Myth of the perfect soil: Quick, general principles of fertile soils

I was once asked by a gardening enthusiast why the perfect soil could not be "manufactured"; that is, one concocted or formulated in such a way that is perfectly suitable for all plants – to which I replied: such type of soil cannot exist because different plants have different nutrient demand. In other words, different plants eat differently, so to speak. In the same way that there is no one type of animal feed suitable for all animals, a one-size-fits-all type of soil is simply impossible.

But if a perfect soil cannot be formulated, my gardening enthusiast friend continued, *then why not develop instead a specific soil perfectly suited for a certain plant?* For instance, one could formulate a soil perfect for mango trees, another for roses, yet another for chilies, and so on.

Yes, why not indeed. In fact, some stores are already selling bags of potting soil or mix formulated specifically for certain plants such as tomatoes, cactus, vegetables, and flowers. So, are these formulated plant growing media perfect?

I don't quite remember what my exact reply was, but I do remember not being quite satisfied with my answer. It was a question that cannot be answered in just short few sentences or in a hurry.

A fertile soil is essentially one that is able to meet the plant's nutrient and water demand, as well as physically able to support the plant. In other words, developing a fertile soil is not a case of simply packing the required plant nutrients and in their sufficient quantities into the soil. Instead, soil fertility is governed by a myriad of biological, chemical, and physical factors that interact with one another in a complex matter to affect the final outcome of soil fertility.

Soil fertility is determined by a myriad of factors that interact with one another. A perfectly fertile soil requires each of these factors to be simultaneously attained. (c) andreusK @ fotolia.com.

So, if we want to create a perfect soil, even if for one specific target plant, we need to simultaneously attain or meet all the criteria that ultimately create a fertile soil. But in practice, it is very difficult, if not impossible, to simultaneously achieve all these criteria at once.

Urban gardeners often ignore soil structure. A soil must be strong enough to securely support the plant, yet weak enough to allow us to work it: to till the soil to improve soil aeration, for instance. A soil must be strong enough to resist erosion particularly by water but yet sufficiently weak enough to allow water to penetrate and wet the soil and allow the plant roots to expand freely within the soil in search of more water, nutrients, and anchorage.

A very coarse-textured soil like sandy soils (like those at the beaches) are structurally too weak to support large or tall trees. Sandy soils also suffer from lack of inherent plant nutrients because these soils are unable to hold onto the nutrients. Sandy soils are also very porous. They receive water very easily (which is good), but they also lose it very easily too (which is bad). “Easy come, easy go,” is the unfortunate story of sandy soils when it comes to water and nutrients.

On the other extreme, very fine-textured soils like clayey soils (like those we can wet and mold into shape, like clay pottery) might be strong enough to physically support large trees, but they also tend to suffocate the plant roots. Clayey soils are very much less porous, so they tend to be easily inundated with water (*i.e.*, flooded); thus, more they are more prone to erosion and plants grown in such soils experience greater risk of plant root rot or decay. But clayey soils do have one advantage over sandy soils: clayey soils hold onto soil nutrients stronger than by sandy soils, so more nutrients would be available to the plants planted in clayey than sandy soils.

What we need then is a soil that is between these two extremities: one that is not too sandy and not too clayey. Generally, a good, fertile soil is one with equal parts of sand and clay (50:50 % by weight). But even better is one with more sand than clay, about 60:40 to no more than 70:30 % sand and clay proportion. Having such proportions provide the best of both worlds: the sand part in the soil provides good drainage and aeration, whereas the clay part provides strong nutrient retention, and at this sand and clay combination provides strong physical support and environment for a growing plant.

Potting mix, commonly sold at stores, are very popular because they are light, easy to work with, and formulated to be in rich in nutrients for plants in general. Potting mix rarely contain any soil, so while their absence makes potting mix very light, they cannot support large or tall plants. Potting mix are also very porous, so they risk drying out very quickly and can experience large losses in nutrients via the downward drainage of water (caused by over-watering, for instance). One way to remedy potting mix’s very rapid drainage and weak structural support for plants is to mix some fertile soil in equal parts with the potting mix.

