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The Hidden Dial Under Your Tomatoes: How Soil pH Controls Micronutrient Supply

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Tomato plants often show pale leaves, stunted tips and poor fruit set even when the soil holds enough nutrients. In many fields the cause is soil pH, which decides how much of each micronutrient is dissolved and within reach of the roots. This article explains how pH controls the supply of iron, manganese, zinc, copper, boron and molybdenum. Iron, manganese, zinc and copper become harder to absorb as soil turns alkaline, boron is held more tightly at high pH, and molybdenum behaves in the opposite way. Very acid soils can instead cause manganese and copper toxicity. The article also describes how tomato roots respond, how to read deficiency symptoms on the plant, and how growers can test the soil, adjust pH, choose suitable nutrient forms and use foliar sprays wisely. A pH of about 6.0 to 6.8 suits most tomato crops.

Keywords: soil pH, micronutrients, tomato, nutrient availability, iron chlorosis, zinc deficiency, boron, liming, foliar spray

Introduction

A tomato grower can do almost everything right and still watch the crop struggle. The seedlings were healthy, the fertilizer was applied on time and the watering was regular. Yet the youngest leaves turn pale between the veins, the shoot tips look small and crinkled, and flowers drop before they set fruit. Many growers respond by adding more fertilizer, and that often makes no difference. In many such cases the soil does contain the nutrient the plant needs. What has gone wrong is that the plant cannot get at it. The factor most often responsible is soil pH, a single number that quietly decides how much of each micronutrient is dissolved and available at the root surface and how much stays locked in solid form. This article explains how soil pH influences the supply and uptake of micronutrients in tomato, what the symptoms of imbalance look like, and what a grower can do about it. It is written for farmers, gardeners, students and extension workers, and it avoids technical jargon wherever possible.

Small amounts, large effects

Plants need seven elements in very small quantities: iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo) and chlorine (Cl). Some lists add nickel. These are called micronutrients because the plant needs them in milligrams rather than kilograms. Small does not mean unimportant. Each has a job that no other element can do (Marschner, 2012).

- **Iron** is needed to make chlorophyll and takes part in electron transfer in photosynthesis and respiration.
- **Manganese** is part of the system that splits water during photosynthesis and activates many enzymes.
- **Zinc** supports enzyme function, protein synthesis and the production of growth hormones, so it strongly affects shoot elongation.
- **Copper** is involved in electron transport and in enzymes that protect cells from damage.

- **Boron** helps build cell walls and supports pollen germination and pollen tube growth, which is why it matters so much for fruit set.
- **Molybdenum** is a part of the enzymes that convert nitrate into forms the plant can use to make protein.

A shortage of any one of these slows the plant down, whatever the supply of nitrogen, phosphorus and potassium. This is the old principle of the limiting factor. A crop can only grow as well as its scarcest essential nutrient allows.

What soil pH is, and why it matters

Soil pH measures how acidic or alkaline the soil solution is on a scale that usually runs from about 4 to 9 in agricultural soils. A value of 7 is neutral. Lower values are acidic, higher values are alkaline. The scale is logarithmic, so a soil at pH 5 has ten times more free hydrogen ions than a soil at pH 6 and a hundred times more than one at pH 7. Soils become acidic through heavy rainfall that washes away basic elements such as calcium and magnesium, through the breakdown of organic matter, and through long use of ammonium-based fertilizers. Soils become alkaline in dry regions where rainfall is too low to wash out salts, and where calcium carbonate, the main component of lime, is present in the soil. Irrigation water rich in bicarbonate can push the pH up further over the years (Neina, 2019).

The reason pH matters for micronutrients comes down to three processes that occur in the soil.

1. **Dissolution and precipitation.** Metal micronutrients exist partly as solid minerals. At low pH these minerals dissolve and release ions into the soil water. At higher pH the same ions combine with hydroxide and carbonate and form solids again.
2. **Adsorption.** Metal ions stick to clay particles and organic matter. The higher the pH, the more strongly they are held.
3. **Charge on the nutrient itself.** Some micronutrients, such as molybdenum, exist as negatively charged ions and behave in the opposite way from the metals.

The plant takes up nutrients only from the soil solution, the thin film of water around soil particles. Whatever drives nutrients out of that solution lowers what the plant can absorb, however much the soil holds in total.

