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Summary

A total of 45 water samples from swine production sites across six states were analyzed to determine the effects of water characteristics on reducing water pH with citric acid. Water characteristics analyzed included hardness, pH, calcium (Ca), and magnesium (Mg). Total hardness was calculated as the combined values of Ca and Mg and expressed as mg of $CaCO_3$/L. Water hardness ranged from 142 to 1,181 mg $CaCO_3$/L with an average of 441.2 mg $CaCO_3$/L. Initial sample pH ranged from 7.42 to 8.47 with an average value of 7.91. In triplicate, 10 mL of water from each source was titrated with citric acid to reach a stable pH of 5.0, 4.5, and 4.0 ± 0.05. An inverse relationship between sample hardness and initial pH was observed (quadratic, $P = 0.002$; $R^2 = 0.22$). The amount of citric acid required to reach a sample pH of 4.0 increased (quadratic, $P < 0.001$) as hardness, Ca, and Mg increased ($R^2 = 0.30$, 0.27, 0.28, respectively). Unexpectedly, high initial sample pH was associated with a reduction (quadratic, $P < 0.001$; $R^2 = 0.31$) in the amount of citric acid required to reach a pH of 4.0. In conclusion, water hardness, Ca, Mg, and initial pH cannot fully predict the amount of citric acid required to reach a stable sample pH of 4.0. However, relationships were observed that can partially explain the variation in the amount of acid required. Although these relationships cannot fully determine the amount of acid required to reach the target pH, titrating to a target pH of 5.0 can predict the amount of acid required to reach a pH of 4.0 (linear, $P < 0.001$; $R^2 = 0.99$). This data suggests that acid titrations of each water source should be completed to determine the amount of acid required to reach a final water pH of 4.0.

Introduction

Water is one of the six fundamental nutrients required for all living organisms, however research on this nutrient has received little attention. Water research often focuses on optimal water delivery and requirements rather than water quality.[2] Water quality can be evaluated using three broad criteria: physical, chemical, and microbiological, with most of the attention placed on chemical and microbiological criteria. When evalu-

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[2] Lozinski, B.M., B. Frederick, Y. Li, M. Saqui-Salces, G.C. Shurson, P.E., Urriola, M.L., Wilson, L.J., Johnston. 2022. Effects of water quality on growth performance and health of nursery pigs. Transl. Anim. Sci. 6:txac002. doi:1093/tas/txac002.

ating chemical criteria, the focus is mainly on contamination from minerals including calcium, magnesium, sulfates, nitrates, other minerals, and heavy metals. These contaminates can be naturally found in the water source due to well location, design, and depth[3].

Acidifiers are often supplied via water systems to reduce the gastrointestinal tract pH of newly weaned pigs. Recent research has shown improvements in pig performance when reducing the acid-binding capacity of the diet.[4] Similar benefits may be achieved through the water source, but additional research is needed. Determining the acid-binding capacity of the water source is critical in determining the concentration of acid required to reduce the pH of the water. It is hypothesized that certain water characteristics negatively impact the ability of acidifiers to reduce water pH. There are many water acidification products that are commercially available including organic, inorganic, and acid-blend products that are utilized to reduce water pH. Citric acid is commonly used as it is inexpensive and readily available. Therefore, the objective of this study was to evaluate water characteristics and their effects on reducing water pH when using citric acid.

Materials and Methods

A total of 45 water samples from commercial swine facilities located in MN, IA, OH, KS, MO, and TN were collected and sent to the Kansas State University Swine Lab. A 25 mL subsample of each water sample was analyzed for Ca and Mg concentrations at the Kansas State University Soils Laboratory. Observed Ca and Mg concentrations were multiplied by their respective ion concentrations and added to calculate total hardness using the following equation:

Acid titrations were completed in triplicate for each water sample, utilizing 10 mL of water per replicate. Each sample's initial pH was recorded and then increasing amounts of citric acid (Citrasol Stock Booster, Northwest Livestock Distribution, Medina, MN) was added to achieve a final pH of 4.0 ± 0.05. The amount of acid required to reach a pH of 5.0, 4.5, and 4.0 was recorded for each replicate and the average determined.

