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Effect of foliar potassium spraying on productivity and quality of grape fruits (*Vitis vinifera*) under different irrigation levels

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ABSTRACT

The escalating scarcity of water resources poses a significant challenge to global agriculture, threatening the yield and quality of high-value crops such as grapes (Vitis vinifera). Using a trellis system, grapes are not only consumed fresh but are also critical raw materials for products like juices, wines, and raisins, where consistent quality, sugar content, and phytochemical composition are paramount. Sustainable strategies to mitigate water stress effects and enhance fruit quality are therefore of immense industrial interest.
This study investigated the efficacy of foliar potassium (K) application as a practical agricultural strategy to ameliorate the adverse effects of different irrigation levels on grape productivity and, more importantly, on key quality attributes relevant to the food processing industry. A field experiment was conducted following a factorial arratement based on a Randomized Complete Block Design (RCBD). Grapevines were subjected to two irrigation levels (100%, 75%, and 50% of crop evapotranspiration - Etc.) and three concentrations of foliar potassium (0.0%, 0.5%, 1.0%, 1.5% $K2O$). Parameters measured included yield, cluster weight, and a comprehensive set of quality traits: total soluble solids (TSS), titratable acidity (TA), pH, berry firmness, and the concentration of anthocyanins and total phenolics. Water deficit significantly reduced yield but enhanced most quality parameters. The 50% Etc. treatment led to a notable increase in TSS, TSS/TA ratio, and anthocyanin content. Foliar potassium application, particularly at 2%, effectively mitigated yield losses under stress and synergistically improved quality. The interaction between 75% Etc. and 2% K spray resulted in an optimal balance, achieving a yield comparable to full irrigation while significantly boosting TSS, phenolic content, and color intensity—attributes highly sought after for premium wine and juice production. The integrated management of deficit irrigation (75% Etc.) and foliar potassium nutrition (2%) presents a viable and sustainable strategy for the grape industry. This approach not only conserves water but also directs the plant's metabolism towards producing grapes with superior techno-functional quality, enhancing their suitability for high-value processed food products and contributing to the sustainability of agricultural practices.

1-Introduction

With their financial worth extending well beyond fresh consumption (e-commerce and industrial purposes), grape (*Vitis vinifera*) is among the most economically valuable fruit crops around the globe. The fruit serves as a Wine, Juice, Jam, Dried Fruit) is a multi-billion dollar Industry. The quality of any derived product is directly related to how fresh grapes were grown (biochemical composition, including the amount of sugar (%Brix), types and number of acids, number and type of phenolics, and intensity of colour). Therefore, any agricultural practice that maximises these quality of grapes would have a direct impact on the Food Industry. Water shortages are another major threat to the sustainable production of grapes. The most common way of saving water has become the use of deficit irrigation. The adoption of controlled water stress is recognized for its ability to increase sugar concentration in fruit and to stimulate the production of secondary metabolites, such as anthocyanins and polyphenols, which contribute to the final product's taste, aroma, health benefits, and visual appeal [4]. Water stress has a negative impact on the health of the plants and overall quality of the crops while also affecting a variety of other factors that lead to increased production & better fruit quality. Therefore, additional methods are required to increase both productivity and fruit quality regardless of the amount of water stress [5]. Potassium (K) is one of the most significant nutrients, as it promotes the ability to tolerate abiotic (non-living) stresses (abiotic stress tolerance) and enhances the quality of fruit. K performs several functions in grapevines, and the primary functions include: osmoregulation (regulating plant cells' water content), regulating the opening and closing of stomata (pores on plant leaves), and activating the majority of enzymes related to sugar and phenolic compound metabolism. Within the grapeberry, an adequate supply of K can improve several quality parameters such as the size of grapeberries, the sugar content of grapeberries, and the color of grapeberries [6]. The foliar application of potassium (applying potassium directly to the leaves and fruit) is the best way to supply this nutrient quickly and efficiently, particularly when soil moisture is limited and the uptake via roots is restricted. There is little published research regarding the interactive effect of irrigation methods and potassium on the quality of grape products, primarily due to the fact that irrigations methods and potassium were studied mainly individually or independently [7]. Many of the previous studies focused on yield and basic quality characteristics of fruit; however, there has been little research focused on technofunctional quality traits of fruit (such as the firmness of grapeberries and the phenolic composition of grapeberries), which ultimately determine whether grapeberries are suited for any of a number of different processed products. The aim of this project was to develop an industry-oriented approach for addressing the lack of sufficient water supply to grape growers in order to enhance the quality of grapes produced from regulated deficit irrigation (RDI) and potassium (K) partnerships through foliar application of K to espada the negative effects of RDI on grape production. The goals of the study were to evaluate the impact of differing levels of irrigation and K on yield, a variety of quality attributes including total soluble solids, acidity, pH, firmness, and concentration of anthocyanins and phenolic compounds and to develop a scientifically-based practical protocol for producing high-quality raw material for food processing under drought conditions.

