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Potassium Fertilizer Application Rates for Fertigated Edamame Grown on Low-K Soils

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Abstract

Edamame, a legume consumed fresh as a vegetable, is highly nutritious, particularly protein-rich, and holds significant economic value. However, its cultivation faces challenges, especially on dry land, due to water scarcity and limited nutrient availability, particularly potassium (K). This study, which investigated the impact of potassium fertilization rate on edamame cultivation, underscores the need for further research. The study utilized a single factor, potassium fertilization rate, arranged in a completely randomized block design. Potassium rates consist of 0% X, 50% X, 100% X, 150% X, and 200% X, where X represents the recommended potassium fertilization rate according to the dry soil test device (DSTD) guidelines. Each treatment was replicated five times. Data were analyzed using ANOVA at a 5% significance level, and any significant effects were further examined using orthogonal polynomial and regression analysis. The results indicated that potassium fertilizer rates did not significantly affect edamame height, pod weight per plot, and marketable yield. However, the study identified the optimal potassium fertilizer rate, which was between 83%X and 119%X, equivalent to 83–119 $kg.ha^{-1}$ of KCl (50–72 $kg.ha^{-1}$ of K_2O). This range positively increased total branch yield, productive branches, number of flowers, pod weight per plant, number of pods per plant, and plant dry weight, producing a quadratic response pattern. The study recommends further research to optimize potassium fertilizer doses based on DSTD recommendations, particularly at a low K nutrient status, to maximize marketable yields through fertigation.

Keywords: dry soil test device (DSTD), marketable, nutrient uptake, pods, seeds

Introduction

The preference for dry soybean edamame has made them the third most important commodity after rice and corn. However, soybeans are not only consumed in their dry form; they can also be enjoyed fresh. Edamame are typically consumed fresh. Edamames are highly nutritious, especially protein-rich (Zarkadas et al., 2007; Pujiwati et al., 2020), and have significant economic value (Ma'sum et al., 2020). Edamame are usually harvested when they are young, with lower sucrose, oligosaccharide, and anti-nutrient levels and an intense green color (Xu et al., 2016).

The high economic value of edamame presents an excellent opportunity for cultivation. In 2019, export demand for edamame reached 6,790.7 tons (Kementan, 2023). Edamame cultivation is generally conducted in medium or highland areas where the crop receives full sunlight, warm temperatures, and moist soil for optimal growth (Worwood, 2014). Cultivation in lowland areas poses challenges, particularly regarding water availability on dry land (Heryani and Rejekiningrum, 2020). Plants grown under these conditions may experience water deficits, which can lead to yields that do not meet their potential (Aulya et al., 2019). To address these issues, drip irrigation and mulching can be employed to maintain water availability. Drip irrigation helps sustain soil moisture and reduces water loss, ensuring adequate plant water supply and potentially enhancing nutrient uptake (Witman, 2021). Modern drip irrigation systems can also incorporate fertigation, a precision technology that combines irrigation and fertilization. Fertigation has the advantage of improving water and fertilizer use efficiency, which can ultimately enhance crop yield and quality (Zotarelli et al., 2009).

Optimal fertilization is crucial during plant growth, as inadequate fertilization can hinder nutrient uptake and reduce yields (Wood et al., 1973). Drylands often

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have variable nutrient statuses, especially concerning macronutrients. Hence, soil fertility is a key factor in boosting crop production, and soil analysis should determine optimal fertilization (Prabowo and Subantoro, 2017). Soil analysis can be conducted using the dry soil test device (DSTD), a tool designed to assess nutrient levels in dry soils, making it suitable for field uses. The DSTD measures nutrient levels of phosphorus (P), potassium (K), organic carbon (C), pH, and lime requirements (Hamdani and Permadi, 2015).

Potassium (K) is one of the essential nutrients for plant growth, playing a vital role in photosynthesis by enhancing growth and leaf area index, which boosts CO_2 assimilation. Potassium also aids in the translocation of photosynthetic products to the roots, which are then utilized by *Rhizobium* (Mulyadi, 2012). Potassium fertilization has significantly impacted pod length, pod diameter, and seed diameter in soybeans (Almasprabowo et al., 2020). Therefore, this study aims to determine the optimal potassium rate for improving edamame growth and yield.

Material and Methods

The research was conducted from December 2023 to February 2024 at the Cikarawang Experimental Farm in Dramaga, Bogor, located 250 meters above sea level on inceptisol soil. Before the research, soil analysis was carried out at the Agronomy and Horticulture Testing Laboratory and the AGH IPB Postharvest Laboratory.