Statistical analysis

Data were analyzed using the lm function in R (Version 4.3.0 (2023-03-01), R Foundation for Statistical Computing, Vienna, Austria) to analyze the linear and quadratic relationships between water measurements including starting pH, hardness, calcium, and magnesium concentrations to the amount of acid required to reach the target pH. All results were considered significant at $P \leq 0.05$.

Results and Discussion

Water hardness ranged from 142 to 1,181 mg $CaCO_3$/L with an average of 441.2 mg $CaCO_3$/L (Table 1). Initial sample pH ranged from 7.42 to 8.47 with an average of 7.91. An inverse relationship between sample hardness and initial pH was observed (quadratic, $P = 0.002$; $R^2 = 0.22$; Table 2; Figure 1). Unexpectedly, high initial sample

[3] Patience, J.F., 2012. The Importance of water in pork production. Animal Frontiers. 2: 28-35. doi:10.2527/af.2012-0037.

[4] Stas, E.B., M.D. Tokach, J.M. DeRouchey, R.D. Goodband, J.C. Woodworth, J.T. Gebhardt. 2022. Evaluation of the acid-binding capacity of ingredients and complete diets commonly used for weanling pigs. Transl. Anim. Sci. 6:txac104. doi:10.1093/tas/txac104.

pH was associated with a reduction (quadratic, $P < 0.001$; $R^2 = 0.31$; Figure 2) in the amount of citric acid required to reach a pH of 4.0. A weak relationship between the amount of acid to reach a stable pH of 4.0 and hardness, Ca, and Mg was observed (Figures 3, 4, and 5). The amount of citric acid required to reach a sample pH of 4.0 increased (quadratic, $P < 0.001$) as hardness, Ca, and Mg increased ($R^2 = 0.30$, 0.27, 0.28, respectively). A strong relationship between Ca and Mg concentrations was observed; the concentration of one mineral increased the other mineral concentration (linear, $P < 0.001$; $R^2 = 0.80$; Figure 6) as well.

Titrating to a target pH of 5.0 can predict (linear, $P < 0.001$; $R^2 = 0.99$; Figure 7) the amount of acid required to reach a pH of 4.0. Thus, titrating acid required to reach one pH endpoint can be used to predict the amount of acid required to reach a lower pH endpoint.

A direct relationship between citric acid and Activate WD was observed (linear, $P < 0.001$; $R^2 = 0.87$; Figure 8) to reach a pH of 4.0. Thus, the amount of acid required to reach a pH of 4.0 is independent of acid type. Further titrations should be completed to validate this relationship.

In conclusion, water hardness, Ca, Mg, and initial pH cannot fully predict the amount of citric acid required to reach a stable pH of 4.0. Thus, an acid titration of each water source should be completed to determine the amount of added acid required to reach a final target water pH. Additional research should be conducted to determine the other factors that influence the amount of acid needed to reduce final water pH.

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Table 1. Range of analyzed water characteristics[1]

Variable	Minimum	Average	Maximum
Sample pH	7.42	7.91	8.47
Total hardness, mg $CaCO_3$/L [2]	142.3	441.2	1181.3
Calcium, ppm	33.6	110.4	300.1
Magnesium, ppm	8.5	40.2	105.0

[1]A total of 45 swine production-site water samples across six states were collected and analyzed.
[2]Total hardness, mg $CaCO_3$/L = .

Table 2. Relationship between water characteristics and mL of citric acid[1] required to reach a stable pH of 4.0[2]

	Linear		Quadratic	
Relationship	***P*** **=**	R^2	***P*** **=**	R^2
Start pH and hardness	< 0.001	0.22	0.002	0.22
mL of acid to 4.0 and hardness	0.001	0.19	< 0.001	0.30
mL of acid to 4.0 and Ca concentration	0.002	0.19	< 0.001	0.27
mL of acid to 4.0 and Mg concentration	0.002	0.18	< 0.001	0.28
mL of acid to 4.0 and starting pH	< 0.001	0.31	< 0.001	0.31
mL of acid to 5.0 and mL of acid to 4.0	< 0.001	0.99	---	---

[1] Citrasol Stock Booster, Northwest Livestock Distribution, Medina, MN.
[2] A total of 45 swine production-site water samples across six states were collected and analyzed.