2-Materials and Method

2.1. Experimental Site and Plant Material

The 2024 cropping year was when the experiment was performed using commercial space in a vineyard in Iraq's Diyala region. The vines used in this study were Vitis vinifera L. 'Halawani' grown as 7-year-old vines and supported on a vertical vine trellis with a 2.5-m (row width) × 3.0-m (between row width) planting density (or about 1333 vines per ha). The soils are classified as having well-drained (loam) but medium to heavy soil textures. Throughout the year, all experimental vines received the normal viticultural practices, including dormant cutting, canopy care, weed control, and pest/disease control.

2.2. Experimental Design and Treatments

The design of the test was a two-way (factorial) randomised complete block design (RCB) with three replicates (blocks) per test unit (plot) consisting of three adjacent vines. The two factors tested were:

1. **Irrigation Level (I):** Two deficit irrigation regimes were applied.

○ **I_1 (Full Irrigation):** 100% of the crop evapotranspiration (Etc.). ○ **I_2 (Deficit Irrigation):** 50% of Etc.

Irrigation scheduling was based on the standard FAO-56 Penman-Monteith method for reference evapotranspiration (Eto) [9]. Daily Eto was calculated using meteorological data (solar radiation, temperature, humidity, and wind speed) from a nearby automated weather station. The crop according to the phenological stage of the grapevine (initial, development, mid-season, and late season) to determine Etc. (Etc. = Eto × Kc). Drip irrigation was used to deliver the calculated water volume weekly.

2. **Potassium Foliar Application (K):** Four concentrations of potassium sulfate (K_2SO_4, 0-0-50) were applied.

○ **K_0 (Control):** 0.0% K_2SO_4 (distilled water spray only). ○ **K_1:** 0.5% K_2SO_4 (w/v). ○ **K_2:** 1.0% K_2SO_4 (w/v). ○ **K_3:** 1.5% K_2SO_4 (w/v).

Three replicates of these eight (2 Irrigation levels × 4 K concentrations) treatment combinations were made resulting in a total of Eight separately treated plots.

2.3. Application of Treatments

Irrigation: The differential irrigation regimes were initiated at berry set (EL Stage 27; Eichhorn and Lorenz system) and maintained until harvest.

Potassium Sulfate - Foliar Sprays: A 0.1% (v/v) non-ionic surfactant added to distilled water will allow proper leaf coverage and adhesion when spraying both sides of your plant's leaves with foliar potassium sulfate. Spraying will be done using a calibrated backpack sprayer at three different times in the plant's life cycle until you see runoff from the leaves and all parts of the foliage.:

1. **Spray 1:** Immediately after fruit set (EL Stage 29).
2. **Spray 2:** At the onset of veraison (EL Stage 35).
3. **Spray 3:** Twenty days after the second spray (approximately three weeks preharvest).

Control plots (K_0) were sprayed with distilled water and surfactant at the same times.

2.4. Data Collection

Measurements were taken at three phenological stages: Stage 1 (post-fruit set), Stage 2 (veraison), and Stage 3 (three weeks pre-harvest).

