Substrate pH and Water Quality

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The pH of the substrate solution, as estimated by measuring the pH of a substrate extract, is very important in plant nutrition, and an out of range pH can lead to problems (Figure 1). The pH directly affects the availability of many plant nutrients, especially micronutrients (Figure 2).

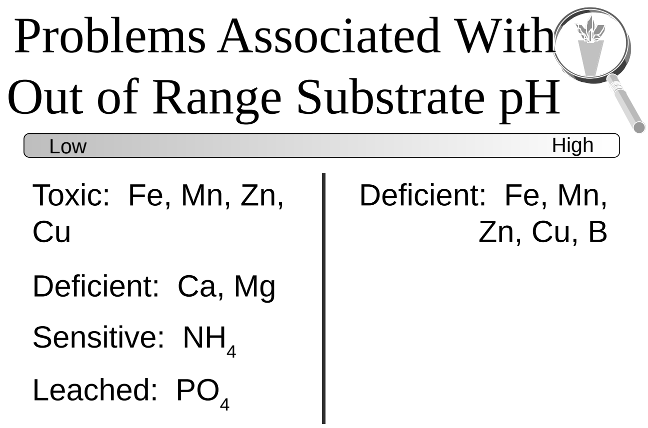

Figure 1. Avoid excessively high or low substrate pHs.

Too low of a pH can result in increased micronutrient availability that can lead to phytotoxic responses in some plant species. For example, a low pH in conjunction with excessive levels of iron and manganese can result in iron and / or manganese toxicity in celosia, geraniums and marigolds (Table 1). Calcium and magnesium deficiencies can develop when the pH is too low. There is a greater chance of ammonium toxicity problems in low pH conditions; and phosphorus leaching increases at a low pH.

Table 1. Suggested substrate pH ranges for specific greenhouse crops grown in a soilless substrate. For crops not listed, the recommended pH range is 5.4 to 6.8.

Species	pH	Why?
Azalea	4.5 to 5.8	prevent Fe deficiency
Celosia	6.0 to 6.8	prevent Fe & Mn toxicity
Dianthus	6.0 to 6.8	prevent Fe & Mn toxicity
Easter lily	6.5 to 6.8	prevent F toxicity and Ca deficiency
Geranium	6.0 to 6.8	prevent Fe & Mn toxicity
Hydrangea (Blue)	5.2 to 5.6	prevent Fe deficiency and assist in blue coloration
Hydrangea (Pink)	5.8 to 6.2	prevent Fe deficiency and assist in pink coloration
Marigold (African)	6.0 to 6.8	prevent Fe & Mn toxicity
Pansy	5.4 to 5.8	prevent B & Fe deficiency; avoid *Thielaviopsis*
Petunia	5.4 to 5.8	prevent B & Fe deficiency
Salvia	5.4 to 5.8	prevent B & Fe deficiency
Snapdragon	5.4 to 5.8	prevent B & Fe deficiency
Vinca	5.4 to 5.8	prevent B & Fe deficiency; avoid *Thielaviopsis*

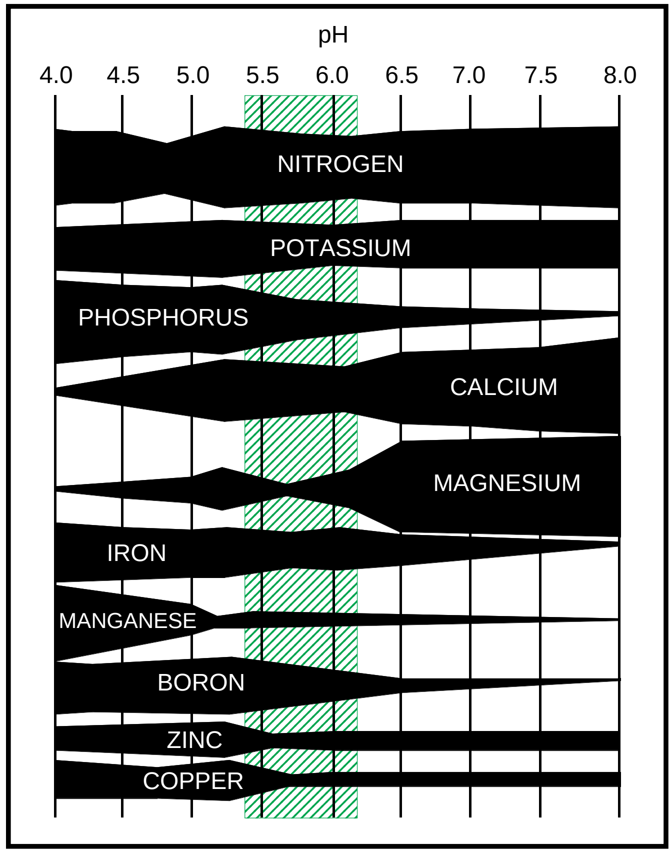

Figure 2. Influence of pH on the availability of essential nutrients in a soilless substrate containing sphagnum peat moss, composted pine bark, vermiculite, and sand. The pH range recommended for most greenhouse crops is indicated by slashed lines.