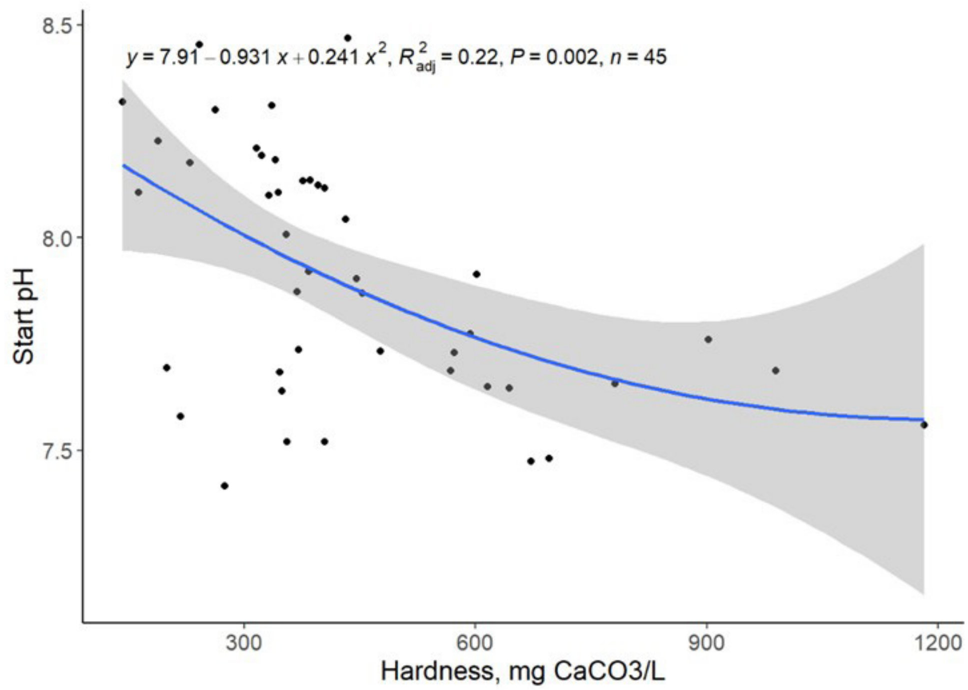

Figure 1. Relationship between starting pH and hardness.

