FERTILIZERS AND MINERAL NUTRITION: FOLK FICTION AND FUCHSIA PHYSIOLOGY

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Fertilizers are essentially manufactured sources of mineral nutrients which are deliberately applied to plants. The subject of fertilizer is often treated by amateur gardeners and professional horticulturists a very personal matter of conviction, like home medical remedies, family recipes, child rearing techniques, or even religious beliefs. The physiology of mineral nutrients in flowering plants is not really a matter of conviction; it is a relatively old science. It also has been translated into a popular science because of its practical applications, some distortions occur with simplification or mixing with non-scientific beliefs. Commercial vendors of fertilizers, and their marketing consultants, are quite capable of exploiting both the tendency towards dogma and orthodoxy among gardeners, and the popular appeal of simple explanations. Many have participated in a somewhat mythical account of what fertilizers are, what they do, and how they work—usually in a way that is most flattering to the type of fertilizer they sell. Many horticultural books and periodicals adopt the mixture of commercial promotion and popular science that surround fertilizer use. Scientific studies of plant nutrition in horticulture, agriculture, and botany are often left out of popular horticultural discussions of fertilizers, as though there were two entirely separate languages and cultures working parallel to each other, without significant exchange.

A very basic overview of the mineral nutrition of garden plants would set bounds on some claims occasionally exchanged in horticultural contests. Fuchsia books and articles are no different in their tendency to be somewhat dogmatic and precise in their prescriptions about the best types, times, and doses of fertilizer for fuchsia culture. The following discussion is a brief attempt to reconcile common fertilizer claims with basic physiology of plant mineral nutrition, without prejudice to any particular practical system or theory of fertilizer use.

Mineral vs. Organic nutrients: Mineral nutrition refers to the plant's uptake of dissolved substances in soil water. They are ultimately derived from the weathering and decay of rocks and minerals in the soil, or substances formed from gases in the atmosphere. Mineral nutrients contrast with organic nutrients like sugar, protein, and fat—"organic" in the strict scientific (chemical, biological) sense means "containing carbon," the basic component of coal and charcoal, and all living things as well. (This must not be confused with the popular meaning of "organic" as freedom from artificial pesticides and fertilizers.) Animals require consumption of both mineral and organic nutrients, and require their organic nutrients in bulk because they "burn" them metabolically, like fuel, and because they depend on them to build and maintain almost all of their structures. Plants, or at least green plants, generally do not require external sources of organic nutrients as long as they are exposed to light, which enables them to manufacture all the organic nutrients they require, and satisfy their own needs for energy. In fact, plant roots generally can't even absorb organic nutrients that animals consume, such as fats, oils, starches and proteins. Even the so-called "carnivorous" plants that trap and absorb insects are primarily scavenging their mineral nutrients, not "eating" them as animals eat food to obtain energy.

Macronutrients and micronutrients: Plants do have specific mineral nutrients requirements. Essential mineral nutrients are needed as chemical building-blocks of basic components of the plant's physiological machinery. Fertilizers are made of a select few mineral nutrients that green plants generally consume in the greatest abundance. There are called "macronutrients," which simply means "big nutrients." Nitrogen, potassium and phosphorus are the elements which comprise the macronutrients in typical commercial fertilizers. Sulfur, calcium, and magnesium area also considered macronutrients, but they are not usually required in the high quantities of the "big three." There are many other mineral nutrients that plants require in very small amount—"trace element," as they were once know, now called micronutrients. Micronutrients are normally found in sufficient quantities for healthy plant growth in most soils, and are replenished by natural weathering and decomposition of soil mineral particles. Macronutrients, in contrast, are rapidly depleted in the soil by plant growth. Fertilizers replace depleted macronutrients in the soil. With the exception of some seashore plants which may absorb significant amounts of certain nutrients from salt spray (especially potassium, calcium and magnesium); green plants obtain nearly all their mineral nutrient supply from the soil water.