At the other end of the spectrum, pH above 6.2 can lead to problems such as iron deficiency chlorosis in hydrangeas and pansies; and boron deficiency in salvia, petunias, and pansies (Table 1).

Most greenhouse crops grow best at pH 5.4 to 6.4, but some crops such as azaleas and hydrangeas prefer a more acidic substrate; others such as Easter lilies are grown at a higher pH (Table 1). Growers should target substrate pHs based on the species being produced and should treat species according to their requirements rather than using a blanket production system.

The ideal production situation is one where substrate pH is identical to the requirements of the particular species being produced; and no changes occur. Preventing pH changes will eliminate many of the nutrient problems encountered in plant production. Unfortunately, there are many forces at work that affect substrate pH, and maintaining a constant pH is no easy task.

There are four major forces that affect the substrate solution pH during plant production: ❶ preplant materials such as dolomitic limestone put into the substrate and the substrate components themselves; ❷ the alkalinity of the irrigation water; ❸ the acidity / basicity of the fertilizers used during production; and ❹ the plant species being grown. With so many factors affecting pH, it's no wonder that pH stabilization is easier to write about than to implement!

Preplant Materials

The starter lime charge is based on the substrate components used in the mix and the desired starting pH. Although you know what starting substrate pH is best for the species you intend to grow, it may take from 24 hours to 7 days for the pH to adjust up to the desired level after the mix has been moistened. The length of this "equilibration period" will depend on the ratio of components used in creating the substrate; particle size and grade of lime used; the salts used to make the base nutrient charge, and the pH and alkalinity of your irrigation water.

Prior to using a mix, fill a few pots with it, water them in with distilled water, and set them in the greenhouse for a few days, keeping them moist. After this equilibration period, measure the pH of the substrate; it should be within the range targeted for the species being grown. If it is far off target, you may need to adjust your pH control strategy.

Water Alkalinity

Introduction to pH and Alkalinity. High water pH and high alkalinity can be limiting factors in container production of greenhouse crops. An understanding of both is needed to accurately treat water with a high pH.

The recommended range of irrigation water pH and substrate solution pH for container production depends on the crop being grown. The generally accepted range for irrigation water is 5.4 to 6.8. Acid treatment of high pH water may be needed prior to use in container production, if pH and alkalinity are too high.

Alkalinity is a measure of a water's capacity to neutralize acids; the concentration of soluble alkalis in a solution. Dissolved bicarbonates such as calcium bicarbonate ($Ca(HCO_3)_2$), sodium bicarbonate ($NaHCO_3$), and magnesium bicarbonate $Mg(HCO_3)_2$); and carbonates such as calcium carbonate ($CaCO_3$) are the major chemicals contributing to alkalinity in irrigation water. Dissolved hydroxides are but a minor contributor in most cases; and ammonia, borates, organic bases, phosphates, and silicates can also be minor contributors to alkalinity.

Since bicarbonates and carbonates are the major components of water alkalinity, most laboratories assume that Total Carbonates (TC; carbonates + bicarbonates) equals alkalinity. In most cases, this is a safe assumption.

The term "alkalinity" should not be confused with the term "alkaline," which describes situations where pH levels exceed 7.0. Laboratory test results will express alkalinity as milligrams per liter of calcium carbonate (mg/L $CaCO_3$) or milliequivalents per liter of calcium carbonate (meq/L $CaCO_3$). You can convert between these two units using the following conversion: 1.0 meq/L $CaCO_3$ = 50.04 mg/L $CaCO_3$. The term "total carbonates" (TC) may also be used by some labs to refer to alkalinity of a solution. Some laboratories assume that all alkalinity is derived solely from bicarbonates (HCO_3^-) and will report bicarbonates as mg/L or meq/L. To convert between these two units, use the following conversion: 1 meq/L HCO_3^- = 61 mg/L HCO_3^-.

