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Sweet Potato (*Ipomoea batatas L.*) Response to Incremental Application Rates of Potassium Fertilizer in Mississippi

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Abstract: Potassium (K) fertilization is a crucial component of sweet potato (*Ipomoea batatas L.*) production. The basis for K fertilizer recommendations in sweet potato production varies greatly and relies on studies conducted in the late 1950s–1970s. Changes in agronomic practices and increasing costs emphasize the need to revisit fertilizer recommendations. A field experiment was conducted to investigate the impact of seven different K fertilizer (K_2O) application rates on sweet potato storage root yield, tissue K concentration, and economic implications in Mississippi. Incremental applications of K fertilizer did not influence sweet potato yield at any grade. Leaf tissue K concentration exhibited a quadratic trend in response to K fertilizer rate, with maximum leaf and root K content achieved at 269 and 404 kg·ha^{-1} K_2O, respectively. Both the predicted K application rate for maximum yield and maximum profitability were the same, at 174 kg·ha^{-1} K_2O. Accordingly, comparable sweet potato yields were achieved while applying substantially less fertilizer than the recommended rate. Further research is warranted to examine the impacts of only potassium fertilizer applications on soil characteristics and temporal trends in sweet potato potassium uptake, as well as refine fertilization recommendations for sweet potato production.

Keywords: fertilizer; potassium; storage root; sweet potato; total marketable yield

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1. Introduction

The acreage of U.S. sweet potato (*Ipomoea batatas L.*) production has increased by 65% over the last 20 years (2000–2020); with an increase in yield of 35% (18.2 to 24.6 Mg·ha^{-1}) [1]. This enormous increase in aggregate sweet potato production is largely due to yield and harvested area gains in North Carolina, California, Mississippi, and Louisiana [2].

Potassium (K) fertilization is a crucial component of sweet potato production. Sweet potatoes use K for functions such as photosynthesis, sugar transport, water and nutrient movement, protein synthesis, and starch formation [3,4]. The potassium removal of sweet potato is five times greater than corn, soybean, or wheat [5], thus, some level of K fertilization should be required for optimal root yield. Previous research has demonstrated uptake of K positively influences sweet potato yield and root formation, suggesting an increase in K availability results in greater yields and improved root set [6,7].

However, recommended K fertilizer rates needed for optimal sweet potato production vary greatly. The majority of studies establishing K fertilizer requirements for sweet potatoes were conducted in the late 1950s–1970s or extrapolated from other crops, and they are the basis for sweet potato fertilizer recommendations in reports from soil testing laboratories. Due to changes in agronomic practices and availability of newer varieties, it is likely that these recommendations are outdated and focused on growing environments not representative of the Mississippi production region. This has resulted in a wide range of recommended K fertilizer rates (120–350 kg·ha^{-1} K_2O) for sweet potato production [6], [8–10].

Previous research has revealed inconsistent responses of sweet potatoes to K fertilization. Some demonstrate no impact of increased K fertilization rate [11,12] whereas others report splitting K fertilization application across the growing season positively impacts yield [13]. However, the previous authors collectively failed to report fertilizer recommendations based on soil tests and utilized K fertilization rates far below those typically recommended for sweet potato production in the United States [8].

With sweet potatoes requiring such a large range of K for optimal yields, there is great potential for excessive fertilizer use, resulting in increased production costs. The estimated K use efficiency for the world cereal crop is 19%, emphasizing the need to revise current fertilizer management and recommendation practices [14]. Moreover, the price of potash fertilizer increased from \$445 Mg^{-1} in early 2021 to \$898 Mg^{-1} in early 2022 [15], further reinforcing the need to identify optimal fertilizer rates for Mississippi producers. With the finite supply of K fertilizer sources, fertilizer K rate recommendations should not be based only on the yield response curve and initial soil test K but also on the value of the crop and the cost of fertilization [16].

Therefore, the objectives of this study were to (1) identify the optimum K rate for sweet potato production and (2) determine the optimum K rate for profitability, taking into consideration seven K application rates for the commonly grown sweet potato cultivar Beauregard.

