

Effects of Soil pH on Root Uptake, Accumulation of Aluminum, and Growth Enhancement in Camellia¹

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This publication is intended for those growing camellias in their gardens and those interested in the uptake and effects of aluminum on these plants.



Figure 1. A Vietnamese camellia flower, *Camellia vietnamensis*.

Credit: Dr. Craig Tisher, Wilmot Botanical Gardens at the University of Florida

Camellia spp.

Camellia japonica, or the Japanese camellia, is a woody flowering ornamental plant. It, among others of the same genus, is distributed in tropical and subtropical areas of the world and grows best in acidic soils (Sun et al. 2020). There are many varieties, with different growth times and blossoming periods. It is best to plant them in winter or early spring. They need good drainage to ensure the roots have enough aeration (Kimbrough and Smith 1945).

Acidic Soils for Camellias

Most plant species prefer soil with neutral to slightly acidic pH values for optimum growth and health. However, some plants are known as ericaceous or “acid-loving” plants, requiring more acidic soils. Camellias are acid-loving plants, as are azaleas, gardenias, and blueberries.

How Soil pH Affects Nutrient Availability for Root Uptake by Plants

Hydrogen ion concentration [H⁺] determines the relative acidity/basicity of the soil. H⁺ ions are isolated ions, often broken off from water molecules (H₂O). An ion is an atom with a positive or negative electrical charge. These H⁺ ions are measured on the pH scale from 0 to 14, with increasing acidity corresponding to a lower value on the scale (Miller 2016). The pH is calculated using the concentration of these hydrogen ions.

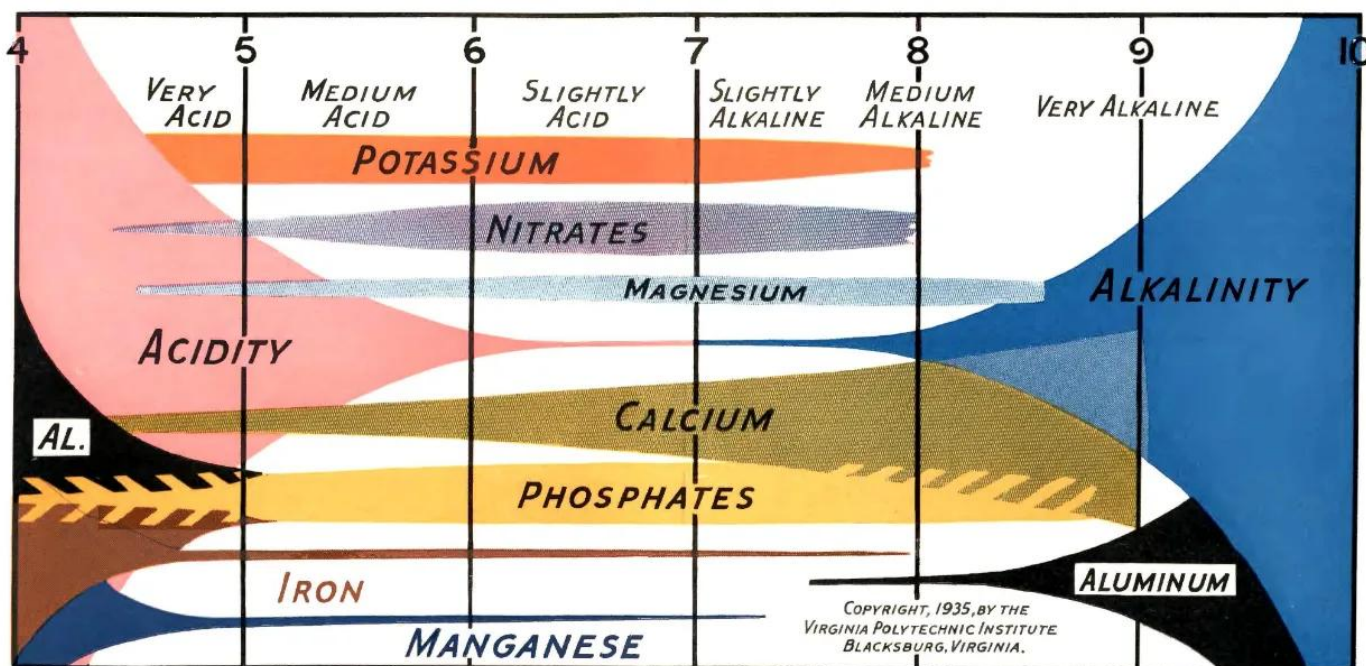
Soil pH influences what is known as the exchange capacity, or the ability of the soil to retain nutrients. Cation exchange capacity (CEC) is the ability of the soil to hold positively charged ions known as cations. This includes the hydrogen ion and other atoms with positive charges. The pH affects CEC and the solubility of many essential nutrients (Miller 2016). As pH increases, CEC increases as well. In other words, the soil can hold more cations as it becomes more basic. Initially, nutrients may be bound to soil particles. However, at different pH values, various nutrients become water-soluble in the soil and can then be taken up by plant roots. For example, most macronutrients (except phosphorus) are available for plant uptake between pH 6.5 and 8.0. Phosphorus is most available for uptake between pH 6.0 and 7.0 (McCauley et al. 2017). Plants need phosphorus, nitrogen, and potassium in the highest quantities compared to other nutrients. When soil pH is outside the solubility range of a desired nutrient, this can lead to nutrient deficiencies.