Alkalinity is related to pH because alkalinity establishes the buffering capacity of a water. Alkalinity affects how much acid is required to change the pH. The following example may help explain the importance of alkalinity when trying to acidify water (Figure 3): Grower A has a water with a pH of 9.3 and an alkalinity of 71 mg/L $CaCO_3$ (TC = 1.42 meq/L $CaCO_3$). To reduce the pH of this water to 5.8, it takes 15.8 fl oz. of 35% sulfuric acid per 1,000 gallons of water. In contrast, Grower B

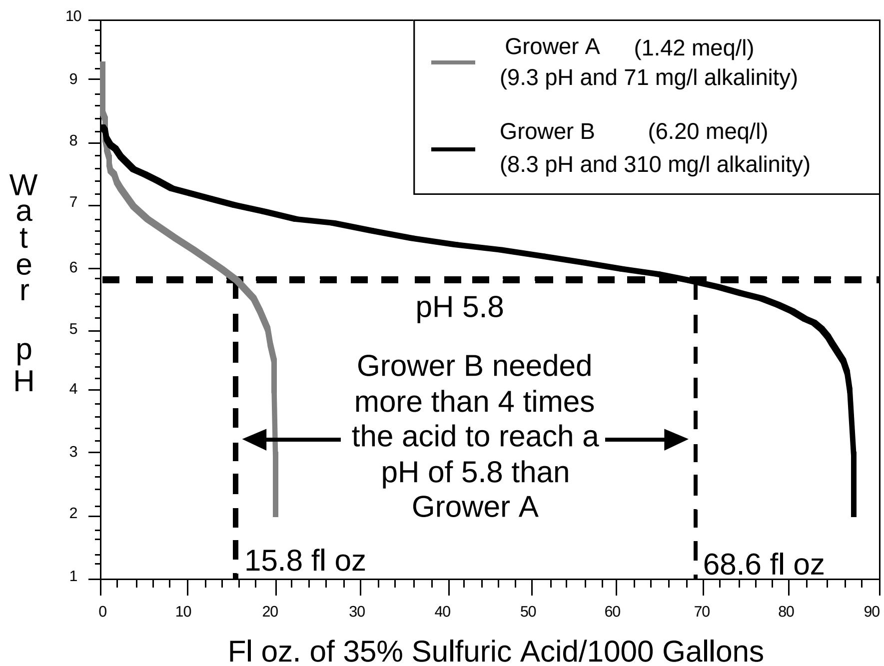

Figure 3. Titrations of two different waters with sulfuric acid. Notice that although the beginning pH of Grower A water is a full unit higher than Grower B water, it takes more than 4 times the acid to drop Grower B water to pH 5.8, due to the greater alkalinity in Grower B water.

has a water with a pH of 8.3 and an alkalinity of 310 mg/L $CaCO_3$ (TC = 6.20 meq/L $CaCO_3$). To reduce this water to a pH of 5.8, it takes 68.6 fl oz. of 35% sulfuric acid per 1,000 gallons of water. Despite the fact that Grower B's water is a full pH unit lower than Grower A's, it takes *more than four times more acid* to lower the pH to 5.8. Both alkalinity and pH are important to consider when attempting to adjust the pH of a water.

Alkalinity can be a major problem in many regions in North America. Levels below 2 meq/L and lower are safe for most crops. However, plug seedlings are more sensitive to alkalinity because the small volume of substrate provides little buffering against a rise in pH. Problems can occur in plug production if using water with more than 1.5 meq/L . If the alkalinity of your irrigation water is above 2.0 meq/L (or above 1.5 meq/L for a plug producer), you should consider injecting an acid to neutralize the bicarbonates (alkalinity) present, thus preventing an undesirable rise of substrate pH over time.

Research at NCSU that varied the initial lime charge in plug trays and varied the alkalinity of irrigation water used in plug production shows that over time, the effect of the alkalinity in the irrigation water far exceeds that of the initial lime charge (Figure 4). Acidification of high alkalinity water may be required to prevent an undesirable rise in substrate pH.

In-House Analysis of Water Alkalinity. Water alkalinity is caused by the presence of carbonates, bicarbonates, hydroxides, and other dissolved salts. It is measured by titrating a water sample with an acid (usually dilute sulfuric acid) to an endpoint pH of about 4.6 (varies from 5.1 to 4.5 depending on the indicator dye used and the initial alkalinity). A pH indicator dye (usually bromcresol green plus methyl red) is added to a known volume of water (indicated in the test kit instructions; usually about 8 fl oz.), and acid is added until the solution changes color. With the bromocresol green plus methyl red dye system, the color will change from green to pink.