The equipment used in this study includes the dry soil test device (DSTD) and fertigation system components. The materials utilized are edamame seeds of the "Ryokkoh" variety, goat manures, SP-36, KCl, urea, polyethylene mulch, and soil analysis materials. For potassium (K) analysis, reagents K-1, K-2, and K-3 were used. Phosphorus (P) analysis involved P-1 and P-2 reagents; soil pH analysis included pH-1 and pH-2. The determination of organic carbon (C-Organic) involved reagents C-1 and C-2. This study used a single factor, potassium fertilization rate, arranged in a completely randomized block design. Potassium fertilization rates tested are 0% X, 50% X, 100% X, 150% X, and 200% X, where X represents the recommended potassium (KCl) fertilization rate according to dry soil test device (DSTD) guidelines. Each treatment was replicated five times. The collected data were analyzed using analysis of variance (ANOVA) at a 5% significance level. Further analysis was conducted using Orthogonal Polynomial and Regression tests if a significant effect was observed. Data processing was carried out using R Studio and Microsoft Excel.

This study included 25 plots, each measuring 5 m x 1.5 m and 90 cm in height. The planting distance was 40 cm x 20 cm, and each plot contained 24 plants for 600 plants.

Soil Analysis

Soil analysis was conducted using the dry soil test device. Soil samples were taken at 24 composite points from a soil depth of ±15-20 cm. The soil samples' nutrient status was tested using reagents available in DSTD (Cita, 2022; Figure 1).

Determination of K nutrient status was conducted by adding 0.5 mL of soil samples to test tubes, 4 ml of reagent K-1, stirring until homogeneous with a glass stirrer, and letting stand for 5 minutes until transparent. Next, two drops of reagent K-2 were added, shaken, and let stand for about 5 minutes. Slowly add 2 ml of reagent K-3 through the tube wall and leave until white precipitate settled between the K-3 solution and below it.

Determination of P nutrient status was conducted by adding 0.5 mL of soil samples to test tubes, 3 ml of reagent P-1, and stirring until homogeneous with a glass stirrer. Next, add 10 grains or a spatula tip of

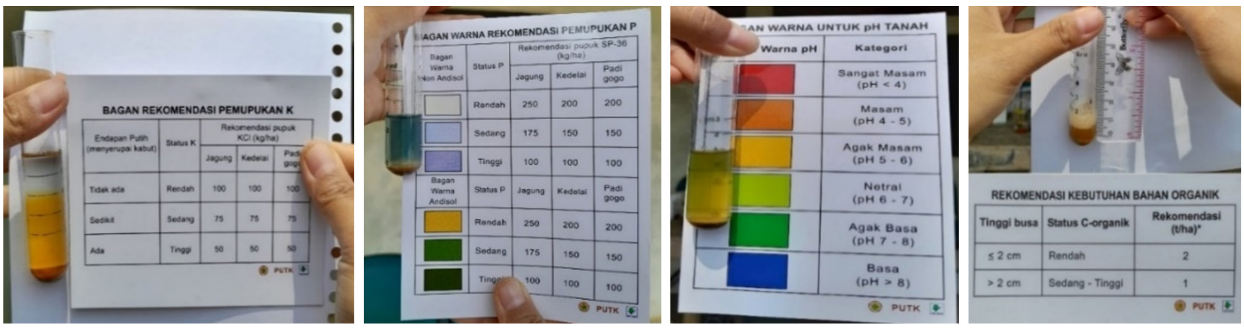

Figure 1. The results of DSTD analysis on K nutrient status (a), P nutrient status (b) soil pH (c), and organic matter requirements (d).

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reagent P-2 (needed in small quantities), shake for 1 minute, and let stand ±for 10 minutes. The colour from the clear solution above the soil surface was then compared with the P-soil colour section.

The soil pH was determined by adding 0.5 mL of soil samples to test tubes. Four mL of pH-1 reagent was added, and the mixture was stirred until homogeneous with a glass stirrer. Add 1-2 drops of colour indicator pH-2 reagent and let it stand for about 10 minutes until set and colour formed in the supernatant liquid. The color in the clear solution is then compared with the pH color chart.

C-Organic was determined by adding 0.5 mL of soil to test tubes, 1 mL of reagent C-1, and stirring until homogeneous with a glass stirrer. Then, add three drops of reagent C-2 (without stirring) and let it sit for 10 minutes until the foam forms.