Nutrients vs. Plant hormones and growth regulators: Mineral macronutrients are not like vitamins or hormones, although they may be important for the plant's production of vitamins and hormones. Hormones, or natural plant growth regulators, are organic substances which have specific controlling effects on plant growth and development, fine-tuning the timing, number, proportions and initiation of leaves, stems, roots, flowers and fruits. Plant hormones are present in very minuscule quantities when effective. Macronutrients, in contrast, are primarily bulk limiting factors of plant growth, and in most respects have relatively limited and indirect effects on plant development. Macronutrients typically provide very crude control of overall plant size, production, growth rate and the overall ratio of below-ground and above-ground parts, or the relative masses of vegetative and reproductive plant parts. They do not generally act as specific regulators of plant development, with some exceptions. They certainly do not have the organ-specific effects often advertised on retail fertilizer labels. When a fertilizer advertisement offers catechisms like "phosphorus for big blooms, potassium for strong roots," there is about as much physiological truth in them as aphorism like "fish is brain food," "jello for better-looking fingernails," "carrots for keen eyes" or other tenets of folk nutrition.

Nutrient deficiency and specific symptoms: Of course, like many folk beliefs, there is some underlying basis for some gardening dogma about the effects of fertilizers on plant growth and development. The basic principle they all have in common is that when there is a **deficiency** of a particular nutrient, specific symptoms regularly appear in specific parts of an organism. Deficiency of vitamin A may cause a particular eye disorder that could be prevented or treated by vitamin A in carrots, for example. However, eating extra helping of carrots (or taking vitamin A supplements) does not promote extra-sharp vision. Similarly, a young child starved of a protein may suffer from impaired intellectual development, and fish provides excellent quality protein in abundance; yet a fish-rich diet does not cause above-average intellect. The beneficial effects of nutrient addition tend to stop when the availability of the nutrients is sufficient; there is no additional benefit from excessive supply, and excess may even impose a risk of nutritional imbalance or other harmful effects.

So it is also true of fertilizer macronutrients and plant growth. For example, phosphorus deficiency often causes impoverished growth and a lack of energy for flowering. But loading a plant's root system with extra phosphorus-rich fertilizer definitely does not in itself stimulate flowering, except when flowering is limited by phosphorus deficiency. Potassium deficiency, for another example, is often marked by diminished resistance to disease, and weak root growth; yet loading on potassium-rich fertilizers will not induce exaggerated disease resistance or exceptionally robust roots, except when it reverses the specific symptoms of potassium deficiency. So the association between particular macronutrients and particular types of plant growth is based on correction of nutrient deficiency symptoms, not positive effects of nutrient addition on non-deficient plants.

Nitrogen and vegetative growth: Nitrogen is typically the limiting nutrient for plant growth, and nitrogen availability has the strongest influence on overall plant growth in most horticultural environments. Nitrogen in the atmosphere is a gas which is unavailable to plants. It has to be reduced to chemical forms such as nitrate or ammonium to be used by plants, and these "fixed" forms are usually scarce in soils. Even though plant physiologists have long known that factors other than nutrients are the most important influences on flowering, the influence of soil nitrogen has been recognized as a relatively important nutrient influence on vegetative and flowering growth even when plants are not deficient in nitrogen. Horticulturists have long observed that nitrogen deficiency can hasten and increase flowering in fruit trees, and hasten the onset of flowering in many annual plants. Abundant soil nitrogen can increase the relative proportions of vegetative (foliage and stem) growth to flowering, prolong the production of vegetative growth, increase the degree of shoot branching and increase the ratio of shoot growth to root growth. Nitrogen levels have a strong effect on vegetative shoot growth, but the primary controls of flowering are usually environmental factors, such as day/night length, light intensity and light quality (e.g., the ratio of red light wavelength to infra-red light wavelengths), temperature and maturation factors, such as size and age. These factors act as "cues" or triggers for hormonal regulation systems that more directly affect flower initiation. Nitrogen typically has only a moderating influence on flowering compared to the dominant controlling environmental influences on plant development.

