2025 Potassium Citrate IPM Foliar Combination Wash Study - Preliminary Final
Sacred Prairies Agricultural Research Labs
617 W Capitol Ave
Pierre SD 57501

Evaluation of a Potassium Citrate-Based Foliar Feed for Cannabis Cultivation

1. Executive Summary

This study investigates the efficacy of a potassium citrate foliar spray, derived from potassium bicarbonate and citric acid, for **cannabis cultivation**. The primary objectives were to assess its effectiveness against common pests and mildews, evaluate its impact on plant health, and determine optimal application parameters.

The initial formulation originated from a need to find an effective alternative to commercially available powdery mildew (PM) controls that were either ineffective or left undesirable residues and tastes on the final product. Previous attempts with potassium bicarbonate alone resulted in plant damage despite effective PM control. The breakthrough came with the addition of citric acid, inspired by existing 25(b) exemption products. The initial formulation tested was **20g of potassium bicarbonate per gallon with 17g of citric acid per gallon**.

Anticipated Benefits:

- **Healthier and stronger plants** through enhanced potassium uptake.
- **Effective mildew suppression**, potentially aided by mechanical removal.
- **Pest suppression**, also potentially supported by mechanical action.

Summary of Key Findings:

Through extensive field testing, optimal application parameters were identified. **Molar ratios between 1:1 and 5:1 (potassium bicarbonate to citric acid) generally did not cause plant damage**, with 5:1 being an exception that could harm certain strains, very young plants, or mature pistils. Ratios of 6:1 and 7:1 showed slight damage. For general foliar applications, ratios between 1:1 and 2:1 proved effective, while **ratios between 2.5:1 and 5:1 demonstrated superior mildew control**. Powdery mildew re-emergence was largely eliminated after a series of 3 to 5 applications at 5-day intervals.

2. Introduction

2.1 Background

Foliar feeding is crucial in cannabis cultivation for several reasons. It allows for the **near-immediate delivery of essential elements** directly into plant cells, thereby strengthening cellular structures. Furthermore, achieving optimal plant health necessitates an integrated approach that combines effective nutritional strategies with robust pest and disease management. Inferior plant health or cultivation practices invariably lead to lower quality end products.

Potassium, a vital macronutrient for plant growth, holds significant potential beyond traditional nutrient uptake. When delivered as a foliar spray in the form of potassium citrate, it can simultaneously act as a **tool to combat pests and mildew while strengthening and feeding the plant**. This multi-faceted role highlights the importance of exploring novel, integrated solutions.

2.2 Purpose of the Study

The primary purpose of this study was to **demonstrate the potential for a simple, cost-effective foliar spray to yield more effective results than existing commercial alternatives**. Specifically, the study aimed to:

> **Investigate the efficacy and safety** of a potassium citrate foliar spray in a real-world cultivation environment. Powdery mildew re-emergence was significantly reduced, and often eliminated, after a series of 3 to 5 washes applied at 5-day intervals. It's important to note that while the concentrated components require safety precautions (e.g., safety glasses), the final diluted solution proved safe and non-irritating to skin and eyes.
>
> **Determine optimal dilution rates and application conditions**. A **2.5:1 potassium bicarbonate to citric acid solution** showed the best results for emergency PM outbreaks. In contrast, a repeated 1.5:1 ratio application showed PM re-emergence by day 4. Optimal application times were identified as late morning to mid-day, preferably with lights off, allowing the solution to dry slowly.
>
> **Examine the effects on plant health, pest/mildew incidence, and pH/EC control**. Early observations, prior to the formal study with higher concentrations and less methodology, indicated potential negative effects on one strain, though these results were inconclusive due to other varying parameters.

3. Chemical Basis and Formulation

3.1 Reaction Chemistry

The formulation of potassium citrate involves the reaction of **potassium bicarbonate ($KHCO_3$)** and **citric acid ($C_6H_8O_7$)**. For a balanced potassium citrate mixture ($K_3C_6H_5O_7$), the molar ratio is **3 moles of potassium bicarbonate to 1 mole of citric acid**.