Most water sources acceptable for greenhouse use will have alkalinity in the range of 0 to 8 meq/L (0 to 400 ppm alkalinity expressed as $CaCO_3$). When looking for a test kit, this is the range that is needed. The level of accuracy does vary from kit to kit; ± 0.4 meq/L (20 ppm alkalinity expressed as $CaCO_3$) is accurate enough for most situations, but more precise kits are available. We have used Hach alkalinity kits #24443-01 (about $30 for 100 tests) and #20637-00 (about $155 for 100 tests, but includes versatile digital titrator) and are satisfied by both (Hach Company, P.O. Box 389 Loveland, Co 80539; phone (800) 227-4224). Although the second model is more expensive, it does have twice the accuracy (± 0.2 meq/L) and also comes with a digital titrator that can be used to measure other solution parameters (using different titrants and indicators) such as water hardness, chlorine, iron, nitrite, and sulfite concentrations.

Neutralization of Alkalinity. Cooperative research between Allen Hammer and Brian Whipker at Purdue University and the authors of this article led to the development of an Excel® spreadsheet that allows users to input their water pH and alkalinity then select sulfuric, phosphoric, or nitric acid to use as an acidifying agent to reach a target pH or alkalinity. The spreadsheet modules calculate the nutrient additions from the acid injection and will report your acidification costs, if you input the price per gallon for the acid you wish to use. You can acquire a copy of this spreadsheet to aid in your water acidification needs via the world wide web at http://www2.ncsu.edu/unity/lockers/project/floriculture/www or by contacting the authors.

Table 2 gives general guidelines for water acidification. For exact acidification recommendations to any endpoint pH or alkalinity concentration, you should contact your state's floriculture extension specialist or acquire a copy of the acidification calculator (in Excel spreadsheet format) located on the world wide web at the address given previously.

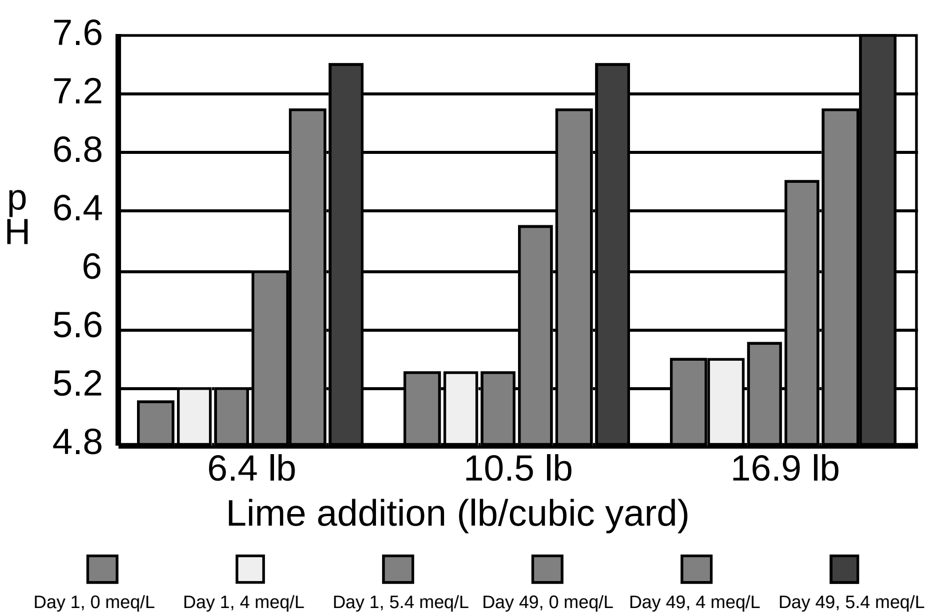

Figure 4. Change in vinca 'Pretty in Rose' substrate pH due to initial substrate liming charge (dolomitic limestone) and irrigation water alkalinity.

Fertilizer Acidity / Basicity

Most of the fertilizer salts we use have some effect on the substrate pH (Table 3). Some such as 21-7-7 are very acid (high acidity) while others such as 15-0-15 are fairly basic (high basicity). Fertilizer acidity / basicity relates to how the pH of the substrate solution changes after the fertilizer is applied and plants absorb nutrients from the substrate. The ratings given in Table 3 are used by fertilizer manufacturers, but are based on the fate of fertilizer salts in a mineral based soil out in the field as measured by researchers in the 1930s! Further research is needed to better define acidity and basicity of common fertilizers in greenhouse substrates.