The secondary effects of nitrogen fertilizers on flowering can be observed in fuchsia hybrids. Once a fuchsia is in a "flowering mode" (that is, the plant has been "induced" to flower by internal and environmental signals, and embryonic flower buds have been initiated at the shoot tip) addition of extra nitrogen simply encourages faster growth and more overall growth of both leaves and flowers. Adding nitrogen to a flowering induced fuchsia will not generally cause it to revert to vegetative growth. When a fuchsia is in a non-flowering mode, (that is, only leafy shoots are initiated at the growing shot tip) addition of extra nitrogen encourages rapid vegetative growth and may delay somewhat the onset of flower bud initiation. Similarly, withholding nitrogen fertilizer doesn't induce flowering that would not otherwise occur under the prevailing environmental conditions. The main effect of nitrogen is in how much leafy vegetative growth the plant produces before it gets the cue to flower.

The physiological roles of nutrients in plant growth: If it isn't true that "nitrogen is for leaves, phosphorus for flowers, and potassium for roots and health." As fertilizer labels often proclaim, then what do nutrients actually do? The answers, unfortunately, are not simple matters of plant anatomy and health! The real functional roles of nutrients occur at physiological levels, and have wide reaching effects. Asking what particular nutrients do generally in plants is like asking what wires, pipes, nails, wood and plaster do in homes. Their roles are usually systemic—even their specific functions affect the whole system, and don't operate in isolation. Most nutrients are important key components of enzymes or substances which activate or help enzymes work in many different physiological systems. Enzymes are proteins which perform specific biochemical functions in a very orderly way, often like specialized manufacturing machinery in an assembly line. Enzymes are needed for the plant to produce just about everything from sugar to wood to wax. Most micronutrients have very specific enzyme-aiding functions, and so do many macronutrients. This function exists at an invisible physiological level, not a visible anatomical level. Some examples are discussed here to illustrate this.

Some nutrients, like nitrogen, sulfur, and calcium are also bulk components of raw construction materials for building up the plant's mass. Most of the plant's mass is made of water, and most of its dry weight is made of carbohydrates like cellulose, pectin and lignin, which are components of wood and fiber. After wood and fiber, starches, sugars, protein, fats and oils comprise the majority of the remaining dry weight.

Nitrogen is used heavily in the plant's manufacturing of proteins, which are composed of amino acids that contain nitrogen. The plant needs nitrogen in bulk to maintain its protein. Leaves are relatively demanding of nitrogen for protein. This is why vegetative growth depends on the availability of nitrogen. Nitrogen-deficient plants look yellowish ("chlorotic" is the botanist's jargon) because the production of chlorophyll, the green pigment in plants, requires lots of nitrogen. In fact, about 70% of a green plant's nitrogen supply is often tied up in chloroplasts, the microscopic bodies that contain chlorophyll. Nitrogen is usually the limiting nutrient for plant productivity.

Phosphorus is essential for the plant's general energy storage and use for manufacturing or breaking down substances—in other words, the plant's metabolism. Some substances containing phosphorus work like rechargeable batteries, releasing energy for biochemical work when phosphorus is broken off, and storing up energy when phosphorus is rejoined. When phosphorus is deficient, the plant may not be able to keep up with the sugar like substances produced in photosynthesis, and so sugars may accumulate or the partially manufactured sugars may be converted to pigments such as anthocyanin, which causes reddish or purplish colors in leaves.

Potassium is used in large quantities in part to control the plant's water balance, just as athletes require potassium and other electrolytes to maintain water balance during heavy exercise. It also has many effects on metabolic systems.

Magnesium is the heart of the chlorophyll molecule, the substance which enables green plants to convert solar energy to chemical energy stored in carbohydrates—the process of photosynthesis. Magnesium's role in the plant pigment chlorophyll is very similar to iron's role in hemoglobin of animal blood.

Calcium is essential for the manufacture of pectin, a component of wood and fiber. Calcium is also important for the plant's ability to absorb or exclude particular substances. It is also used to stabilize or neutralize some potentially toxic substances. Iron in plants is needed for many enzyme systems to work, including ones used for basic metabolism, and particularly for certain pigments which are sensitive to light.