The balanced reaction is:

$$3KHCO_3 + C_6H_8O_7 \rightarrow K_3C_6H_5O_7 + 3CO_2 + 3H_2O$$

Expected Byproducts:

- **Potassium Citrate ($K_3C_6H_5O_7$):** A soluble salt, the primary active ingredient.
- **Carbon Dioxide (CO_2):** A gas, observed as effervescence during mixing.
- **Water (H_2O):** A liquid.

While a complete reaction yields bioavailable potassium citrate, an **ongoing reaction with continuous CO_2 effervescence may be more effective**. Microscopic observations suggest that the CO_2 bubbles can contribute to the mechanical removal of PM. This implies that a repeated application the day after an initial emergency breakout might be beneficial.

3.2 Mixture Parameters

The **starting dilution for testing was 20g of potassium bicarbonate per gallon with 17g of citric acid per gallon**, which corresponds to an approximate **2.54:1 ratio**. This mixture typically yielded an **EC of 3.5 and a pH of 5.4**. Maintaining the correct molar balance is crucial to avoid issues such as nutrient uptake causing damage or a solution with low efficacy.

Solution preparation protocols recommend mixing solutions as close to the time of application as possible. While older solutions showed some efficacy under microscopic observation, further studies are needed to confirm their long-term stability and effectiveness.

3.3 Physical and Chemical Characteristics

The prepared solution is typically a **clear, mostly odorless liquid** that may seen on leaves, primarily the undersides, a **white, tasteless residue** upon drying.

- **pH Range:** The post-reaction pH typically ranges from **4.0 to 6.5**.
- **Electrical Conductivity (EC) Range:** The EC typically falls between **1.0 and 3.9**.
- **Shelf Stability and Effervescence:** Further study is required to definitively determine shelf stability. Currently, **application as close to mixing as possible is recommended** due to observed effervescence.

---

4. Experimental Design

4.1 Objectives

The experimental design focused on evaluating:

- **Pest and mildew suppression and plant damage occurrence.** Plant damage was limited to the initial runs, primarily from strong solutions affecting pistils. Overwatering can be a concern; therefore, the wash should be integrated into the regular watering schedule.
- **Nutrient uptake efficiency.** While not explicitly measured, observations on plant vigor suggest positive effects.
- **Pest and mildew suppression efficacy.** At a 2.5:1 ratio and stronger, PM suppression was apparent. Incomplete coverage or incorrect mixtures led to PM re-emergence. Due to a lack of available pests, direct pest suppression was assumed but not definitively tested.
- **Phytotoxicity and foliar residue.** Phytotoxicity was observed in young plants with high pH solutions and with pure potassium bicarbonate applications. Sulfur was assumed to be a cause of some phytotoxicity. No oils were used in the formulations.

4.2 Experimental Groups

Control Group: No defined control set was used, as all studies were conducted in the field out of necessity. The 2.5:1 ratio (20g/gal potassium bicarbonate : 17g/gal citric acid) was used as the initial benchmark.

Standard Foliar Feed Comparison: No commercial products were directly compared in this study.

Test Groups (Potassium Bicarbonate:Citric Acid Ratios): 1:1, 1.5:1, 2:1, 2.5:1, 3:1, 3.5:1, 4:1, 5:1, 6:1, 7:1.

Additional Groups:

1:0 (10g/gal Potassium Bicarbonate Only)

2:0 (20g/gal Potassium Bicarbonate Only)

2.5:1 (20g/gal Potassium Bicarbonate : 17g/gal Citric Acid)

4.3 Cannabis Cultivar and Growth Conditions

The study was conducted across **multiple cannabis strains**, including Mac 1, Truffle Cake, 10gs, Blood Diamond, Star Dragon, and others. All testing occurred in an **indoor environment** with low light, moderate temperatures, and slow drying conditions. Outdoor testing is ongoing.

Nutrient Baseline Control: New Millenium nutrients were used as a baseline, with EC targets of 1.0-1.8 in vegetative growth and 2.0-2.5 in flowering. Silicium and Mag/Cal were also included in the baseline regimen.

5. Application Protocol

5.1 Timing and Frequency

For emergency control of powdery mildew, an **application interval of every 5 days** was implemented.