A nutrient-by-nutrient guide

The best-known rule is that the availability of iron, manganese, zinc and copper falls as pH rises. Classic soil chemistry work by Lindsay (1979) suggests that the amount of these metals dissolved in solution drops steeply with each unit rise in pH, roughly a hundredfold for zinc, manganese and copper, and a thousandfold for iron, when mineral solubility is controlling the supply. These are approximate textbook figures and real soils vary, but they show how sensitive the system is. Boron and molybdenum follow different patterns.

Micronutrient	Low pH (strongly acid)	Moderate pH (about 6 to 7)	High pH (alkaline or calcareous)
Iron	Plentiful, rarely deficient	Adequate	Often deficient
Manganese	May be excessive, risk of toxicity	Adequate	Often deficient
Zinc	Plentiful	Adequate	Often deficient
Copper	Plentiful, toxicity possible where copper sprays were used	Adequate	Less available, but deficiency is uncommon
Boron	Can be lost by leaching in light soils	Adequate	Held more tightly, deficiency possible
Molybdenum	Often deficient	Adequate	Plentiful

Iron: Iron is abundant in most soils, but nearly all of it is in forms the plant cannot use. In alkaline and calcareous soils the dissolved iron is extremely low, which leads to lime-induced chlorosis. The youngest leaves turn yellow while the veins stay green. Iron does not move easily from old leaves to new ones, so the new growth shows the problem first (Fageria et al., 2002).

Manganese: Manganese is the micronutrient with two faces. In alkaline soils it can become deficient and cause pale patches between veins. In very acid soils, often below about pH 5.5, and especially in waterlogged ground, manganese becomes much more soluble and the plant may absorb too much. Excess manganese produces brown spots on older leaves and slows growth (Fageria et al., 2002). Acid soils therefore carry a toxicity risk and alkaline soils a deficiency risk.

Zinc: Zinc deficiency is widely reported across the world and is among the most common micronutrient problems in Indian soils (Alloway, 2008). In tomato it shows as shortened internodes, small leaves bunched at the tip, a rosette look and pale areas between veins. High pH, calcareous soils, cold wet spells and very high phosphorus levels all make it worse. Heavy phosphate use can therefore trigger a zinc problem even where zinc in the soil is adequate.

Copper: Copper binds very tightly to organic matter, and its availability also declines as pH rises. True copper deficiency in tomato is less common than the other problems here. A different issue arises in orchards and vegetable fields that have received repeated copper-based fungicide sprays for many seasons. Copper can build up, and in acid soils it may become available at levels that damage root growth.

Boro: Boron behaves differently from the metals. It occurs in the soil mainly as boric acid, which is weakly held and can wash out of sandy, acid soils in heavy rain. At high pH boron is adsorbed more strongly, and so it becomes less available. The range between too little and too much is narrow, so over-application can burn leaf edges. Deficient tomato plants show thick, brittle, curled young leaves, poor flowering and fruit set, and cracked or deformed fruit (Havlin et al., 2014).

Molybdenum: Molybdenum is the odd one out. Its availability rises with pH. Acid soils often give low molybdenum supply, and liming is a common cure. A grower who limes acid soil for the first time may therefore improve molybdenum supply while lowering manganese and aluminium toxicity risks at the same time.

How the tomato root responds

Roots are not passive. Tomato belongs to the group of plants that use what researchers call Strategy I to obtain iron (Marschner & Romheld, 1994). When iron is short, the root pumps hydrogen ions into the surrounding soil to make it more acidic. It then releases an enzyme at the root surface that converts ferric iron into the ferrous form, and specialized transporters carry that iron into the root. This system works well in moderately acid and neutral soils. In a strongly calcareous soil, or when the irrigation water carries a lot of bicarbonate, the root cannot acidify its surroundings enough and the process fails. Plants in such conditions develop chlorosis even when the soil contains plenty of iron. The form of nitrogen also changes the picture. Ammonium-based fertilizers tend to acidify the zone around the roots because the plant releases hydrogen ions when taking up ammonium. Nitrate-based fertilizers tend to raise pH near the roots. Growers on alkaline soils often benefit from ammonium-type or acidifying fertilizers, while those on acid soils may do better with nitrate sources (Rengel, 2015). Soil microbes, organic acids from decomposing residues and compounds released by roots also change conditions in this small zone, so the pH next to the root can differ from the pH of a soil sample.

Reading the plant

Symptoms give early clues, but they must be read carefully. Several nutrient problems look similar, and diseases, drought and herbicide injury can mimic them. Position on the plant is a helpful guide. Nutrients that move poorly inside the plant, such as iron, zinc, boron and manganese, show deficiency first on young leaves. Nutrients that move easily show it on older leaves.