Based on Figure 1, the soil has low K, moderate P, neutral soil pH, and organic matter requirement of 2 tons.ha^{-1}.

Land Preparation

Land preparation is done three weeks before planting. Plots of 5 m x 1.5 m (7.5 m^2) were made. The plots were ± 90 cm high, and the distance between holes was 40 cm x 20 cm. Polyethylene mulch was installed on each plot to maintain soil moisture and suppress weed growth.

The position of the planting holes was made double row or two rows with a zig-zag model. The drip irrigation pipe in this study used only one installed under polyethylene mulch along the plot and between the planting holes, with the emitter position facing downwards. The fertigation system consisted of a head unit and an infield unit. The head unit components consisted of tendons, plunger pump, pump engine, filter disc ¾, and pressure setting 20 psi. Then, it was connected to the infield unit components, including 16 mm polyethylene pipes and drip tubes (16 mm diameter, 20 cm drip hole spacing, emitter discharge 1.7 liter per hour) according to each treatment in the experimental plots. Planting was done by placing two seeds in each planting hole. After that, planting was done, followed by irrigation and pest control.

Fertilization

The fertilizers applied consist of N (50 kg Urea or 23 kg N per ha), P (150 kg SP-36 or 54 kg P_2O_5 per ha), and K (100 kg KCl or 60 kg K_2O per ha) applied in split dosages as described in Table 1(Susila et al., 2020). Forty percent will be applied pre-planting in the plot area before mulching, and 60 percent will be delivered through drip irrigation.

Supplementary fertilization through drip irrigation (Table 1) was administered in the second, third, and fourth weeks after planting. Edamame was harvested 65 days after planting (DAP) by manually picking the pods that met consumption standards. The measurement variables included the total number of branches per plant, the number of productive branches per plant, the total number of flowers, 50% flowering time, the per plant pod weight, the number of per plant pods, the per plot pod weight, the marketable pod weight, the number of marketable pods, pod weight per ha, 100-seed weight, plant dry weight, and N, P, and K uptake.

Result and Discussion

Edamame Growth

The results showed that varying potassium rates significantly affected the total number of branches per plant, productive branches per plant, and the number of flowers per edamame plant. However, potassium rates did not impact the time to 50% flowering (Table 2).

Table 2 shows that the potassium rate treatments did not influence the time to 50% flowering. Genetic

Table 1. Rate of K fertilizer at pre-plant and through fertigation with drip irrigation

Time	Urea (g)	SP-36 (g)	Potassium fertilizer treatment				
			0%X	50%X	100%X	150%X	200%X
			KCl (g)				
Dosage	37.5	112.5	0	37.5	75	112.5	150
Preplant	15	112.5	0	15	30	45	60
Drip 1	7.5	-	0	7.5	15	22.5	30
Drip 2	7.5	-	0	7.5	15	22.5	30
Drip 3	7.5	-	0	7.5	15	22.5	30

Note: X = recommended K rate based on the dry soil test device (DSTD) results

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factors can influence flowering time, as Kurniawan et al. (2014) noted that edamame soybean flowering is affected by genetic traits and environmental conditions. Soybeans are short days, meaning they will not flower if the day length exceeds a critical limit.

The number of branches and productive branches per plant was measured at harvest, showing a quadratic response pattern about plant growth (Figures 2a and 2b). The highest number of branches, 8.7, was obtained at a potassium fertilizer rate of 96.5%X. X represents the recommended K rate according to DSTD, equivalent to 96.5 kg.ha⁻¹ of KCl (58 kg.ha⁻¹ of K_2O). Similarly, the highest number of productive branches, 8.1, was achieved at a potassium fertilizer rate of 83%X (83 kg.ha⁻¹ of KCl or 50 kg.ha⁻¹ of K_2O). According to Gorung et al. (2022), an excess of certain nutrients can suppress the availability and uptake of others, making higher fertilizer rates less optimal for plant response.