2. Materials and Methods

2.1. Study Location

Non-irrigated field trials were conducted at the Pontotoc Ridge-Flatwoods Branch Experiment Station in Pontotoc, MS (34.1331° N, 89.0063° W) during the growing seasons from the years 2018 to 2021. Monthly rainfall data was collected from the Delta Agriculture Weather Center website (http://deltaweather.extension.msstate.edu/) (accessed on 2 April 2022) and the amount of total annual rainfall ranged from 149 to 188 cm (Figure 1), which was typical of the experimental site. The soils of the experimental site are classified as Falkner silt loam (fine-silty, siliceous, thermic Aquic Paleudalfs) [17]. An aggregate soil sample was taken at a depth of 15 cm prior to the growing season each year. Initial soil testing data and fertilizer recommendations are presented in Table 1. Soil nutrient concentrations were analyzed using the standard methods as outlined by [18]. More specifically, samples were initially extracted using 0.05 M HCl, followed by extraction using a solution containing 1.57 M acetic acid, 0.063 M malonic acid, 0.089 M malic acid, 0.032 M ammonium fluoride, and 0.012 M aluminum chloride. In all years, the forecrop was corn.

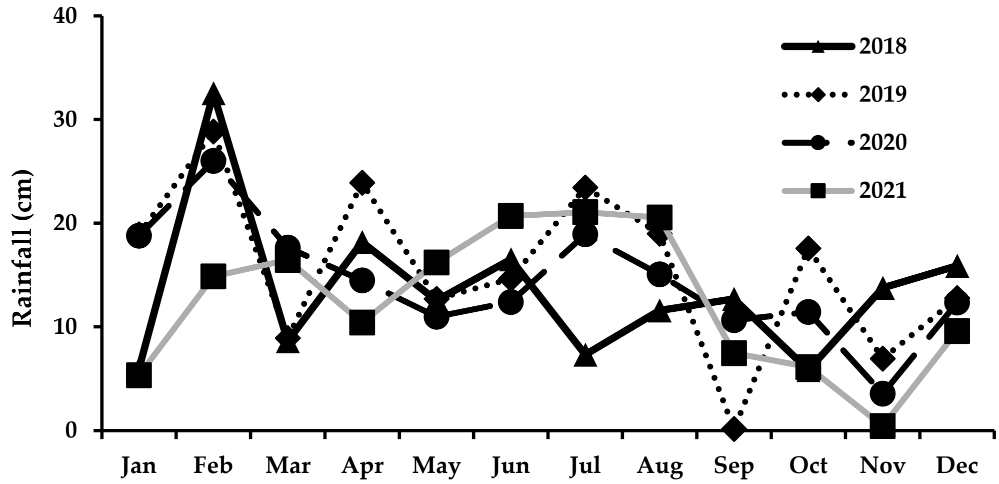

Figure 1. Monthly annual rainfall (cm) at the Pontotoc Ridge-Flatwoods Branch Experiment Station during 2018–2021 growing seasons.

Table 1. Initial soil properties and recommended fertilizer rates based on soil testing results provided by a commercial laboratory at the Pontotoc-Ridge Flatwoods Branch Experiment Station, Pontotoc, MS during the 2018–2021 growing seasons.

Item	2018	2019	2020	2021
Initial soil properties [1]				
Soil pH	7.37	6.41	7.18	6.58
Cation exchange capacity (cmole+ kg^{-1})	6.9	9.9	7.2	4.1
Soil organic matter (g kg^{-1})	13.4	16.6	17.0	12.0
Extractable nutrients (kg ha^{-1})				
Phosphorus (P_2O_5)	151	142	64	160
Potassium (K_2O)	212	141	88	196
Sulfur ($SO_4{}^{-2}$)	147	267	240	123
Calcium	2931	3447	3039	1059
Magnesium	56	123	46	52
Zinc	4.5	1.2	0.9	0.1
Recommended fertilizer application (kg ha^{-1})				
Nitrogen	56	56	56	56
Phosphorus (P_2O_5)	84	112	224	112
Potassium (K_2O)	308	404	404	336
Sulfur ($SO_4{}^{-2}$)	22	22	22	22
Magnesium	34	0	34	0
Zinc	2	4	8	11
Planting date	4 June	26 June	23 June	16 June
Harvesting date	17 September	24 October	22 October	11 October

[1]: Soil pH was determined using a 1:2 soil water ratio. Extraction of nutrients from soil and nutrient content was performed using established methods [18].