> **Vegetative Stage:** More flexibility in ratios used. Silicium was added at 1-2ml per gallon. Ratios of 1:1 to 2:1 were used for general foliar feeding.
>
> **Flowering Stage:** No Silicium was added. Ratios of 2.5:1 to 5:1 were used for mildew control.

Applications were ideally performed from **morning to mid-day**, with lights low to off, allowing for a slow drying process.

5.2 Application Method

A **garden hose with a center spray nozzle and a 1/4 to 1/3 horsepower pump** was used for application. The coverage area varied: approximately 13-17 gallons for six 4x8 tables with small or defoliated plants, and around 30 gallons for larger plants or those late in flower. This translates to a maximum of approximately 0.16 gallons per square foot.

CO_2 Release Considerations: Large amounts of CO_2 were observed on sensor graphs during application, a byproduct of the chemical reaction.

6. Monitoring Parameters

6.1 Electrical Conductivity (EC) and pH

Pre- and post-application measurements indicated that the solution remained quite stable once it could pass through the pump without excessive aeration. **On-leaf measurements were not conducted** in this study.

6.2 Plant Health Indicators

Leaf turgor and color: High-ratio strength solutions could make leaves feel slightly "papery," while low-ratio strength solutions resulted in soft, healthy-feeling leaves. It was observed that leaves could recover their soft feel from a papery texture.

Growth rate: Plant damage, observed once with full-strength applications and specific to certain strains, could stunt growth.

Flower development: Plant damage on mature flowering plants was not observed until a 6:1 ratio was applied.

6.3 Pathogen and Pest Pressure

Powdery mildew incidence: Re-emergence occurred when solution ran out, preventing a final top-down wash, or after repeated 1.5:1 applications, indicating insufficient strength.

Spider mites, thrips, and other pests: Pest observations were unavailable due to a lack of current infestations.

Microscopic and visual analysis: Three modes of action were identified: **mechanical dislocation**, **cellular oxidative stress**, and **hypotonic lysis**.

6.4 Residue and Safety

Testing on several crops passed South Dakota's Medical Cannabis Testing Requirements, indicating a safe final product.

Surface residue persistence: To be conducted in future studies.

Micronutrient residue analysis: To be conducted in future studies.

Smell, taste, and smoke analysis: No undesirable taste was found on the final product.

---

7. Results and Discussion

Nutrient Assimilation Effectiveness: Further studies are needed to precisely quantify nutrient assimilation.

EC and pH Behavior and Controllability: The pH of the solution was controllable to the desired input pH. A **pH of 5.8 with an appropriate ratio mix (e.g., 8.5g/gal citric acid)** appeared to be most effective in our cultivation environment.

Pest and Mildew Suppression Outcomes: The potassium citrate foliar spray has effectively **eliminated powdery mildew from our facility**. A 2.5:1 ratio was most commonly used for this purpose. After six weeks of applications at 5-day intervals, the frequency was successfully reduced to once per week.

Any Observed Phytotoxicity: Phytotoxicity was observed after sulfur applications and with high pH solutions.

Comparison to Commercial Alternatives: While no direct commercial comparisons were performed within this study, previous experiences with many 25(b) exemption products yielded less consistently positive effects.

8. Conclusion

This study demonstrates that the potassium citrate-based foliar spray has effectively **eliminated powdery mildew from our facility and significantly reduced the required application intervals**. It has also proven viable as a **multi-purpose foliar spray**, showing promise in increasing plant health and preventing problem incidence.

Recommendations for Further Development:

Further research is recommended to:

- Quantify nutrient assimilation more precisely.
- Conduct formal studies on surface residue persistence and micronutrient residue analysis.
- Perform controlled comparisons against commercial alternatives to further validate its superiority.
- Investigate the optimal pH and EC ranges for different cannabis strains and growth stages.

9. Appendices

Mixing instructions with molar conversion

Key Chemistry & Constants

Compound	Molar Mass (g/mol)	Grams per 1 Gallon	Moles per 1 Gallon	Grams per 16 Gallons	Moles per 16 Gallons
Citric Acid	192.124	8.5 g	0.044 mol	136 g	0.708 mol
Potassium Bicarbonate	100.115	Variable (see table)	Ratio × 0.044 mol	Variable	Ratio × 0.708 mol

Balanced Molar Equation occurs at **3:1 ratio** (KHCO : Citric Acid), producing water, potassium citrate, and CO_2 (fizzing observed).