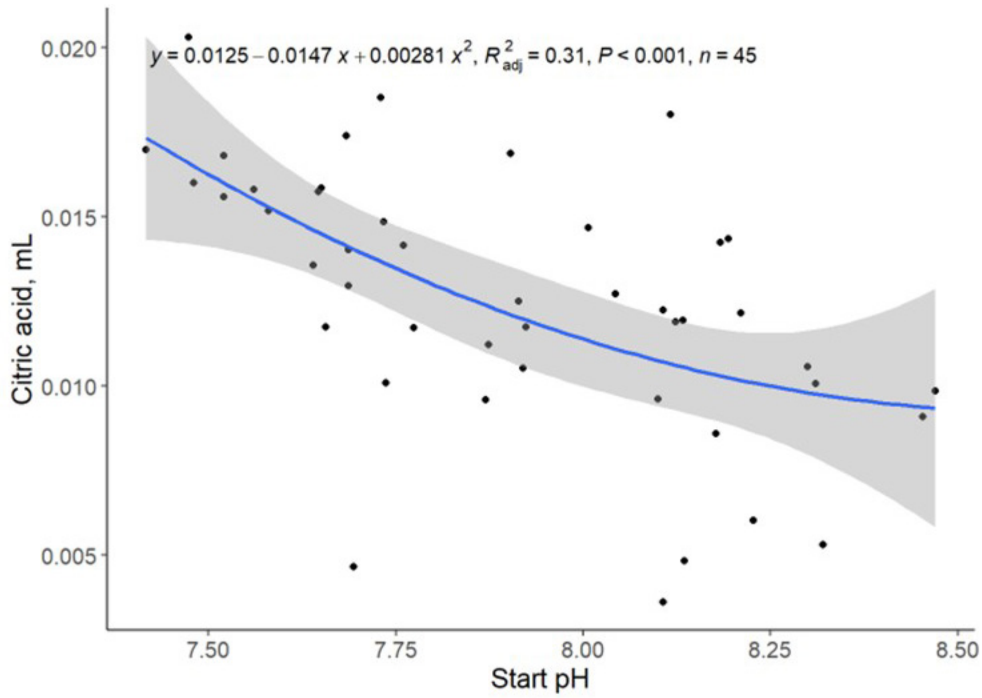

Figure 2. Relationship between mL of citric acid to reach a pH of 4.0 and starting pH.

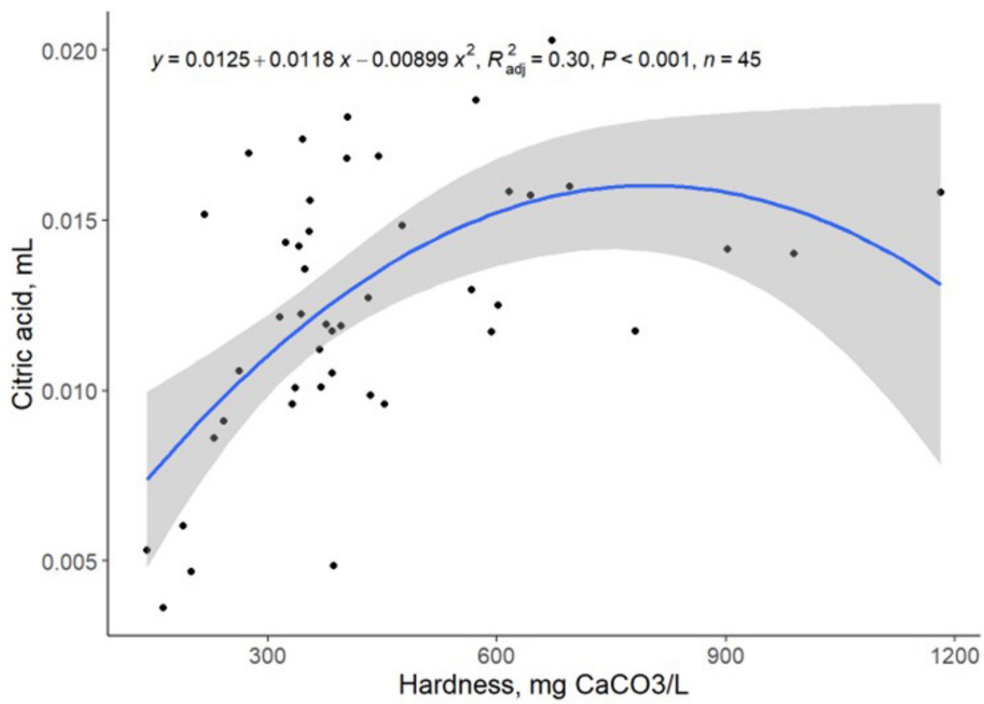

Figure 3. Relationship between mL of citric acid required to reach a pH of 4.0 and hardness.

