.9	2319.4	1.3	35.7	1114.5	957.1	D

VC-variable cost (labor and fertilizer), MSY- adjusted medium yield, TSY- adjusted total seed tuber yield, MY- adjusted marketable yield, GB - gross benefit, NB - net benefit, MR – the marginal rate of return, selling price $312.5/ t fresh, and $781.25 /t seed tuber, GBMS=GBMS seed +GB remaining fresh potato, GBTS=GBTS seed +GB remaining fresh potato, GBMY= GB fresh marketable potato.

4. Discussion

The data presented in the result sections above revealed that there was no convincing evidence that proves the interaction between variety and nutrient management options to alter the growth, yield, and quality traits. The non-significant interaction effect between varieties and nutrient management options infers that the varieties had the same demand for P, K, or combined application of P and K fertilizers. This finding indicated that there was no specific P, K, or combination P and K fertilizer requirement for the tested potato varieties. In line with this,[19] reported that different potato cultivars respond with the same trend for increasing P levels in different soils. The evidence demonstrated that the same fertilizer recommendation might work for potatoes grouped in similar maturity categories when grown under comparable conditions. This might have encouraged the commercial use of broadly applicable nutrient management recommendations and resolved the applicability dilemma in seed tube production.

In the assessment, the application of P fertilizer altered most crop growth, yield, and quality traits. Interestingly, all P fertilizer management levels significantly improved the most important yield traits (MTY, MY, and TSTY) more than the control. Particularly, P_1 had a remarkably higher tuber yield than the control and was equivalent to P_2 and P_3. This result was evidently because of the production of a lesser amount of VSTY and R&D tuber yield in P_1 as compared to P_2 and P_3. In Support of this finding, [7] reported that increasing phosphorus management increased tuber number and decreased the size of tubers in potato production. Abbasian [21] and Akoto [22] also reported similar results from different phosphorus management experiments in Tehran and Kenya. The authors found more tuber yield from low (21-ppm) phosphorus application executed in an open hydroponic medium pot experiment in Tehran and a decreasing trend of seed-sized potatoes with increasing P levels from field experiments in Kenya. Similarly, the present study highlighted that changing P management by a quarter of the recommended level required for ware potato could optimize seed the tuber yield of the tested varieties by improving yield limiting traits on par with the half (P_2) and full (P_3) dose of the ware potato recommendation. This was because, increasing P management levels facilitates root and shoot growth and advanced flowering and maturity in potato crops, which increase tuber formation and limit further tuber filling [23]. On the other hand [19] reported that higher (54.6, 109.2, and 218.4 kg ha^{-1} P) were sufficient for soils with high, medium, and low available P in Brazil, and suggested that P fertilizer management should be adjusted based on soil fertility. Conversely, our finding indicated that P fertilizer adjustment should be not only based on the fertility status of the soil but also the purpose (ware and seed) of the potato tuber production because it has production cost penalties.

On the other hand, although potassium fertilizer management is suggested to be essential in the yield and quality improvement of potato seed tubers [24][20], it harmed some growth and quality traits. It affected the growth (emergence and maturity period) and quality traits (specific gravity and starch content) of the test varieties negatively. This unpredictable result might be due to the source of K because KCl might create a high salt concentration in the soil solution during the early growth period that hinders sprout growth at emergence. After all, a higher concentration of salts in irrigation water retards the emergency of the potato plant at planting [25]. Besides, [26] reported that a high concentration of NaCl treatments on sprouted potato mini tuber could reduce shoot growth dramatically and restrain emergence. Thus, K fertilizer management in the form of KCl harmed seed tuber production despite its ability to enhance soil fertility. Hence, the finding might help potato seed growers not to invest in it assuming that it is worth improving the yield and quality of potato seed tubers.

Based on the yield and quality assessment result, only phosphorus management had seed tuber yield and quality advantages. The partial budget analysis result also verified that the lower amount of phosphorus (P_1) was more cost-effective than higher levels (P_2 and P_3). This was because, all P treatment levels had comparable economic yields (MTY, TSY, and MY) while production costs rose with increasing levels. In support of this result,[27] also reported more yield and production cost advantage from nutrient expert recommendations than farmers' practice and soil test recommendations. Therefore, changing nutrient management from the control to P_1 (a quarter of the recommended P for ware potato) appeared to be optimum in seed tuber production. Hence, applying the lower amount of P fertilizer will have practical importance in cutting production costs and stabilizing seed tuber market value encouraging both seed producers and small-scale potato growers and maintain sustainable potato production.