Because pH affects nutrient availability (Figure 2), certain methods can be taken to raise or lower soil pH. Different plants have differing abilities to obtain nutrients from the

soil, and pH is not the only factor on which the uptake of nutrients depends. Moisture levels, temperature, and light can also affect the nutrient uptake. The application of one of several forms of calcium carbonate, known as “liming,” is often used to increase soil pH. Alternatively, using peat moss or fertilizers with nitrogen or ammonium sulfate can decrease soil pH.

Soil pH is most often measured by mixing soil with deionized water in a ratio of 1:1 V/V or a diluted salt solution in a ratio 1:2 V/V. An electrode is placed in the

solution to obtain the precise measurement. Often, soil samples are sent to laboratories for the accurate determination of soil pH. However, a soil’s measured pH can vary from season to season and year to year due to the application of nitrogen and potassium fertilizers, decomposition of organic matter, and seasonal rainfall levels. Acidic soils are predominantly found in tropical and subtropical regions, but many soils are becoming more acidic worldwide due to acid rainfall and the excessive use of nitrogen fertilizers (EPA 2021).



A large lecture size, 36" x 72", of this same chart, on 80-pound offset paper, may be obtained by writing to the Office of Publications, V. P. I., Blacksburg, Virginia, and enclosing \$1.00 to cover cost of printing and mailing.

Figure 2. Essential nutrient availability as a function of soil pH ranging from 4.0 to 10.0. Nutrient availability is indicated by the width of the colored area for each element or compound shown. Not all essential plant nutrients are shown. The diagram created by Pettinger is not based on empirical evidence; rather, it is used conceptually (Hartemink and Barrow 2023).

Credit: Created by Pettinger (1935) and provided by Virginia Cooperative Extension, Virginia Tech, and Virginia State University

The Effects of Arbuscular Mycorrhizal Fungi on Nutrient Availability

Arbuscular mycorrhizal fungi (AMF) are symbiotic soil fungi that colonize the roots of most plants. These fungi allow plants to more easily take up phosphorus because they allow the plant to get access to otherwise unavailable phosphorus sources. AMF also allow the plant to more easily take up nitrate and ammonium (Han et al. 2025). Overall, AMF improves nutrient uptake for the plant.

The Process of Aluminum Uptake

Aluminum (Al) is the most abundant metal in soil and the third most abundant element in the Earth’s crust (Mridha 2016). For aluminum to be soluble in the soil and absorbed

by plants in sufficient quantities, generally, the soil pH must fall below 5.5 (Figure 2; Watanabe 2022). While aluminum is toxic to most plants, it is less toxic to camellias (Chenery 1955). Tea plants (*Camellia sinensis* L.), a distinct species of camellia, often do not grow well in soils with an alkaline pH (above 7.0). This is because aluminum is largely unavailable for root uptake in alkaline soils. Acidic soils make aluminum more soluble in the soil, allowing the plant to access higher levels of aluminum (Sun et al. 2020). All species in the genus *Camellia* are aluminum accumulator plants, meaning they have a higher tolerance to aluminum. The plant accumulates aluminum throughout all its parts, generally without harm. Aluminum accumulators are more formally defined as plants that can have aluminum levels of up to 1,000 mg kg⁻¹ in their leaves and/or shoots (Chenery 1948). Anions are negatively charged atoms, and organic acid anions can form stable

complexes with aluminum cations. This renders the aluminum inactive, reducing its ability to cause harm to the plant. Because aluminum accumulator plants can concentrate organic acid anions within the plant, they can survive the acidic soils that allow aluminum to be accessed by the roots. For tea plants, aluminum is stored in the cell wall or vacuole, parts of the plant cell that can detoxify the nutrient from the plant's leaves and roots, preventing harm (Morita et al. 2004; Zhang et al. 2023).

Where Aluminum Is Stored in Camellias

Aluminum accumulators are mainly eudicots and pteridophytes. Eudicots are flowering plants that have two seed leaves during germination, and pteridophytes are ferns, which reproduce using spores rather than seeds. While most plants sequester aluminum in the roots or exclude aluminum from the roots, aluminum accumulator plants such as *Camellia* spp. accumulate aluminum throughout the plant. More of their aluminum content is stored in older leaves than in younger ones (Chenery 1955; Lu et al. 2023). This is, in part, because much of the aluminum is stored in the cell wall, and the cell wall's volume generally increases with leaf age. Once aluminum accumulates in the cell wall, it is difficult to mobilize again. For example, the aluminum content in the cell wall was found to be 66.03% in young leaves and 86.51% in old leaves. The aluminum content was also found to be higher in hemicellulose than the pectin and cellulose components of the cell wall. Hemicellulose plays a role in strengthening the cell wall. Since aluminum accumulates in the cell wall, hemicellulose reduces how much aluminum enters the cell, thereby reducing potential toxicity to the plant.