Table 2. Amount of acid to inject to drop water pH to approximately 5.8 and the resulting concentrations of nutrients provided by injecting 1 fl oz. per 1,000 gallons water of each acid.

Acid	Amount of acid to add for each meq of alkalinity (fl oz/1,000 gals)*	Concentration of nutrient provided by one fl oz. of acid per 1,000 of water
Nitric (76%)	6.6	1.64 ppm
Phosphoric (75%)	8.1	2.88 ppm
Sulfuric (35%)	11.0	1.13 ppm

*Add this amount for each meq of alkalinity present. For example, if your water report indicates an alkalinity of 3 meq/L and you choose to use sulfuric acid, you would add 33 fl oz. of 35% sulfuric acid per 1,000 gallons of water.

We can lower, raise, or hold constant the pH of container substrates by fertilizer selection. Unfortunately, most acidic fertilizers also have a correspondingly high proportion of ammoniacal nitrogen and cannot be relied on as the only means of reducing the substrate pH in all cropping situations. For example, if too much ammoniacal nitrogen is applied in plug production, the plants will stretch excessively and will develop undesirably succulent growth. However, in many cases, it is possible to rotate between an acidic and basic residue fertilizer, say between a 20-10-20 and a 13-2-13 to maintain a constant pH.

Species Effect on Substrate pH

Research at NCSU has shown that bedding plants will modify the substrate pH during germination and seedling growth (Figure 5). However, many species change the pH to a level that is not best for their growth! For example, celosia

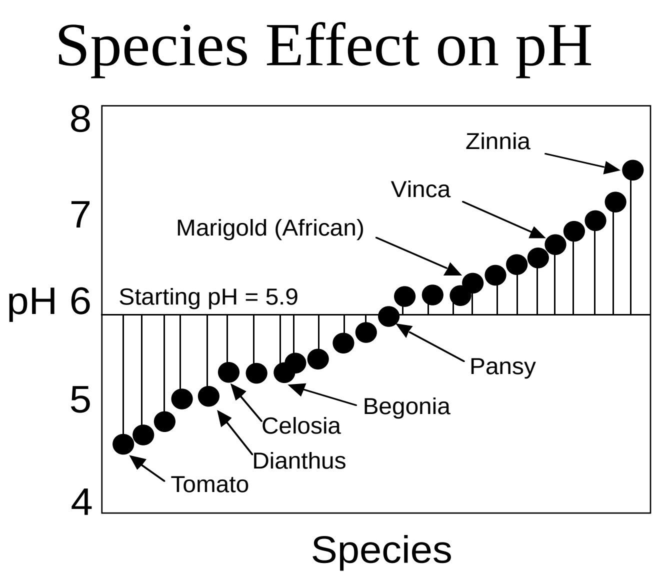

Figure 5. Seedlings have the ability to alter the substrate pH, and the resulting change is not always in their favor.

Table 3. Potential acidity or basicity, percent of total nitrogen in the ammonium plus urea form, and Ca, Mg, and S components (when these are ≥ 0.2%) for several commercial fertilizers.

Fertilizer*	Potential acidity or basicity**		NH_4 (%)***	Ca (%)	Mg (%)	S (%)
21-7-7	1,700	A	90			10.0
21-7-7	1,560	A	100			
20-2-20	800	A	69			
20-18-18	710	A	73			1.4
24-7-15	612	A	58		1.0	1.3
20-18-20	610	A	69			1.0
20-20-20	583	A	69			
20-9-20	510	A	42			1.4
20-20-20	474	A	69			
16-17-17	440	A	44		0.9	1.3
20-10-20	422	A	40			
21-5-20	418	A	40			
20-10-20	393	A	38			
21-7-7	369	A	100			
15-15-15	261	A	52			
17-17-17	218	A	51			
15-16-17	215	A	47			
15-16-17	165	A	30			
20-5-30	153	A	56			
17-5-24	125	A	31		2.0	2.6
20-5-30	118	A	54		0.5	
20-5-30	100	A	54			
15-11-29	91	A	43			
15-5-25	76	A	28		1.3	
15-10-30	76	A	39			
20-0-20	40	A	25	5.0		
21-0-20	15	A	48	6.0		
20-0-20	0		69	6.7	0.2	
16-4-12	73	B	38			
17-0-17	75	B	20	4.0	2.0	
15-5-15	135	B	28			
15-3-20	75	B	16	3.8	1.9	
13-2-13	200	B	11	6.0	3.0	
14-0-14	220	B	8	6.0	3.0	
15-0-15	319	B	13	10.5	0.3	
15.5-0-0	400	B	6	22.0		
15-0-15	420	B	13	11.0		
13-0-44	460	B	0			

*Notice that identical analyses can have different acidities, basicities, and percent NH_4, depending on the manufacturer.