5. Conclusions

The study demonstrated that the fertilizer demand of the test varieties does not change across the varieties, nutrient types, and the interactions between them. Nevertheless, changing the phosphorus application rate from the control is required, and a fourth of the supplementary phosphorus advised for producing ware potatoes is sufficient for yield and economic benefit of the seed tuber production. It improved the standard-quality seed tuber yield and profitability by increasing medium-sized tuber and decreasing smaller-sized tuber and the associated production cost. Conversely, the finding highlights that K fertilizer (KCl) management affected the quality traits of seed tubers negatively by prolonging emergency and maturity days, which affected tuber dry matter production. Hence, as stewards of their products, resources, and the environment, potato growers are advised to use a quarter of the P fertilizer recommended for ware potato production and avoid K fertilizer to maximize the yield and economic benefit of quality seed tubers in the study area and similar cultivar, soil and environmental conditions. The finding may open new insight for agronomists, educators, and researchers to develop novel nutrient management for quality seed-tuber production that reduces the agricultural system's pervasive loop of using substandard seed. The research work is limited to medium potato maturity groups, single P and K fertilizer sources, environment, and growing season. Thus, further study is required on different potato maturity groups, diverse sources of fertilizers, and different environments.

Authors' contribution: All authors contributed to the study's conception and design. Damtew Aragaw Amare performed material preparation, data collection, analysis, and the draft of the manuscript preparation. Both co-authors commented on the draft and final versions of the manuscript.

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References

1 A. C. Degebasa, "Review of Potato Research and Development in Ethiopia: Achievements and Future Prospects," *J. Biol. Agric. Healthc.*, no. October 2019, 2019, doi: 10.7176/jbah/9-19-04.

2 C. J. Rosen and P. M. Bierman, "Potato Yield and Tuber Set as Affected by Phosphorus Fertilization," pp. 110–120, 2008, doi: 10.1007/s12230-008-9001-y.

3 J. Etiang, "Journal of Soil Science & Plant Health Effect of Macro-Nutrient Combinations on Yield and Economic Returns of Potato," 2018.

4 S. K. Das, A. Sarkar, J. K. Tarafdar, and A. Chacraborty, "Potato (Solanum tuberosum L.) seed tuber production as influenced by intra-row spacing, dehaulming time and nutrient management in lower Indo-Gangetic plains of India," *J. Crop Weed*, vol. 16, no. 1, pp. 20–28, 2020, doi: 10.22271/09746315.2020.v16.i1.1268.

5 M. J. Sadawarti, S. P. Singh, R. K. Singh, S. Katare, and R. K. Samadhiya, "Agro-techniques for Production of Seed Size Tubers in Conventional Seed Potato Production System–A Review," *Int. J. Bio-resource Stress Manag.*, vol. 12, no. 3, pp. 238–246, 2021, doi: 10.23910/1.2021.2272.

6 A. M. Fernandes, R. P. Soratto, and J. R. Gonsales, "Root morphology and phosphorus uptake by potato cultivars grown under deficient and sufficient phosphorus supply," *Sci. Hortic. (Amsterdam).*, vol. 180, pp. 190–198, 2014, doi: 10.1016/j.scienta.2014.10.035.

7 C. J. Rosen, K. A. Kelling, J. C. Stark, and G. A. Porter, "Optimizing Phosphorus Fertilizer Management in Potato Production," *Am. J. Potato Res.*, vol. 91, no. 2, pp. 145–160, 2014, doi: 10.1007/s12230-014-9371-2.

8 M. Leonel, E. Lopes, and A. Mazetti, "Chemical composition of potato tubers : the effect of cultivars and growth conditions," 2017, doi: 10.1007/s13197-017-2677-6.

9 Don Horneck and Carl Rosen, "Measuring Nutrient Accumulation Rates of Potatoes-—Tools for Better Management," *Better Crop.*, vol. 92, no. 1, 2008.

10 B. Bhattarai and K. C. Swarnima, "Effect of Potassium on Quality and Yield of Potato Tubers – A Review," vol. 3, no. 6, pp. 7–12, 2016.

11 S. Torabian *et al.*, "Potassium : A Vital Macronutrient in Potato Production — A Review," *Agronomy*, vol. 11, no. 543, pp. 1–18, 2021, doi: https://doi.org/10.3390/agronomy11030543.