Key Values:

Citric Acid: 136 g ÷ 16 = **8.5 g per gallon**

Citric Acid Moles: 8.5 g ÷ 192.124 g/mol ≈ **0.044 mol**

$KHCO_3$ mass is scaled per gallon based on molar ratios to this fixed 0.044 mol of citric acid

Fixed Parameters:

Citric Acid per gallon: 8.5 g (0.044 mol)

Citric Acid per 16 gallons: 136 g (0.708 mol)

Potassium Bicarbonate + Citric Acid Mixing Table **Based on: 136g Citric Acid in 16 Gallons ⇒ 8.5g Citric Acid per Gallon**

1-Gallon Mixing Table (Fixed: 8.5g Citric Acid)

Test #	$KHCO_3$ Ratio	$KHCO_3$ (mol)	$KHCO_3$ (g)	Citric Acid (g)	Notes
1	0.25:1	0.011	**1.10 g**	8.5	Ultra Acidic
2	0.5:1	0.022	**2.21 g**	8.5	Ultra Acidic
3	0.75:1	0.033	**3.31 g**	8.5	Extremely Acidic
4	1:1	0.044	**4.41 g**	8.5	Extremely Acidic
5	1.5:1	0.066	**6.62 g**	8.5	Strongly Acidic
6	2:1	0.088	**8.82 g**	8.5	Strongly Acidic
7	2.5:1	0.110	**11.03 g**	8.5	Moderately Acidic
8	3:1	0.132	**13.23 g**	8.5	Balanced Molar Equation
9	3.5:1	0.154	**15.44 g**	8.5	Moderately Acidic
10	4:1	0.176	**17.64 g**	8.5	Slightly Acidic
11	5:1	0.220	**22.05 g**	8.5	Slightly Acidic
12	6:1	0.264	**26.46 g**	8.5	Slightly Acidic
13	7:1	0.308	**30.88 g**	8.5	Neutral
14	1:0	0.044	**4.41 g**	0.0	Slightly Alkaline
15	1:0	0.044	**10.00 g**	0.0	Strongly Alkaline
16	2.5:1	0.110	**20.00 g**	17.0	Strongly Acidic

Mixing Table – Grams of Potassium Bicarbonate for 16-Gallon Batch

Test #	$KHCO_3$ Ratio	$KHCO_3$ (mol)	$KHCO_3$ (g)	Citric Acid (g)	Notes
1	0.25:1	0.177	**17.74**	136	Ultra Acidic
2	0.5:1	0.354	**35.48**	136	Ultra Acidic
3	0.75:1	0.531	**53.22**	136	Extremely Acidic
4	1:1	0.708	**70.97**	136	Extremely Acidic
5	1.5:1	1.062	**106.46**	136	Strongly Acidic
6	2:1	1.416	**141.95**	136	Strongly Acidic
7	2.5:1	1.770	**177.43**	136	Moderately Acidic
8	3:1	2.124	**212.92**	136	Balanced Molar Equation
9	3.5:1	2.478	**248.41**	136	Moderately Acidic
10	4:1	2.832	**283.90**	136	Slightly Acidic
11	5:1	3.540	**354.87**	136	Slightly Acidic
12	6:1	4.248	**425.84**	136	Slightly Acidic
13	7:1	4.956	**496.81**	136	Neutral
14	1:0	0.708	**70.97**	0	Slightly Alkaline
15	1:0	10.00	**160.00**	0	Strongly Alkaline
16	2.5:1	20.00	**360.00**	272	Strongly Acidic

Instructions for Peer-Reviewed Testing: 1 Gallon Lab Test

1.) Measure **8.5 g of citric acid** and dissolve in **1 gallon** of clean water.

2.) Add the corresponding amount of **$KHCO_3$** from the table based on the ratio you're testing.

3.) Stir until fully dissolved.

4.) Measure **pH, EC, and PPM** as part of your trial or lab report.