2.2. Treatments and Sampling

Each growing season, seven K application rates, 67 kg·ha^{-1} K_2O (K67), 135 kg·ha^{-1} K_2O (K135), 202 kg·ha^{-1} K_2O (K202), 269 kg·ha^{-1} K_2O (K269), 336 kg·ha^{-1} K_2O (K336), and 404 kg·ha^{-1} K_2O (K404) in the form of muriate of potash or KCl (0-0-60), as well as an untreated control (CON; no K), were laid out in a randomized block design with four replications. Plots consisted of two rows, each 9.14 m long and 1.0 m apart, with an in-row plant spacing of 30 cm; both rows were treated but only one was harvested.

"Beauregard" G2 sweet potato slips obtained from local certified grower plant beds were transplanted on 4 June 2018; 26 June 2019; 23 June 2020; and 16 June 2021. The B-14 mericlone of "Beauregard" was used as it represents the predominant rose-skinned, orange-fleshed, table stock cultivar grown in Mississippi [19]. All fertilizers were applied five days before transplanting, including nitrogen as ammonium nitrate (34-0-0) and P_2O_5 as triple superphosphate (0-46-0) as recommended by a commercial laboratory (Table 1), as well as K treatments. The other fertilizers were broadcast and incorporated into the experimental areas, whereas K fertilizer treatments were weighed and spread by hand across their respective treatment plots before rows were formed again to ensure complete incorporation. Herbicides and insecticides were applied according to standard industry practices, whereas no fungicides were applied. Leaf tissue samples were taken 35 days after transplanting consisting of the 5th fully open leaf from 20 plants per plot. Tissue nutrient concentrations were analyzed at a commercial laboratory (Waypoint Analytical, Memphis TN 38133) using inductively coupled plasma spectroscopy following the digestion of dried tissue samples. The sweet potatoes were harvested 105, 120, 121, and 117 days after transplanting in 2018, 2019, 2020, and 2021, respectively, with a platform digger and using a Kerian L-30 Speed Sizer (Kerian Machines Inc., Grafton, ND, USA). The sweet potatoes were graded according to USDA standards [20], which included canner (>2.5 to 4.4 cm diameter), U.S. No. 1 (>4.4 to 8.9 cm), and jumbo (>8.9 cm) grades. Misshapen roots of U.S. No. 1 size or greater were separated and classified as culls. The sum of jumbo, U.S. No.1, and canner grades represents total marketable yield (TMY).

In 2019 and 2020, a subsample of U.S. No. 1 grade roots was collected from two plots in each fertilizer treatment for determination of root tissue nutrient content. Funding for this experiment limited this analysis to two years. These samples were processed at the Louisiana State University Soil Testing and Plant Analysis Lab and nutrient content was determined using inductively coupled plasma mass spectrometry (ICP-MS) according to established methods [21].

2.3. Data Analysis

A plot was considered the experimental unit for all analyses. Data were combined across years and analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC, USA). Model statements for yield, tissue, and root variables included the fixed effect of treatment, plot (treatment $\times$ year), and year as random effects. All results are reported as least square means and separated using PDIFF. Significance was set at $p \leq 0.05$. The relationships between K rates and yield components were studied using linear and quadratic fit models. The quadratic model was best suited to describe the response of sweet potato yields to K fertilizer rates and predict the profitable K fertilizer rate.

One of the primary goals of the present experiment was to identify the rate of potassium fertilizer to maximize profitability, all other production factors kept constant. The profitable K fertilization rate (kg·ha^{-1} K_2O) was defined as the rate of K application of $1 of additional K fertilizer returned $1 worth of sweet potatoes, and it describes the minimum rate of K required to maximize profitability [22]. The cost assumed for muriate of potash (KCl) is $513/Mg [23]. To accurately determine the profitability of K fertilizer rates, and due to considerable differences in grade prices, sweet potato value was calculated using both yields and prices of grades. Assumed sweet potato prices of different grades were obtained from USDA 6 June 2022, the FOB shipping point report for Mississippi [24], and communication with local sweet potato brokers and processors. The prices per grade were U.S. No 1. at $0.99/kg, jumbo at $0.63/kg, and canners at $0.33/kg. Crop value reflects the average yield of each grade for each K fertilizer treatment and the sum of their associated prices.