12 O. E. Zakaria, M. M. El-Rouby, A. I. Nawar, H. E. M. Ibrahim, and A. A. A. El-Salam, "Relative efficiency of replicated and non-replicated statistical designs in quantifying the variations in maize grain yield," *Agron. Res.*, vol. 19, no. 4, pp. 2037–2049, 2021, doi: 10.15159/AR.21.119.

13 East African Community(EAC), *East African Standard:Seed potato spesification*, vol. 753. 2011. [Online]. Available: https://law.resource.org/pub/eac/ibr/eas.753.2011.pdf

14 C. L. Beadle, "Growth analysis," in *Photosynthesis and Production in a Changing Environment*, 1993, pp. 36–46. doi: 10.1007/978-94-011-1566-7_3.

15 A. Ali Zeleke, T. Dejene Abebe, and B. Berihun Getahun, “Genetic Analysis Studies in Potato (<i>Solanum tuberosum </i>L.) Genotypes for Tuber Yield and Yield Related Traits,” *Agric. For. Fish.*, vol. 10, no. 5, p. 196, 2021, doi: 10.11648/j.aff.20211005.15.

16 M. R. Motsara and R. N. Roy, *Guide to laboratory establishment for plant nutrient analysis,Food and Agriculture Organization of United Nations Rome, 2008*. FAO, 2008.

17 N. Mohd Razali and Y. Bee Wah, “Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling tests,” *J. Stat. Model. Anal.*, vol. 2, no. January 2011, pp. 21–33, 2011.

18 CIMMIT, “From Agronomic Data to Farmer Recommendations : An Economics Training Manual.Completly revisededition.,” Mexico, 1988. [Online]. Available: https://repository.cimmyt.org/xmlui/bitstream/handle/10883/859/25152.pdf

19 A. M. Fernandes and R. P. Soratto, “Response of Potato Cultivars to Phosphate Fertilization in Tropical Soils with Different Phosphorus Availabilities,” *Potato Res.*, 2016, doi: 10.1007/s11540-016-9330-z.

20 C. Rosen, C. Hyatt, and M. Mcnearney, “Effects of Phosphorus and Calcium on Tuber Set, Yield, and Quality in Goldrush Potato.” American Journal of Potato Research, · April 2014 DOI:10.1007/s12230-014-9371-2

21 A. Abbasian, A. Ahmadi, A. R. Abbasi, and B. Darvishi, “Effect of various phosphorus and calcium concentrations on potato seed tuber production,” *J. Plant Nutr.*, vol. 41, no. 14, pp. 1765–1777, Jun. 2018, doi: 10.1080/01904167.2018.1454955.

22 E. M. Akoto, C. O. Othieno, and J. O. Ochuodho, “Influence of Phosphorus Fertilizer on Potato Seed Production in Acid Soils in Kenya,” *Sustain. Agric. Res.*, vol. 9, no. 2, p. 101, Apr. 2020, doi: 10.5539/sar.v9n2p101.

23 C. J. Rosen and P. M. Bierman, “Potato yield and tuber set as affected by phosphorus fertilization,” *Am. J. Potato Res.*, vol. 85, no. 2, pp. 110–120, Apr. 2008, doi: 10.1007/s12230-008-9001-y.

24 B. Bhattarai and K. C. Swarnima, “Effect of Potassium on Quality and Yield of Potato Tubers – A Review,” no. December, pp. 6–12, 2018.

25 D. Levy, “The response of potatoes (Solunum tuberosum L.) to salinity: plant growth and tuber yields in the arid desert of Israel 547,” *Ann. appl. Bid. (1992), 120. 547-555*, no. The Volcani Center, Bet Dagan, Israel. No. 2921-E, pp. 120–547, 1992.

26 J. S. Oliveira, D. J. Moot, and H. E. Brown, “Seed potato physiological age and crop establishment,” *Agron. New Zeal.*, vol. 44, pp. 85–93, 2014.

27 X. Xu, P. He, S. Qiu, S. Zhao, W. Ding, and W. Zhou, “Nutrient management increases potato productivity and reduces environmental risk: Evidence from China,” *J. Clean. Prod.*, vol. 369, p. 133357, Oct. 2022, doi: 10.1016/J.JCLEPRO.2022.133357.