Table 2. Total number of branches per plant, number of productive branches per plant, 50% flowering time, and the total number of flowers per plant at various rates of K fertilizer

Treatment (% X)	Total branches per plant	Productive branches per plant	50% flowering time (days)	Total amount of flowers per plant
0	7.74	6.74	30.00	44.32
50	8.58	8.16	29.60	51.96
100	8.86	8.70	30.20	58.76
150	8.14	7.78	29.60	53.48
200	7.70	7.08	30.20	47.46
CV %	3.54	5.09	2.32	9.18
P-value	0.000	0.000	0.462	0.002
Significance	**	**	ns	**
Response pattern[1)]	Q**	Q**	ns	Q**

Notes: X is the recommended potassium rate according to the dry soil test device (DSTD). P-value < 0.05: significant at 5% level. [1)] Orthogonal polynomial test; **: significant at 1% level; ns: not-significant; Q: quadratic response

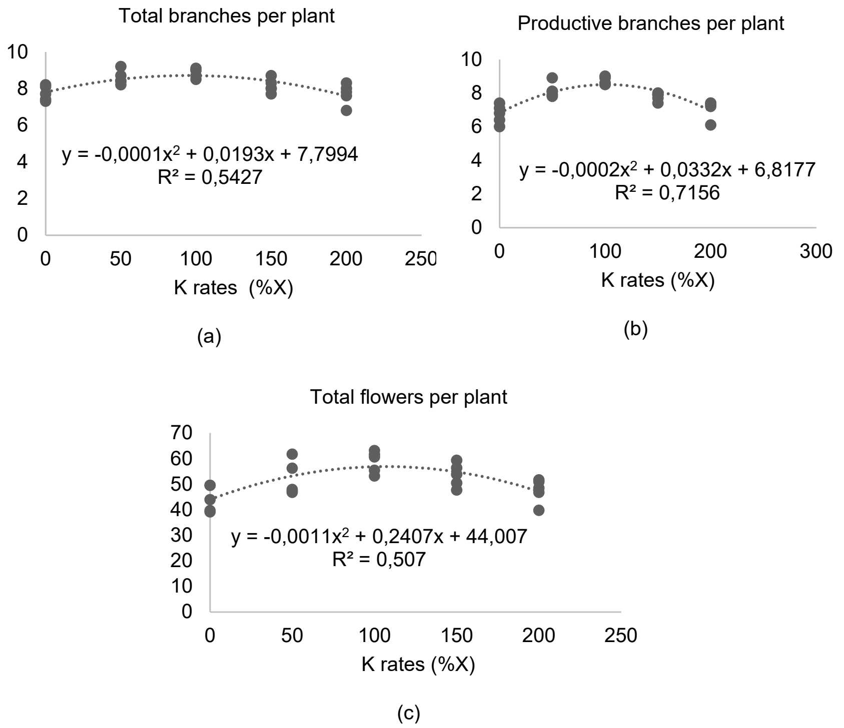

Figure 2. Response pattern of the total number of branches per plant (a), productive branches per plant (b), and the total number of flowers per plant (c) at various rates of K fertilizer

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Potassium (K) plays a crucial role in activating enzymes for protein synthesis, sugar transport, nitrogen and carbon metabolism, and photosynthesis. Efficient photosynthesis generates energy, increasing the amount of photosynthate, which is then translocated throughout the plant. This process promotes cell division, expansion, and differentiation, stimulating vegetative growth, such as increased branches (Yoseva et al., 2022). Additionally, potassium is crucial in strengthening plant stems by building the tissues that connect roots and leaves (Saputra et al., 2021).

The potassium fertilizer rates exhibited a quadratic response pattern for flower production (Figure 2c). The maximum number of flowers, 57.17, was achieved at a potassium rate of 109.4%X, where X is the recommended rate, equivalent to 109.4 kg. ha^{-1} of KCl (62.4 kg.ha^{-1} of K_2O). Potassium is particularly important during the generative phase, as it is essential for forming flowers and pods (Gani and Fauzi, 2023).

Edamame Shoot Dry Weight and N, P, and K Uptake

Table 3 indicates that the rate of potassium (K) fertilizer significantly affects plant dry weight, but it does not significantly impact nitrogen (N), phosphorus (P), and potassium (K) uptake. While plant dry weight increases with higher potassium rates, the results will decline once the dosage reaches a maximum threshold.

The results indicate that the highest plant dry weight, measuring 21.21 grams, was achieved with a potassium fertilizer rate of 114.36%X (equivalent to 114.36 kg.ha^{-1} of KCl or 67 kg ha^{-1} of K_2O) (Figure 3). Nutrients are absorbed by the roots and translocated to various plant parts, optimizing the photosynthesis process, which influences plant dry weight (Riyantini et al., 2016).

Edamame Production

Potassium fertilizer rate significantly affected the weight and number of pods per plant (Table 4).