2.4.1. Physiological Parameters

- **Leaf Water Potential (Ψ_l):** Measured at solar noon (± 2 hours) on clear days using a pressure chamber (Model 1000, PMS Instrument Company, USA). One fully expanded, sun-exposed leaf per replicate vine was selected, excised, and measured immediately following the protocol of Scholander et al. (1965) [12].
- **Leaf Gas Exchange:** Net photosynthetic rate (P_n), stomatal conductance (g_s), and transpiration rate (E) were measured between 09:00 and 11:00 h using a portable infrared gas analyzer (LI-6400XT, LI-COR Biosciences, USA). Measurements were taken on the most recent, fully expanded, sunexposed leaves under ambient CO_2 concentration, photosynthetic photon flux density (PPFD) set to 1500 μmol m^{-2} s^{-1}, and block temperature set to 30°C.
- **Leaf Chlorophyll Index:** Estimated using a portable chlorophyll meter (SPAD-502Plus, Konica Minolta, Japan). The average of three readings from three different leaves per experimental vine was recorded.

2.4.2. Yield and Fruit Quality Parameters

At commercial harvest maturity (determined by stable total soluble solids and berry color):

- **Yield Components:** Total cluster number and total fruit weight (kg) per vine were recorded.
- **Berry Quality:** A random sample of 100 berries was collected from each plot for analysis.
  - **Total Soluble Solids (TSS):** Determined in freshly extracted juice using a digital refractometer (Atago PAL-1, Japan) and expressed as °Brix.
  - **Titratable Acidity (TA):** Analyzed by titrating 10 mL of juice with 0.1 N NaOH to an endpoint of pH 8.2 and

expressed as grams of citric acid equivalent per 100 mL of juice [11].

3-Data analysis

The data were statistically analyzed as in the first part of the study, using two-way ANOVA to test the effects of irrigation, potassium spray, and their interaction. The means were then compared using the LSD test at a 5% probability level.

4-Results

The effect of irrigation and potassium on productivity and quality

The results in Table (1) and figure (1) showed that grape yield under full irrigation (100% Etc.) rated between 9.80 and 11.30 kg/vine, with the highest value in T3 when sprayed with 1.0% K_2SO_4, while yields decreased significantly under water stress (50% Etc.) to 6.50 kg/vine in T5, potassium fertilization gradually increased yields to 8.30 kg/vine in T7. These results are consistent with [15], who reported that water shortages reduce plant growth and yield, while potassium helps improve plant tolerance to water stress.

The number of clusters per vine (clusters/vine) gradually increased with increasing potassium concentration under full irrigation, ranging from 11 to 14 clusters in T1–T4. However, under water stress, yields dropped to 11 to 13 clusters. There was a notable improvement when potassium fertilization was used. This finding aligns with Mengel & Kirkby, 2001, who stated that potassium improves nutrient balance and positively affects cluster formation. Full irrigation treatments showed relatively lower TSS values, ranging from 17.2 to 17.8 °Brix, compared to water stress, where values increased to 18.3 to 19.6 °Brix. Meanwhile, TA decreased under full irrigation from 0.66 to 0.62 g citric per 100g, as K_2SO_4 concentration increased. Acidity was slightly higher under water stress, reaching 0.72–0.67 g citric/100g. Our results show that water stress lowers the relative water content of the fruit and raises the sugar concentration. Previous studies have confirmed this finding [16].

Table 1. Effect of irrigation and potassium on grape productivity and quality

Treatment	Irrigation	K2SO4 (%)	Yield (kg/vine)	Clusters/ vine	TSS (°Brix)	TA (g citric/100g)	RWC (%)	Leaf K (mg/kg DW)
T1	100% ETc	0.0	9.80 ± 0.80	11 ± 1	17.2 ± 0.6	0.66 ± 0.04	87.2 ± 1.7	2150 ± 125
T2	100% ETc	0.5	10.50 ± 0.90	12 ± 1	17.5 ± 0.4	0.64 ± 0.03	88.5 ± 1.5	2320 ± 120
T3	100% ETc	1.0	11.30 ± 1.00	13 ± 1	17.8 ± 0.4	0.62 ± 0.03	89.4 ± 1.5	2600 ± 130
T4	100% ETc	1.5	11.00 ± 0.90	14 ± 1	17.6 ± 0.4	0.63 ± 0.02	88.7 ± 1.6	2550 ± 130
T5	50% ETc	0.0	6.50 ± 0.80	11 ± 1	18.3 ± 0.6	0.72 ± 0.04	75.0 ± 2.1	1950 ± 120