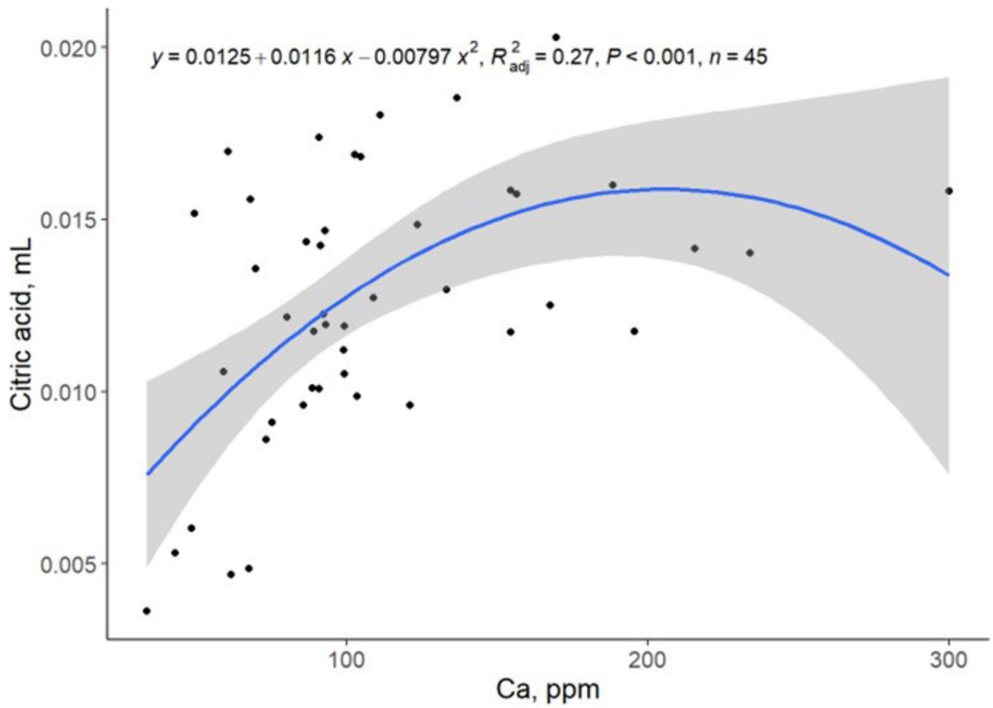

Figure 4. Relationship between mL of citric acid required to reach a pH of 4.0 and Ca concentration.

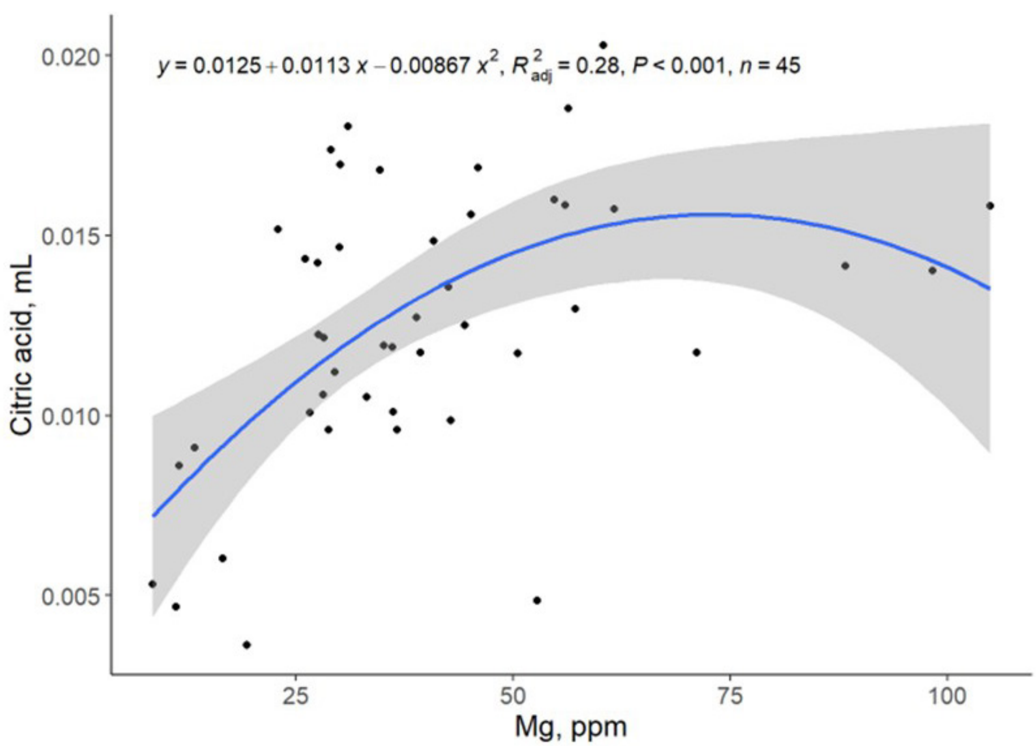

Figure 5. Relationship between mL of citric acid required to reach a pH of 4.0 and Mg concentration.