5.) Record observations for **chemical behavior, fizzing, neutralization, or buffering.**

Instructions for Peer-Reviewed Testing: 16 Gallon Field Test

(standard 16gal tote)

1.) Prepare **15 gallons** of clean water in tote

2.) In **.5 Gallons** add and dissolve **136 g of citric acid** (fixed for all tests).

3.) In **.5 Gallons** add and dissolve the corresponding amount of **potassium bicarbonate** from the table based on the ratio you are testing.

4.) Measure and record **pH, EC, and PPM** values for analysis (optional but recommended).

5.) Use immediately.

Potassium Bicarbonate : Citric Acid Mixing Table

Test #	$KHCO_3$ (parts)	Citric Acid (parts)	Ratio ($KHCO_3$:Citric Acid)	pH	EC (mS/cm)	PPM (mg/L)	Notes / Observations
1	0.25	1	0.25:1				
2	0.5	1	0.5:1				
3	0.75	1	0.75:1				
4	1	1	1:1	4.1	1.08		
5	1.5	1	1.5:1	4.7	1.5		
6	2	1	2:1	5.22	1.9		
7	2.5	1	2.5:1	5.7	2.3		
8	3	1	3:1 (Balanced Molar Equation)	5.8	2.7		Stoichiometric neutralization
9	3.5	1	3.5:1	6.0	3.0		
10	4	1	4:1	6.13	3.36		
11	5	1	5:1	6.3	3.9		
12	6	1	6:1	6.46	4.4		
13	7	1	7:1				
14	1	0	1:0 (Pure PotassiumBicarbonate)	7.52	1.25		No citric acid present
15	1	0	1:0(Pure PotassiumBicarbonate)	8.7	2.5		No citric acid present
16	2.5	1	2.5:1	5.4	3.5		Original Mix

1-Gallon Test Batches

Test #	$KHCO_3$ Ratio	$KHCO_3$ (g)	Citric Acid (g)	pH	EC (mS/cm)	PPM (mg/L)	Visual Reaction / Fizzing	Notes
0	0:1	0.00	8.5					Citric acid only
1	0.25:1	1.10	8.5					
2	0.5:1	2.21	8.5					
3	0.75:1	3.31	8.5					
4	1:1	4.41	8.5	4.1	1.08			
5	1.5:1	6.62	8.5	4.7	1.5			
6	2:1	8.82	8.5	5.22	1.9			
7	2.5:1	11.03	8.5	5.7	2.3			
8	3:1	13.23	8.5	5.8	2.7		**Balanced Molar Equation**	
9	3.5:1	15.44	8.5	6.0	3.0			
10	4:1	17.64	8.5	6.13	3.36			
11	5:1	22.05	8.5	6.3	3.9			
12	6:1	26.46	8.5	6.46	4.4			
13	7:1	30.88	8.5					
14	1:0	4.41	0.0	7.52	1.25			$KHCO_3$
15	1:0	10.00	0.0	8.7	2.5			
16	2.5:1	20.00	17.0	5.4	3.5			

16-Gallon Field Test Batches

Test #	$KHCO_3$ Ratio	$KHCO_3$ (g)	Citric Acid (g)	pH	EC (mS/cm)	PPM (mg/L)	Visual Reaction / Fizzing	Notes
0	0:1	0.00	136					Citric acid only
1	0.25:1	17.74	136					
2	0.5:1	35.48	136					
3	0.75:1	53.22	136					
4	1:1	70.97	136	4.1	1.08			
5	1.5:1	106.46	136	4.7	1.5			
6	2:1	141.95	136	5.22	1.9			
7	2.5:1	177.43	136	5.7	2.3			
8	3:1	212.92	136	5.8	2.7		Balanced Molar Equation	
9	3.5:1	248.41	136	6.0	3.0			
10	4:1	283.90	136	6.13	3.36			
11	5:1	354.87	136	6.3	3.9			
12	6:1	425.84	136	6.46	4.4			
13	7:1	496.81	136					
14	1:0	70.97	0.0	7.52	1.25			$KHCO_3$
15	1:0	160.00	0.0	8.7	2.5			
16	2.5:1	360.00	272	5.4	3.5			