Chemical interactions of soil nutrients: Nutrients in soil interact, and some can reduce the availability of others by binding them up, or converting them to forms that don't dissolve well in water, or forms that plants cannot readily absorb. Excessive calcium in the soil, for example, can make iron, other metals, and phosphorus precipitate out of the soil water into insoluble forms. Calcium abundance is reflected in pH, or the balance of acidity and alkalinity in soils; high pH (alkaline) typically indicates abundant calcium, while low pH (acid) typically indicates scarce calcium. Even when iron and phosphorus are relatively abundant in the soil, excessive calcium and high pH may make them unavailable, and cause deficiency in the plant. Soil pH does not really have much influence on plant growth directly, except at extremes that are rarely encountered, such as peat bogs, alkali basins, and some soils on decomposed granite or limestone. The importance of pH to plant growth really depends on its indirect role on plant nutrient availability in the soil.

Plant uptake of nutrients: Plants aren't entirely selective about taking up nutrients out of the soil. Plants absorb minerals they don't even need, such as arsenic, mercury, and gold. They do take up some minerals more than others, however. Still, they are not frugal when provided extra-rich doses of fertilizer: they are known to perform "luxury consumption," absorbing more nutrients than they can use or store. Even if a nutrient is potentially toxic to plants at high concentrations, plants may still take up the nutrients until damage occurs. This is partly due to the relatively passive way plants transport mineral nutrients from the soil to the leaves. Once absorbed by the root, nutrients travel in the watery sap, which is pulled up the stems like a wick, with the "pull" provided by the transpiration of the leaf—evaporation of water through leaf pores. The more the plant transpires water, the more nutrients are "wicked" up. This is why fertilizer can burn plants: the salts that carry the fertilizer are pulled up the "transpirational stream" and accumulate in leaves until toxic effects or tissue water imbalance occurs.

Nutrient mobility and translocation: When some nutrients are in short supply, they can be scavenged and "recycled" within the plant, translocated from older and less functional structures to new structures of higher priority to the plant's growth and survival, such as new leaves or seeds. For example, when nitrogen is deficient, the plant will ordinarily withdraw mobile nutrients, including nitrogen, form older leaves that it shuts down. The orderly shut-down process—senescence—progresses from rapid yellowing of the leaf as its components are broken down and transported towards growing shoots tips, to the eventual death of the leaf. This is why nutrient deficiency usually causes leaf yellowing and drop. (So do many other kinds of physiological stress, so don'ts leap to conclusions if you observe this symptom!) Phosphorus and potassium are also mobile nutrients. In contrast, some nutrients are not mobile within the plant, and cannot be recycled internally. Examples are iron, calcium, and manganese. When these immobile nutrients are deficient, the symptoms tend to appear more conspicuously in the new tip growth. They also tend to show a pattern of discoloration which is worse a short distance away from leaf veins, and not quite as bad along the veins themselves.

Plant ecology and nutrition: The ecology of a plant is an important factor to consider in providing appropriate nutrition. Plants from unproductive, stressful habitats, such as bogs, rock outcrops or deserts, typically rely on large root systems which expand more or less uniformly to exploit scarce, diffuse sources of nutrients. In contrast, plants from patchy, disturbed habitats, such as streamside marshes or woodlands with tree-fall gaps, typically have adaptable root systems that proliferate in response to locally high availability of nutrients, such as spots where root competition has been reduced by disturbance, or where animals excrete or decompose. This enables them to keep up with plant competitors which could otherwise capture precious nutrients for themselves. Most fuchsia species are adapted to relatively patchy, disturbed, productive habitats, such as landslides, stream sides, tree-fall gaps, and drainages. They have potentially high growth rates, and increase growth rates rapidly in response to increased nutrients. Most fuchsia hybrids are consequently "heavy feeders," producing luxuriant growth at light fertilizer levels. This nutritional "greediness" of fuchsias is an inherited trait from their wild ancestors, for which it was ecologically advantageous. Of course, wild fuchsia species would almost never be indulged by the generous nutrient levels we provide our cultivated fuchsia hybrids.