T6	50% ETc	0.5	7.40 ± 0.70	12 ± 1	19.2 ± 0.5	0.68 ± 0.03	77.0 ± 2.2	2100 ± 130
T7	50% ETc	1.0	8.30 ± 0.80	12 ± 1	19.6 ± 0.5	0.67 ± 0.03	78.7 ± 1.9	2350 ± 120
T8	50% ETc	1.5	8.00 ± 0.90	13 ± 1	19.4 ± 0.4	0.68 ± 0.04	78.0 ± 1.8	2275 ± 130

78.7% in T7 when potassium was applied. This shows how potassium helps improve leaf water retention during drought conditions. These findings align with results from Brandt at 2025 [17].

As for the potassium concentration in the leaves (Leaf K), it increased significantly with increasing the applied concentration in the spray, ranging between 2150–2600 mg/kg DW under full irrigation, while it decreased under water stress to 1950 mg/kg DW in T5, and with increasing the K_2SO_4 concentration, it improved to reach 2350 mg/kg DW in T7, confirming the effectiveness of foliar spray in improving plant potassium nutrition even under waterdeficient conditions. This is consistent with what was found by [18,19].

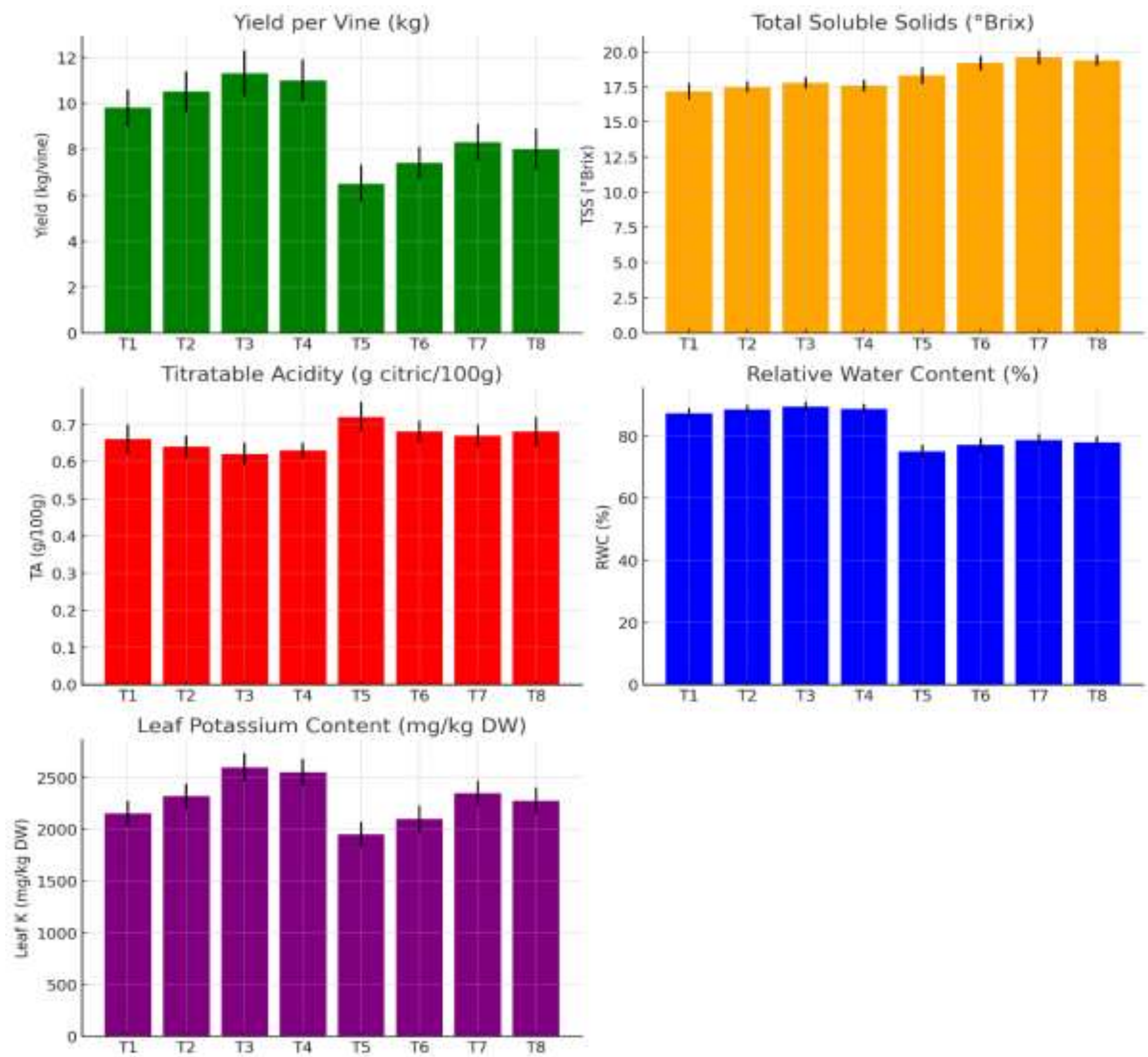

Figure 1. Effect of irrigation levels and foliar potassium application on yield, fruit quality, and physiological traits of grapevine

The effect of irrigation and potassium on the physiological indicators

The results in Table (2) and figure (2) showed that the leaf water potential (Leaf) values under full irrigation (100% ETc) rated between -0.73 and -0.69 MPa (T1–T4), while

they decreased significantly under water stress (50% ETc) to rate between -1.07 and 0.92 MPa (T5–T7). These results are consistent with what was indicated by [15] that water shortage leads to a clear decrease in leaf due to a decline in water absorption efficiency.

Table 2. Physiological indicators of grapes under the influence of potassium foliar spray and water stress

Treatment	Irrigation	K_2SO_4 (%)	leaf (MPa)	SPAD (Unit)	Transpiration rate (mmol $H_2O/m^2 \cdot s$)	Stomatal Conductance (mmol/m²·s)
T1	100% ETc	0.0	-0.73 ± 0.04	39 ± 3	4.9 ± 0.2	152 ± 12