Beneficial Effects of Aluminum in Camellias

Aluminum toxicity and stress in most plants can affect biological processes by preventing growth, reducing nutrient uptake, decreasing photosynthesis, and decreasing crop yield (Lu et al. 2023). It can also cause an excessive accumulation of reactive oxygen species, which can lead to cell death. In many plants, aluminum accumulation stunts root growth (Neina 2019); however, this nutrient can be beneficial for aluminum accumulators. In *Camellias* spp., aluminum increases the activities of some nutrient element transporters, leading to higher rates of essential nutrient uptake and resulting in root growth stimulation (Liu et al. 2020).

Aluminum has a positive growth effect on both the roots and shoots of camellias, including increased biomass, leaf area, and root length. Also, an increase in aluminum uptake is correlated with an increase in chlorophyll *a* and *b* concentrations in the leaves, leading to increased photosynthesis (Hajiboland et al. 2013). The roots grow by

both elongating existing roots as well as creating new ones. Without aluminum, the roots show no change in growth, but when grown in a 1 μ M aluminum solution, the length of new roots increases.

In addition to root growth, aluminum in tea plants can increase pollen tube growth and bud emergence. Aluminum also appears to enhance the stability of DNA in camellia root meristem cells. Meristematic activity increases with aluminum intake as well.

The uptake of aluminum also enhances phosphorus uptake, thus promoting growth (Konishi et al. 1985). Additionally, nitrogen content increases in the camellia root tips in the presence of aluminum. High nitrogen concentration in tea leaves is correlated with increased chlorophyll and amino acid content in leaves, resulting in increased quality. While aluminum has beneficial effects on camellias, aluminum uptake requires acidic soil conditions. Alkaline soils with a pH of 8 will not promote root or shoot growth of camellias, and highly acidic soils with a pH <4 may not necessarily either (Sun et al. 2020).



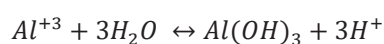
Figure 3. A Vietnamese camellia, *Camellia vietnamensis*.

Credit: Dr. Craig Tisher, Wilmot Botanical Gardens at the University of Florida

The Use of Aluminum Sulfate to Increase Acidity in Soils for *Camellia* spp. Growth

Using aluminum sulfate to effectively lower soil pH is beneficial to camellias, which prefer acidic soils in the pH range of 4.5 to 5.5. This compound also provides aluminum and sulfur that the plant can take up and use for beneficial growth outcomes.

Aluminum sulfate is a salt and, when hydrated, can have the formula, $Al_2(SO_4)_3 \cdot 18H_2O$. When dissolved in an aqueous solution, the salt dissociates to form $2Al^{3+}$ cations and $3(SO_4^{2-})$ anions. Al^{3+} in water serves as a coordination center, forming a hydroxide and releasing protons into the solution, thereby increasing the $[H^+]$ concentration and acidifying the solution.



Aluminum sulfate can be mixed with the soil to be applied before camellias are planted. If applied after a camellia is planted, it can be spread around the plant or treated as a soil drench solution of water and dissolved aluminum sulfate. The recommended dose is no more than 0.5 lb per square yard (Kimbrough and Smith 1945), but 0.25 lb can provide beneficial results as well. The dose can be applied to the soil once or twice per year.

Aluminum Accumulation Effects on Plant Defense

Plants that take up metals will usually develop sclerophyllic leaves, which are adapted to long periods of heat. Aluminum stored in camellia leaves may help to repel herbivores (Ribeiro et al. 2016). This is because metals that are toxic to non-accumulator plants may also be toxic or distasteful to the pests feeding on the leaves of accumulator plants. Accumulation of aluminum and other metals in leaves has reduced the number of leaves lost to herbivores and pests. Therefore, this may provide a growth and health advantage to aluminum-accumulating plants such as camellias.

Summary

In summary, camellias grow better in acidic soils, unlike most other plants. Acidic soils have a lower pH, which affects the solubility of nutrients in the soil and ultimately nutrient uptake. Arbuscular mycorrhizal fungi (AMF) also affect nutrient availability and uptake. Aluminum is more easily taken up at these lower pH levels that camellias thrive in. While aluminum is harmful to most plants, camellias are aluminum accumulators, meaning they can store aluminum without harming the plant. In fact, aluminum has many beneficial effects on camellias, such as root growth, shoot growth, and defense against plant disease and pests.

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¹ This document is ENH1401, one of a series of the Department of Environmental Horticulture, UF/IFAS Extension. Original publication date April 2026. Visit the Ask IFAS website at <https://ask.ifas.ufl.edu> for the currently supported version of this publication. © 2026 UF/IFAS. This publication is licensed under [CC BY-NC-ND 4.0](#).

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