Table 3. Edamame shoots dry weight, and N, P, and K uptake at different rates of K fertilizer

Treatment (% rate)	Shoot dry weight (g)	Total N uptake (%)	P uptake (%)	K uptake (%)
0	12.30	4.07	0.31	1.44
50	17.56	4.14	0.31	1.37
100	21.98	4.18	0.30	1.60
150	19.92	4.25	0.32	1.66
200	16.18	3.84	0.31	1.39
CV (%)	24.47	6.42	6.47	18.00
P-value	0.026	0.182	0.362	0.345
Significant	*	ns	ns	ns
Response pattern[1)]	Q**	ns	ns	ns

Notes: P-value < 0.05; significant at 5% level; **: significant at 1% level; ns: not significant. [1)] Orthogonal polynomial test; **: significant at 1% level; ns: not-significant; Q: quadratic response

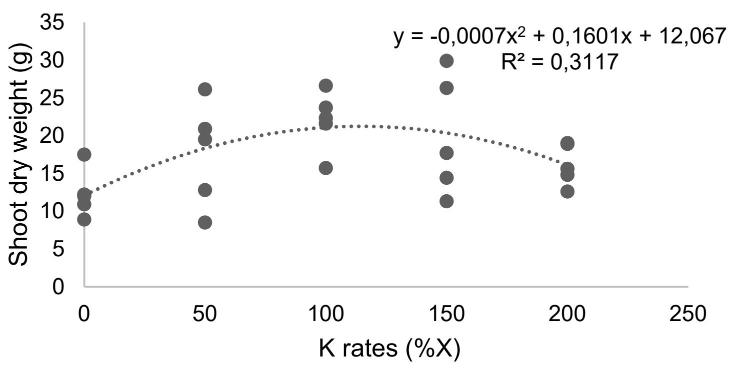

Figure 3. Edamame shoot dry weight at different rates of K fertilizer

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Figures 4(a) and (b) illustrate the quadratic response pattern in the yield of pod weight per plant and the number of pods per plant. The highest pod weight yield per plant was 100.93 grams, achieved with a potassium fertilizer rate of 117.22%X, equivalent to 117.22 kg.ha^{-1} of KCl (70.3 kg.ha^{-1} of K_2O).

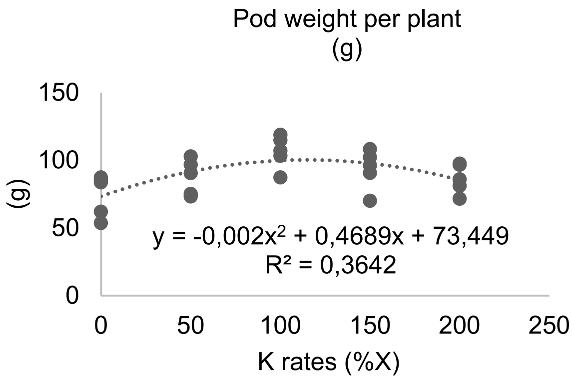
For the number of pods per plant, the highest yield was 44.10, obtained at a potassium fertilizer rate of 119.20%X (119.2 kg.ha^{-1} of KCl or 72 kg ha^{-1} of K_2O). This result significantly exceeds the findings from Yusdian et al. (2023), which reported a pod weight of only 49.44 grams and a pod count of 17.31. The higher yields in this study can be attributed to the sufficient nutrient availability at the 100% potassium dosing, which maximizes pod production compared to other treatments. Efficient fertilizer use aligned with plant needs enhances the production of edamame soybean pods (Astari et al., 2016). Adequate potassium levels in the soil facilitate the absorption of nutrients and minerals necessary for metabolic processes, positively affecting the accumulation of photosynthesis in seeds and other plant organs, as well as the fresh pod weight (Ilham et al., 2020). This finding aligns with research by Maulidya et al. (2023), which indicates that potassium nutrients play a significant role in increasing pod weight yield.