T2	100% ETc	0.5	-0.71 ± 0.05	41 ± 3	5.1 ± 0.2	155 ± 10
T3	100% ETc	1.0	-0.69 ± 0.02	43 ± 2	5.6 ± 0.2	161 ± 11
T4	100% ETc	1.5	-0.69 ± 0.05	41 ± 3	5.2 ± 0.4	159 ± 10
T5	50% ETc	0.0	-1.07 ± 0.06	35 ± 3	3.5 ± 0.3	112 ± 12
T6	50% ETc	0.5	-0.98 ± 0.06	37 ± 3	3.5 ± 0.3	120 ± 10
T7	50% ETc	1.0	-0.92 ± 0.05	39 ± 2	3.8 ± 0.2	128 ± 11
T8	50% ETc	1.5	-0.95 ± 0.06	38 ± 3	3.8 ± 0.2	130 ± 10

As for chlorophyll content (SPAD), the full irrigation treatments recorded higher values (39-43 units), with the highest being in T3 (43 units) when sprayed with 1.0% K_2SO_4, the values dropped to 35 units under water stress in T5. However, spraying with potassium increased them to 39 units in T7. This result is consistent with what was stated by Imtiaz *et al* (2023) [20] that potassium contributes to enhancing chlorophyll synthesis and maintaining the stability of cell membranes, which reduces chlorophyll degradation under water stress.

Regarding the transpiration rate, it reached 4.9–5.6 mmol H_2O/m^2•s in the full irrigation treatments, with the highest value in T3 (5.6 mmol H_2O/m^2•s), while it decreased to 3.5 mmol H_2O/m^2•s in the T5 treatment (50% ETc without spray). Potassium spraying helped gradually increase transpiration under stress to reach 3.8 mmol H_2O/m^2•s at T7 and T8. These results are consistent with what was reported by Cakmak 2005 [15] who showed that potassium enhances the regulation of stomatal opening and closing, thus maintaining transpiration rates even under drought conditions.

Stomatal conductance recorded the highest values under full irrigation (152–161 mmol/m²•s), while it decreased significantly to 112 mmol/m²•s in T5. With increasing potassium concentrations under water stress, the values gradually increased to reach 130 mmol/m²•s in T8. Previous studies such as [21] have confirmed that potassium plays a major role in stomatal efficiency and improving stomatal conductance under water stress.