Determination of K fertilizer rate for predicted maximum yields (regardless of profitability) was determined by taking the derivative from the corresponding quadratic fit formulas so that dy/dx = 1, where the change in rate of K fertilizer is equal to the change in actual yield for various yield grades. The maximum profitable K fertilizer rates were determined by taking the derivative from the corresponding quadratic fit formula so that dy/dx = 1, where the change in rate of K fertilizer is equal to change in crop value as described above.

3. Results and Discussion

3.1. Tissue Nutrient Concentration

A treatment effect was detected ($p < 0.01$) for leaf K concentration, which was greater ($p \leq 0.05$) for rates K202, K269, K336, and K404 compared to CON and K67 rates, whereas leaf K concentration was similar ($p \geq 0.06$) for K135 compared to all investigated rates (Table 2). Accordingly, leaf K concentration exhibited a quadratic response when compared to K application rate (data not shown), with the greatest leaf K concentration resulting at the K269 rate. A treatment effect was detected for root K concentration ($p = 0.02$), which was greater ($p \leq 0.05$) for K404 compared to K336, K269, K135, K67, and CON, and similar ($p = 0.29$) between K404 and K202 (Table 2). Root K concentrations were similar ($p \geq 0.14$) between K336, K269, K202, K135, and K67, whereas root K concentration was greater ($p = 0.04$) for K135 compared to CON (Table 2). These results suggest there may be a maximum capacity of K absorption for sweet potatoes [25], given that tissue K concentrations were not different at rates exceeding 202 kg·ha^{-1} K_2O. However, further research is warranted to validate this rationale.

Table 2. Sweet potato yield parameters and tissue potassium (K) concentrations in response to K application rates from a field experiment conducted at the Pontotoc-Flatwoods Branch Experiment Station in Pontotoc, MS during the 2018–2021 growing seasons [1].

Items	CON	K67	K135	K202	K269	K336	K404	SEM	p =
Total marketable yield [2], kg ha^{-1}	23,045	24,202	26,831	25,880	23,972	23,374	23,033	11,969	0.33
% No. 1	66.13	71.25	65.81	67.19	64.94	64.81	65.69	5.33	0.22
% jumbo	14.25	10.88	15.38	16.75	16.00	15.88	16.25	5.27	0.27
% canner	19.56	17.94	18.81	16.06	19.06	19.25	18.06	3.00	0.43
Leaf K (%)	3.28 [B]	3.36 [B]	3.64 [AB]	3.81 [A]	4.00 [A]	3.94 [A]	3.94 [A]	0.36	<0.01
Root K (%)	1.33 [C]	1.39 [BC]	1.74 [B]	1.83 [AB]	1.55 [BC]	1.60 [BC]	2.07 [A]	0.32	0.02

[1]: Each growing season, seven K rates, 67 kg·ha^{-1} K_2O (K67), 135 kg·ha^{-1} K_2O (K135), 202 kg·ha^{-1} K_2O (K202), 269 kg·ha^{-1} K_2O (K269), 336 kg·ha^{-1} K_2O (K336), and 404 kg·ha^{-1} K_2O (K404) in the form of muriate of potash or KCl (0-0-60), as well as an untreated control (CON), were applied before planting. Data were combined across years and are presented as LSMEANS and separated using PDIFF. [2]: Total marketable yield represents the sum of jumbo, U.S. No. 1, and canner grades [20]. [A–C]: Within rows, values with different superscripts differ at $p \leq 0.05$.

3.2. Yield and Profitable Rate

Despite treatment differences noted for tissue K concentrations, no treatment differences were detected ($p \geq 0.22$) for TMY, percent No. 1, percent jumbo, or percent canner sweet potatoes in response to K application rate (Table 2). This lack of response was surprising given that soil test results indicated low or very low extractable K each year according to the commercial testing laboratory.

However, when U.S. No. 1 yield was regressed onto K application rate (Figure 2), a quadratic response was observed, with maximum yields achieved with K135. These results are similar to those reported by Cecílio et. al. [26], who reported a quadratic response of sweet potato yields with K fertilizer application. The predicted maximum yield for US. No. 1 grade sweet potatoes according to the quadratic model was obtained with a 174 kg·ha^{-1} K_2O rate (Figure 2). Moreover, the K fertilization rate to maximize profitability according to the quadratic model where $dy/dx = 1$ was 174 kg·ha^{-1} K_2O (Figure 3).