Forms of nutrients and fertilizers: Most mineral nutrients are absorbed by the plant only when they are dissolved in water in their simplest forms: electrically charged particles, or ions. For example, nitrogen is ordinarily absorbed by plant roots either as the ammonium ion (NH4+) or the nitrate ion (NO3-); phosphorus as phosphate or complexes of phosphate, potassium as the potassium ion, sulfur as sulfate ion, etc. Even "organic" fertilizers have to be decomposed by soil bacteria to ionic forms of most nutrients in order to be absorbed and used by plants. One exception may be that some metals and perhaps phosphorus may be absorbed as natural organic "chelates," or organic substances which grab minerals like claws, and are then absorbed by the plant root. Otherwise, *both organic and synthetic fertilizers are ultimately reduced to the same basic ionic forms to be absorbed by plants.* The principal difference is that the rate and relative abundance of the nutrients provided by organic fertilizers are determined by the activity of soil bacteria, which depends on soil temperatures. In contrast, solutions of synthetic fertilizers can create a fluctuating "boom and bust" cycle of nutrient availability to the plant. The extent of the fluctuation depends on the dosage and frequency of fertilizer applications. Slow-release synthetic fertilizers work a bit more like organic fertilizers, in that they depend on soil temperature and the amount of rainfall or irrigation to control the rate of nutrient release to the soil. Soil temperatures that control the rate of nutrient release also control the activity of the roots themselves, so an approximate balance is established.

Another difference between organic and synthetic fertilizers is that the organic component of organic fertilizers may benefit bacteria and fungi that may aid the plant's resistance to diseases, and may assist in exploitation of soil nutrients. Most plants in nature absorb soil minerals at least partly through fungi (mycorrhizae) that pervade the soil and link to roots. Bacteria and fungi are typically an integral part of the functional plant root system. Plants that depend heavily on mycorrhizae for their nutrients may actually be absorbing a significant fraction of their nutrient supply in organic form from the fungus.

Practical implications: Some of the orthodoxy about fertilizers appears not to be based in sound plant physiology. Complex and very precise formulations of fertilizer "recipes," however meticulously planned, are probably more fussy than the average fuchsia is about absorbing nutrients. Only in hydroponics, where the natural buffering role of soils is entirely absent, is ultra-precise prescription of nutrient levels and pH important or even effective. Perhaps the most reliable advice is to avoid extremes of imbalanced fertilizers, such as pure urea used by itself (almost pure nitrogen, such as 46-0-0) or nitrogen-free formulations (such as 0-10-10), or other extreme proportions. Even with extreme fertilizer formulations, it is likely that excessive amounts of a nutrient may over-whelm the fuchsia's capacity to absorb them, and they will simple end up unused, wastefully and expensively washed out of the pot. Probably any moderately balanced fertilizer, applied frequently in moderately light doses in proportion with the pace of the fuchsia's seasonal growth, will never do harm, and will probably do as much good as the most arcane philosophy of fertilizing.

There are no hard rules governing fertilizer dosage or frequency that will do better than careful observation of the plant's growth rate, the appearance of the pant, the size of the root system, the weather, and the rate of watering or rainfall. It is likely that any rules about fertilizing will be less than useful unless they incorporate careful observation of plant performance. The recommended dosage on fertilizer labels is typically a generous "all purpose" level geared towards support of very rapid growth. It is seldom harmful to reduce the recommended concentration initially, and increase it gradually until the growth response is satisfactory. Once correctly estimated for your growing conditions and varieties, the adjusted fertilizer rate can be fine-tuned. Other factors to weight in making a fertilizer estimate is the watering rate (frequent watering washes soluble nutrients out of the soil), and the volume of soil in the growing container or the size of the root system (indicating the capacity of the plant to capture the nutrients you apply). The texture of the soil may also affect fertilizer rate: clay and fine organic matter tend to retain fertilizers well, forming a reservoir of nutrients in the soil, whereas sandy or coarse organic soils tend to leach nutrients out readily.