**A = pounds of calcium carbonate limestone required to neutralize the acidity caused by using one ton of the specified fertilizer. B = equivalent pounds of calcium carbonate limestone added by using one ton of the fertilizer.

***Refers to the percentage of total nitrogen that is in the ammonium plus urea forms; the remaining nitrogen is nitrate-N.

and dianthus (both grow best at a higher pH) tend to lower the substrate pH. Vinca raised the substrate pH, though vinca grows best at a lower pH. Growers must be aware of species effects on substrate pH, especially when monitoring the pH of a plug crop during production. Imagine the nightmare of a plug producer basing their entire pH control program on samples of a single species; or on a combined sample of different species. Do you monitor the substrate pH of species *separately* and adjust pH according to sample results? Our research results indicate you should.

Strategies to Control pH

We need to establish pH base lines for all major plant species, similar to those suggested in Table 1. Next, upper and lower "decision points" must be determined for each species. Decision points are limits that determine when action must be taken to correct or prevent an out-of-range pH. We have already described the tools available to us in regulating pH for a given species -- preplant materials, regulation of water alkalinity, and fertilizer selection tailored for each species. The final stage of a pH stabilization strategy is to decide how to control pH in your particular production system, then to monitor frequently to assure that you are within the acceptable pH range for each of your crops.

The example pH plot in Figure 6 is assuming a pH base line of 5.8; an upper decision limit of 6.2; and a lower decision limit of 5.4. For this hypothetical species, a grower would target pH 5.8 when adding the liming components into the substrate prior to seeding. They would want to take corrective measures to lower pH if sampling showed a substrate pH of 6.2 or above. Corrective measures to lower pH include: ❶ acidifying your water down to pH 5.8 (neutralizing ~80% of the alkalinity in your irrigation water); ❷ discontinuing the use of basic residue fertilizers, such as calcium nitrate and using acid-residue fertilizers to lower the pH, if plants are capable of tolerating the ammoniacal nitrogen; and ❸ in severe cases, drenching with aluminum sulfate or iron sulfate to rapidly lower pH. The substrate pH would need to be raised if it fell below 5.4. Corrective measures to raise pH include: ❶ discontinuing irrigation water acidification, if any is employed; ❷ using basic-residue fertilizers to raise the substrate pH; and ❸ in severe cases, injecting potassium bicarbonate to increase the alkalinity of your irrigation water to increase the substrate solution pH

There is still much to learn about pH regulation and how to incorporate it into a nutrition program. We have only begun to outline standards, but we hope to eventually create control graphs similar to Figure 6 for most plant species produced. Through careful monitoring and precise production management, pH-related problems can be avoided.

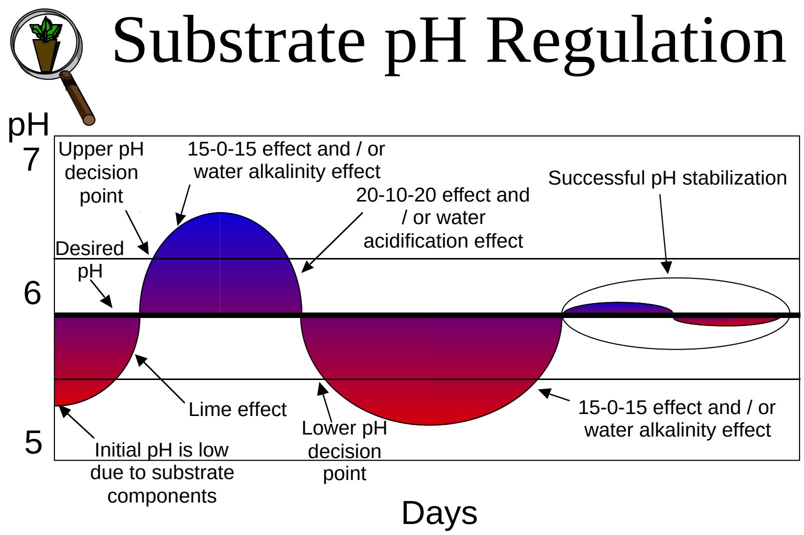

Figure 6. An example pH regulation strategy based on a desired pH of 5.9.

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