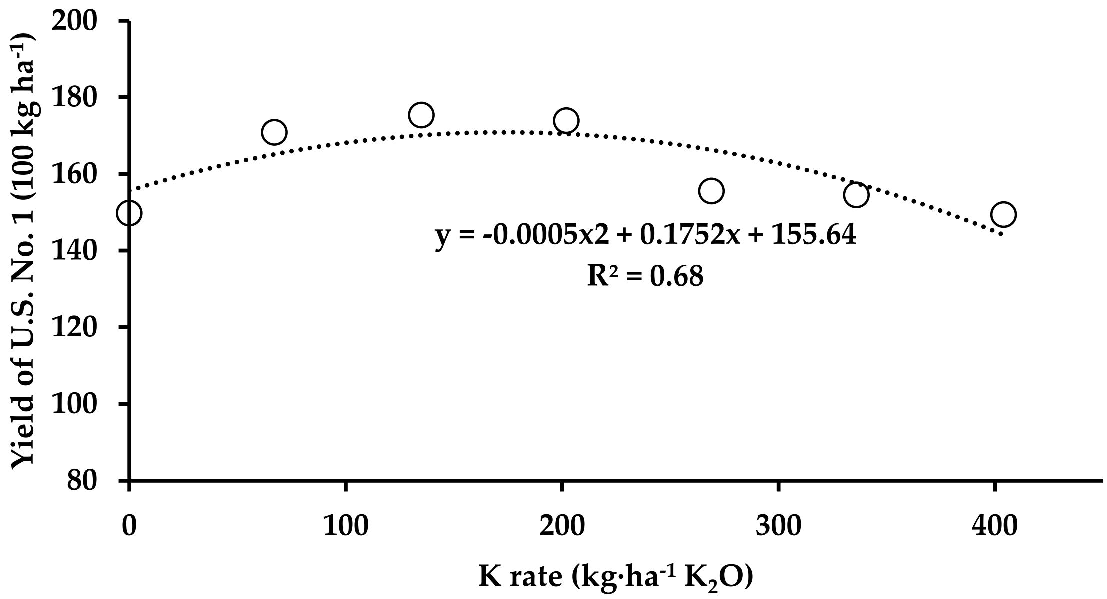

Figure 2. Changes in U.S. No. 1 [20] yield in response to potassium (K) application rate. Each growing season (2018-2021), seven K rates, 67 kg·ha^{-1} K_2O (K67), 135 kg·ha^{-1} K_2O (K135), 202 kg·ha^{-1} K_2O (K202), 269 kg·ha^{-1} K_2O (K269), 336 kg·ha^{-1} K_2O (K336), and 404 kg·ha^{-1} K_2O (K404) in the form of muriate of potash or KCl (0-0-60), as well as an untreated control (CON), were applied before planting. Rate to maximum yield = 174 kg·ha^{-1} K_2O.