Another implication of basic plant nutritional physiology has to do with fertilizer cost. Bearing in mind that all fertilizers must be reduced to the same simple ionic form to be used by plants, consider the relative cost of very weak fertilizers, such as fish emulsion, and very strong synthetic fertilizers which can be diluted to the same weak dosage. If thrift is more important to you than fertilizer esthetics or philosophy, you may do as well with cheap synthetic fertilizer as with expensive organic formulations, as long as you use organic-rich soils. Also bear in mind that nitrogen content is typically the primary nutritional control of overall plant growth, and urea is the cheapest and most potent source. Also, it is much less potentially toxic than ammonium-based fertilizers.

Finally, it would be prudent to let nature be a guide, though not an excessively strict one, for nutrition of cultivated fuchsia. Natural soils of fuchsias don't have extreme fluctuations of extreme proportions of mineral nutrients, and they always maintain nutrient availability to the plant in all seasons. Nutrient availability is roughly proportional with soil temperature in nature. Fuchsias, which come from patchy, productive habitats are suited to exploit patchy or pulsed availalbity of richer nutrient suppliers. We can improve on natural mineral nutrition for fuchsia cultivation, but we can't re-invent basic fuchsia nutrition to match the whims of fertilizer philosophies.

A concluding Confession: Although I try to be respectful of others' horticultural opinions, and I have utmost respect for scientific principles behind horticultural practices, I am not any more unbiased than any other gardener about fertilizing! To dispel any pretense of detached objectivity, I admit I am a liberal user of synthetic fertilizers—liberal about both dosage and frequency when growing fuchsias. For pot-grown plants, I use soluble salt fertilizers at quarter to half recommended label strength about every third or fourth watering. For larger container plants, I used to use eighth strength solution nearly every watering except in dry weather, and I still use eighth strength solutions on freshly rooted plants. My selection of brands of soluble salt fertilze4rs for container plants is opportunistic: any high-concentration brand in roughly equal proportions, not to exceed a 1:2:1 ratio, such as 15-30-15, 18-18-18, 20-20-20, etc…whatever is on sale in bulk! If I am using a relatively soilless medium (lots of peat moss, perlite, sand, compost), I lean toward formulations that include micronutrients. For mature plants in the garden or large containers, I use a base of cheap granular fertilizer, such as 16-16-16 or 14-14-14, which I "spike" with either urea (almost pure nitrogen) or a low nitrogen/high phosphate and potassium formula, depending on how I want to push growth. After pruning in the growing season, I spike with urea.

During mid/late season flowering, I reduce the overall dose of fertilizer. I am not concerned about using proportionally high phosphorus formulations, or nitrogen-deficient for flowering fuchsias; once flowering is induced. The growth rate of leaves and flowers alike is still limited by nitrogen, not phosphorus, as long as phosphorus is supplied proportionally.

I apply the granular fertilizers sparingly, but quite frequently, to achieve the equivalent of slow release. For fuchsia plants that I have to keep in containers smaller than one gallon. I do use the much more expensive slow-release fertilizers, with an occasional boost of soluble salt fertilizer solution a few weeks before re-applying them. I use the slow-release fertilizers for small pots because all the granules are uniform in composition, whereas the cheap landscape fertilizers are mixtures of different granule composition that could become imbalanced in small pots.

Because I enjoy late-season fuchsia flowers, and never have any frost damage that a little routine pruning wouldn't fix, I don't stop fertilizing because the calendar says so—I ease up when the fuchsias tell me "enough" by ceasing flower production. I would be much less liberal in my fertilizer practices if I did not live in such a mild maritime climate, and did not have the benefit of good quality tap water.

My "recipes" are but one of many possible satisfactory approaches in local conditions; they are not general principles for fertilizing fuchsia in other conditions, or with other esthetics of fuchsia form. If I were to prescribe any general principle for fertilizing fuchsias, it would be experimentalism and pluralism: there are lots of different ways of achieving good results with fertilizers and fuchsia, and the best way of exploring them is to experiment.

From Bulletin July/August 1996