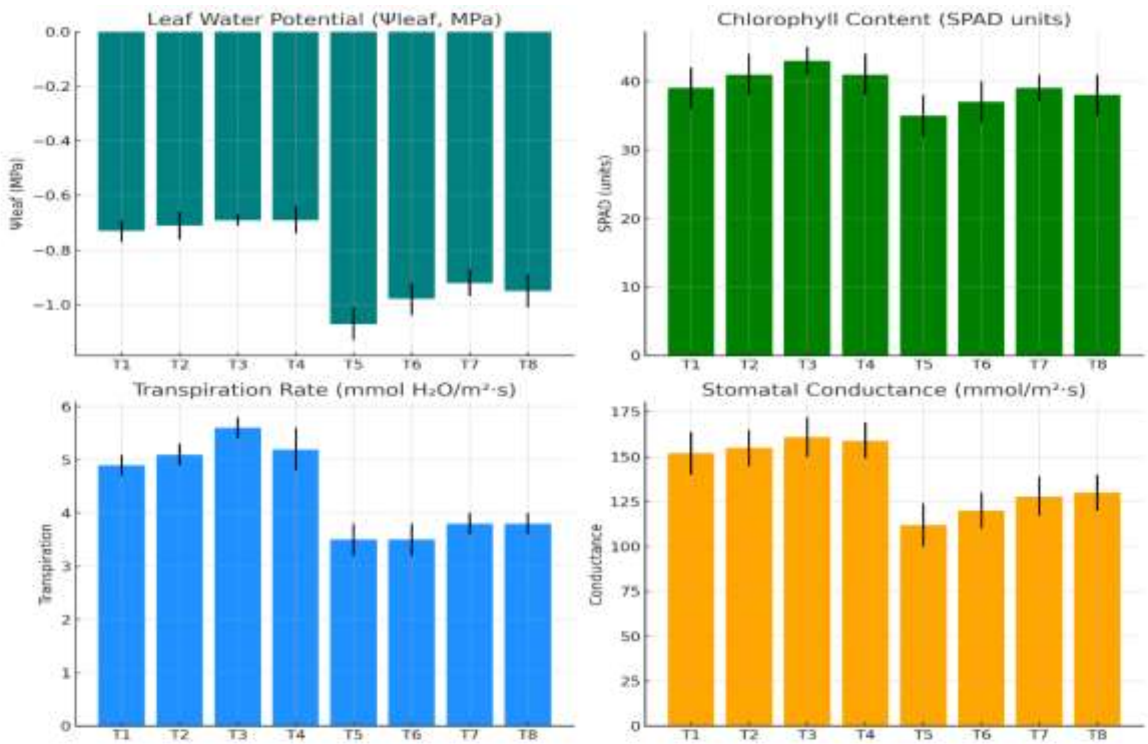

Figure 2. Physiological indicators of grapes under the influence of potassium spraying and water stress

5-Conclusion

The findings indicated that complete irrigation improved grape yield and quality, as evidenced by increased yield, number of clusters and relative water content. In contrast, under conditions of water deprivation, these parameters exhibited lower yields, number of clusters and relative water content. However, potassium applied through foliage, particularly at levels of 1.0% K2SO4, mitigated some of the adverse effects associated with water deprivation. These applications enhanced chlorophyll levels, increased transpiration rates and stomatal conductance, and enhanced leaf potassium concentrations; all of which resulted in improved water use efficiency and increased drought tolerance. Iranian journal of food science and industry Number 168, Volume 22, February2026 Potassium is a good choice of plant nutrient for improving the yield and quality of grapes grown without adequate irrigation supply. Based on the above discussion, it seems that the use of foliar applied potassium is not just another way to fix the deficiency of potassium in the soil but it is also a way to prepare grapes to be of higher quality under conditions of limited water availability. We recommend the use of the 75% ETc + 2% K protocol as an effective recommendation for good management practices for grapevine production that provides high price value to the grape processing market. Future studies should consider whether the 75% ETc + 2% K method will be economically feasible and what effect the use of this sustainable method of grape production will have on the sensory characteristics and shelf-life of process products such as wine and juice produced with grapes produced using the 75% ETc + 2% K method.

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