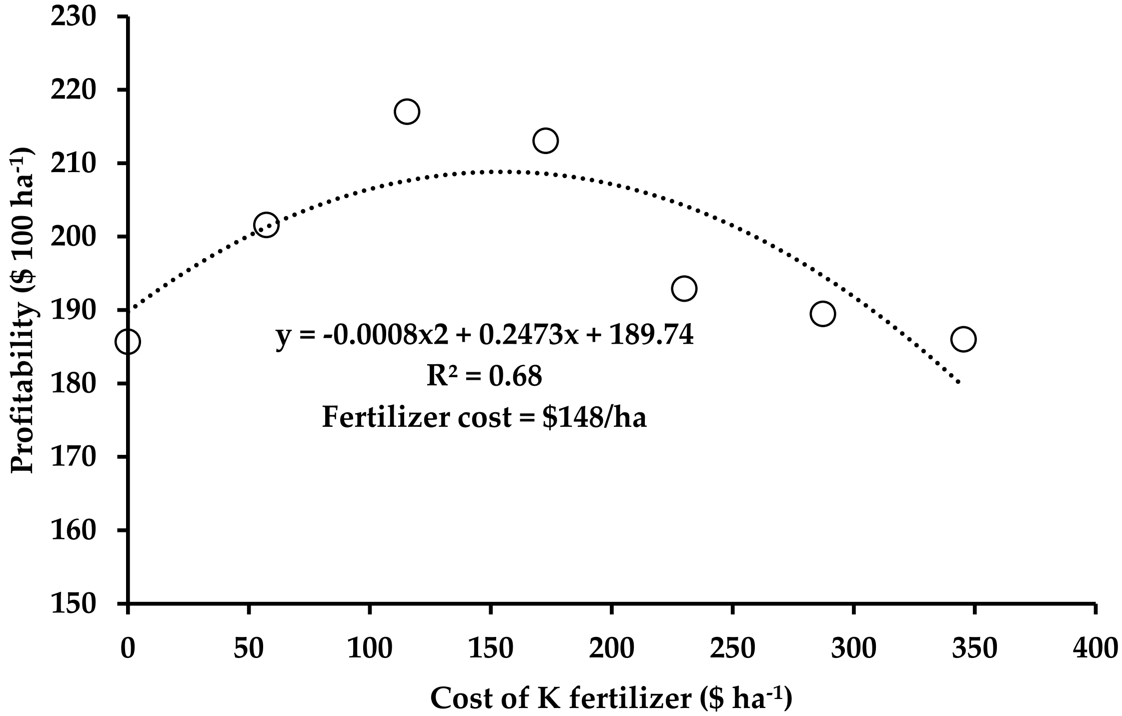

Figure 3. Profitability in response to potassium (K) application rate. Each growing season (2018-2021), seven K rates, 67 kg·ha^{1} K_2O (K67), 135 kg·ha^{-1} K_2O (K135), 202 kg·ha^{-1} K_2O (K202), 269 kg·ha^{-1} K_2O (K269), 336 kg·ha^{-1} K_2O (K336), and 404 kg·ha^{-1} K_2O (K404) in the form of muriate of potash or KCl (0-0-60), as well as an untreated control (CON), were applied before planting. The maximum profitable K fertilization rate (kg·ha^{-1} K_2O) was defined as the rate of K application where $1 of additional K fertilizer returned $1 worth of sweet potatoes, and it describes the minimum rate of K required to maximize economic return [18]. The cost assumed for muriate of potash (KCl) is $513/Mg [23]. To accurately determine the maximum profitable rate of K fertilizer, and due to considerable differences in grade prices, sweet potato value was calculated using both yields and prices of grades. Assumed sweet potato prices of different grades were obtained from USDA 6 June 2022, the FOB shipping point report for Mississippi [24], and communication with local sweet potato brokers and processors, and were U.S. No 1. at $0.99/kg, jumbo at $0.63/kg, and canners at $0.33/kg. Crop value reflects the average yield of each grade for each K fertilizer treatment and the sum of their associated prices. Rate to maximize profitability = 174 kg·ha^{-1} K_2O.

In the case of this experiment, the K rate to maximize U.S. No. 1 yield and the maximum profitable K fertilization rate were the same. This result can be attributed to the relatively low cost of K fertilizer compared to the total value of the sweet potato crop. With high value crops, it is expected that the price of fertilizer has less impact on the most profitable rate compared with lower value crops. Regardless, both the maximum rate for yield and the maximum profitable rate were substantially lower than the rate recommended by soil testing results. Based off this study, using the maximum profitable rate of 174 kg·ha^{-1} K_2O could result in savings of $198/ha in addition to a reduction in unnecessary application of K fertilizers. Collectively, the limited response in leaf and root K levels coupled with the lack of yield response to K fertilization suggest that further research is warranted to fine tune the fertilization recommendations for sweet potato production.

4. Conclusions

In Mississippi, applications of K fertilizer to Beauregard sweet potato plots at, above, or below recommended rates based on soil tests had no impact on storage root yield. Accordingly, comparable sweet potato yields were achieved while applying substantially less fertilizer than the recommended rate. Leaf K content exhibited a quadratic trend in response to K fertilizer application rate, with maximum leaf and root K content achieved at 269 and 404 kg·ha^{-1} K_2O, respectively. The current K fertilizer recommendations for sweet potato production were not validated based off the results of this study; furthermore, the recommended K fertilizer rates do not consider profitability. Both the predicted K application rate for maximum yield and maximum profitability were the same, at 174 kg·ha^{-1} K_2O. There is no doubt that K plays a vital role in sweet potato production in both Mississippi and across the country. Further research is warranted to examine the impacts of potassium fertilizer applications on soil characteristics and temporal trends in sweet potato potassium uptake, as well as refine the fertilization recommendations for sweet potato production.

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