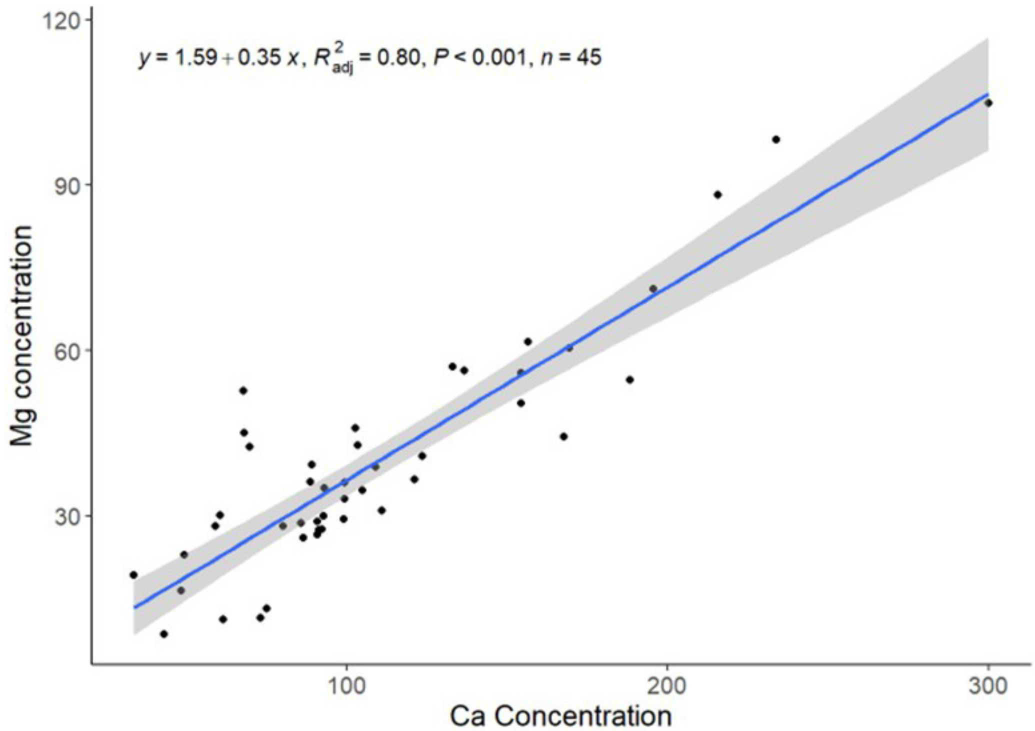

Figure 6. Relationship between increasing Mg and Ca concentrations.