Where it shows	What you see	Possible cause
Youngest leaves	Yellow between veins, veins green	Iron deficiency, often at high pH

Where it shows	What you see	Possible cause
Youngest leaves	Small, bunched leaves, short gaps between leaves	Zinc deficiency
Growing tip and flowers	Thick, brittle, curled leaves; poor fruit set; cracked fruit	Boron deficiency
Mid to young leaves	Pale patches between veins, sometimes with small dead spots	Manganese deficiency
Older leaves	Brown flecks, slow growth in acid or waterlogged soil	Manganese excess
Whole plant on acid soil	Pale, cupped leaves, poor nitrogen use	Possible molybdenum shortage

The best confirmation is a soil test together with a leaf analysis. Visual diagnosis alone can be misleading.

What a grower can do

1. Test before treating

Start with a soil test that reports pH and the main micronutrients. For tomatoes, a pH of roughly 6.0 to 6.8 is widely recommended because this range keeps most nutrients reasonably available (Naika et al., 2005). Zinc, iron, manganese and copper are commonly measured by the DTPA extraction method, and boron by hot-water extraction. Take samples from the root zone and from several spots in the field, then mix them. Testing every few seasons helps because pH changes slowly with irrigation and fertilizer use.

2. Correct the pH where it is practical

- **Acid soils.** Agricultural lime or dolomite raises pH, reduces manganese and aluminium toxicity risks, and improves molybdenum availability. The amount depends on the starting pH, soil texture and organic matter, so follow the soil test recommendation, not a general rule. Overliming is a real hazard, because it can push the soil into the range where zinc, iron and boron become short.
- **Alkaline soils.** Lowering pH in a calcareous soil is slow and costly because of the large lime reserve. Elemental sulphur, acid-forming fertilizers and plenty of organic matter can help in the root zone. Treating irrigation water that is high in bicarbonate can also reduce long-term pH rise.

3. Use the right nutrient form

In alkaline soils, iron salts applied to the ground are quickly locked up. Chelated iron, especially the EDDHA type, remains stable in high pH conditions and is widely used for correcting chlorosis, whereas some other chelates break down as pH climbs above about 6.5 to 7. Zinc sulphate applied to the soil, or as a foliar spray, is the usual answer for zinc deficiency. Boron should be applied in small amounts and evenly, as an excess is harmful. Doses depend on soil test results and local recommendations.

4. Use foliar sprays for quick relief

When symptoms are already visible, a dilute foliar spray of the missing nutrient is the fastest fix because it bypasses the soil completely. It treats the crop, not the cause, so it should be paired with long-term soil management. Sprays at too high a concentration can scorch leaves, so follow label or extension advice and test on a small area first.

5. Build organic matter

Compost and well-rotted manure supply small amounts of micronutrients and release organic compounds that hold metals in forms plants can use. They also buffer pH changes and improve soil structure. In a calcareous soil, organic matter can partly offset the effect of high pH on iron and zinc.

6. Watch the water and the fertilizer balance

Check irrigation water for bicarbonate and salts, because these can slowly change the soil. Avoid applying very large amounts of phosphate without regard to zinc status. In protected cultivation and soilless systems, nutrient solution pH is usually kept in the mildly acid range,

commonly around 5.5 to 6.5, because that keeps iron, manganese and zinc available. Regular checking with a pH meter is essential.

Common mistakes

- Applying more NPK fertilizer to cure a problem that is really a pH or micronutrient issue.
- Liming without a soil test, which can swap an acidity problem for a deficiency problem.
- Applying iron or zinc as plain salts on alkaline soil and expecting a lasting response.
- Treating symptoms with foliar sprays year after year without correcting the cause.
- Confusing manganese toxicity in acid soil with a deficiency and adding more.

Conclusion

Soil pH works like a hidden dial that sets the supply of micronutrients to the tomato root. Turn it too far toward alkaline and iron, zinc, manganese and boron become hard to reach. Turn it too far toward acid and manganese and copper can reach harmful levels while molybdenum runs short. A moderate pH range of about 6 to 7 gives the best overall balance for most of these elements. The tomato plant is not helpless, since its roots can acidify the soil around them and mobilize iron, but this ability has limits, especially in calcareous soils and with bicarbonate-rich water. The practical lessons are clear. Test the soil before acting, correct pH sensibly, choose nutrient forms that suit the soil, build organic matter and use foliar sprays as a short-term remedy. A crop that cannot take up the nutrients that are already in the soil needs a corrected pH, not more fertilizer.

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