In addition to adequate nutrients, applying fertilizer through drip irrigation significantly influences edamame growth. Split fertilization via drip irrigation has enhanced crop yields (Susila et al., 2020). Water availability is critical for edamame plants' growth and yield. Research by Ramadhani et al. (2016) indicates that providing 75% of the water required by plants improves the soil's physical, chemical, and biological properties, leading to better nutrient uptake and enhanced plant metabolic processes. This ultimately

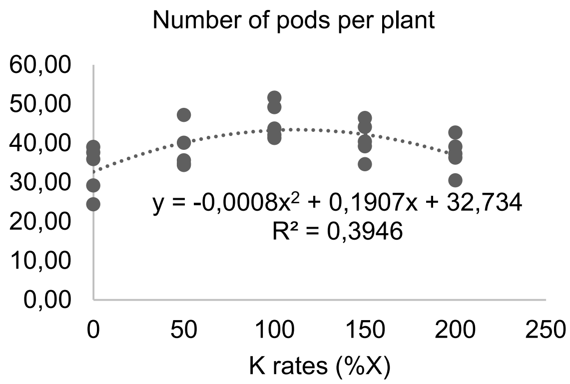
Table 4. Edamame pod weight per plant, number of pods per plant, and 100-seed weight at various rates of K fertilizer

Treatment (% X)	Pod weight per plant (g)	Number per plant pods	100 seed weight (g)
0	74.45	33.22	69.96
50	87.68	38.42	68.34
100	106.22	45.58	73.64
150	93.45	40.94	71.98
200	86.56	37.18	67.08
CV	13.60	13.13	5.66
P-value	0.013	0.020	0.111
Significance	*	*	ns
Response pattern[1)]	Q**	Q**	ns

Notes: P-value < 0.05: significant at 5% level; [1)] Orthogonal polynomial test; **: significant at 1% level; ns: not-significant; Q: quadratic response



(a)



(b)

Figure 4. Response pattern of pod weight per plant (a), and pod number per plant (b) at various K fertilizer rate

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results in the formation of carbohydrates and proteins essential for pod filling.

In this study, the average weight of 100 seeds was 73.64 grams, significantly higher than the 53.75 grams reported by Sipayung et al. (2023) for the same variety. In plant metabolism, potassium functions as an enzyme activator. Sufficient potassium availability can enhance enzyme activity, allowing metabolic processes to operate efficiently. This, in turn, facilitates the production of photosynthates, which are translocated to seeds to increase seed weight (Kurniawati et al., 2022).

The results indicated that applying different potassium fertilizer rates did not significantly affect pod weight per plot, yield per hectare, marketable weight per plot, or the number of marketable pods (Table 5). As flower drop occurred, not all flowers developed into edamame pods, impacting the overall yield per hectare. Additionally, the pods were affected by pod-sucking pests such as *Riptortus linearis*, which attacked during pod ripening, leading to a reduction in the number of marketable pods. However, the yield per plot and hectare of edamame plants using the fertigation system was significantly higher than the study by Gani et al. (2023), which reported only 940 grams per plot and a yield of 1.57 tons.ha^{-1}.

This study achieved better results, highlighting that soil analysis using the dry soil test device (DSTD) can effectively identify soil fertility in tropical regions, particularly in drylands. The results can serve as a guideline for tailored fertilization recommendations based on specific soil conditions, as fertigation through drip irrigation enhances fertilizer efficiency and can easily be adjusted to the crop's nutrient requirements.

Conclusion

The optimal rate of potassium fertilizer in low K soil based on total branches per plant, productive branches, pod weight per plant, pod number per plant, and shoot dry weight is between 83%X and 119%X, which corresponds to 83–119 kg.ha^{-1} of KCl (50–72 kg.ha^{-1} of K_2O). Potassium fertilizer application results in a quadratic plant growth and yield response pattern. Further research is needed to optimize potassium fertilizer rates for maximum marketable yield using fertigation and mulch.

Table 5. Edamame pod weight per plot, marketable pod weight per plot, marketable number of pods per plot, and pod weight per ha at various K fertilizer rates

Treatment (% K rates)	Pod per plot weight (g)	Marketable pod weight per plot (g)	Marketable number of pods per plot	Pod weight (t.ha^{-1})
0	1920.22	1898.38	806.40	2.66
50	2115.98	2090.66	857.00	2.93
100	2320.02	2089.58	859.50	3.22
150	2243.40	2227.30	869.80	3.11
200	2092.46	2074.92	851.00	2.90
CV %	14.38	14.33	13.55	14.38
P-value	0.332	0.558	0.918	0.332
Significance	ns	ns	ns	ns
Response pattern[1)]	ns	ns	ns	ns

Notes: P-value < 0.05: significant at 5% level; **: significant at 1% level; ns: not significant. [1)] Orthogonal polynomial test; **: significant at 1% level; ns: not-significant; Q: quadratic response

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