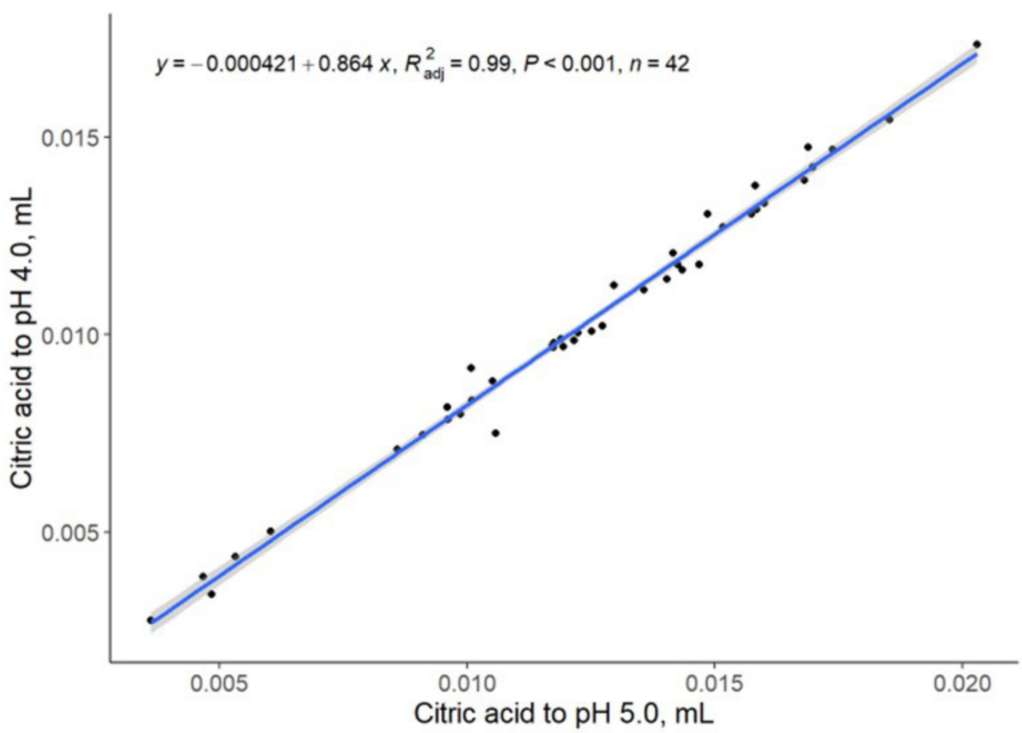

Figure 7. Relationship between quantity of citric acid required to reach a pH of 5.0 and 4.0.

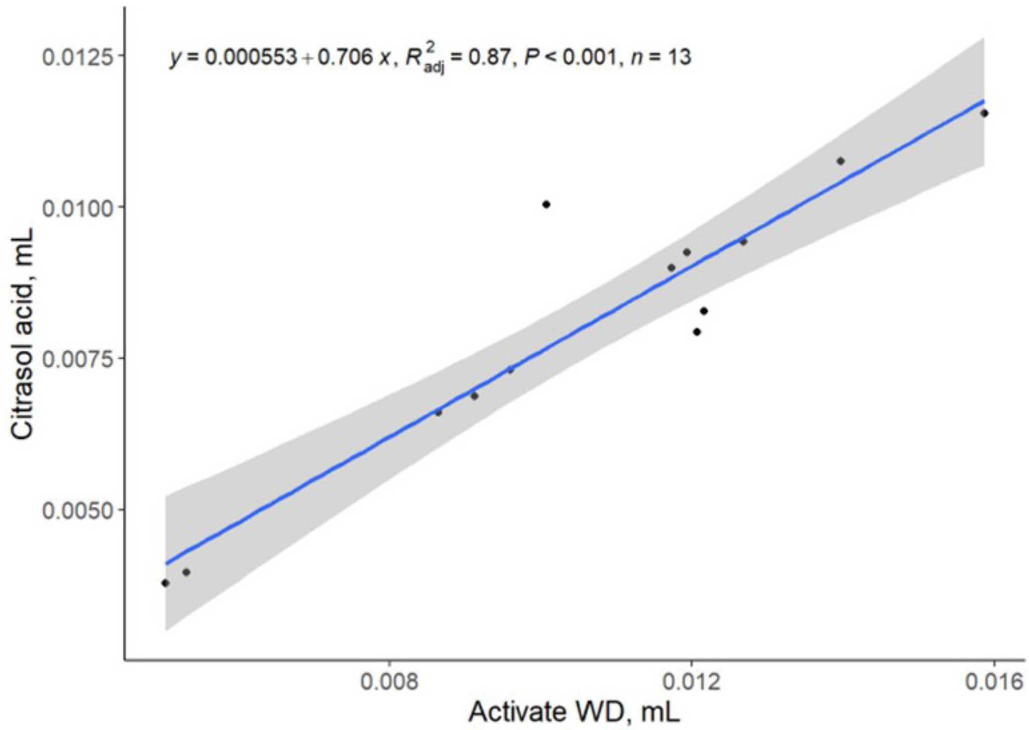

Figure 8. Relationship between amount of citric acid and Activate WD required to each a pH of 4.0.