But, unless we are dealing with soils in a few potted plants, it is difficult, costly, and impractical to alter a soil’s texture; that is, to change the soil’s proportion of sand and clay because this would involve bringing in vast quantities of soil from an external source (or buying way too many bags of potting mix) and mixing them with the soil in our garden.

Another important factor that strongly affects soil fertility is soil acidity, which is measured in the unit pH (recall that pH ranges between 1 to 14, where 1 is strongly acidic, 7 neutral, and 14 strongly alkaline). Malaysian soils are unfortunately very acidic in nature and often range between pH 2 to 4. In this acidic range, vital soil nutrients for plants like nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), and magnesium (Mg) are very much less available for plants (Fig. 1). That they are less available does not mean they are in low quantities or absent in the soil. Instead, these nutrients tend to be in chemical forms that cannot be directly used or taken up by the plants.

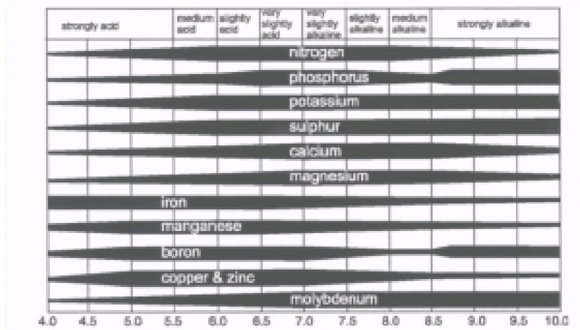

Fig. 1. Nutrient availability depends on soil pH (image from Kgopa, P., Moshia, M. & Shaker, P. (2014). Soil pH management across spatially variable soils, 4: 203-218.).

Even worse is low soil pH also encourages elements like aluminum (Al), iron (Fe), and manganese (Mn) to be more available to plants, and these elements are toxic to plants in excess amounts. In other words, Malaysian soils are inherently not fertile due to their low soil pH. In fact, if I were to grade our Malaysian soils, where grade A means very fertile soils and grade F means toxic soils, our Malaysian soils in general score a grade C – not the worst but not great either.

Ideally, soil pH should be between 5.5 to 6.5 (near neutral) because, at this range, most nutrients are in forms available for direct plant uptake. How then to raise the soil pH? One common method is to add lime (calcium hydroxide or calcium oxide) to the soil. Generally, for Malaysian soils, about 600 g of lime is needed for every 1 square meter of soil area (or roughly, 40 g per medium-sized pot).

As stated earlier, essential plant nutrients are N, P, K, Ca, and Mg, so one common question I am asked is what are the quantities of nutrients should fertile soils have? Their approximate quantities have been worked out, like shown in Table 1-5, but we must remember these approximates are exactly just that: general guidelines. This is because, as stated earlier, different plants have different nutrient requirements. Moreover, plant nutrient requirement would change as the plant ages or progresses into different life phases or stages, so the nutrient requirement of a seedling would be different than a plant that has matured or a plant that has started to the next life phase: flowering or fruiting.

Table 1. Nitrogen (N) levels in soil

N (% by weight)	Description
<0.05	Very low
0.05-0.15	Low
0.15-0.25	Medium
0.25-0.50	High
>0.50	Very high

Table 2. Phosphorous (P) levels in soil

P (mg P / kg soil)	Description
<5	Very low
5-10	Low
10-17	Moderate
17-25	High
>25	Very high

Table 3. Potassium (K) levels in soil

K (cmol / kg soil)	Description
<0.2	Low
>0.6	High

Table 4. Calcium (Ca) levels in soil

Ca (cmol / kg soil)	Description
<4	Low
>10	High

Table 5. Magnesium (Mg) levels in soil

Mg (cmol / kg soil)	Description
<0.5	Low
>4	High

To complicate things even further, one nutrient can affect the plant uptake of another, either positively (synergistic) or negatively (antagonistic) (Fig. 2). Having an excess of N (a very important nutrient that is often applied in large quantities), for instance, can suppress the uptake of K and the micronutrients boron (Bo), and copper (Cu). Too much of Ca would instead reduce the uptake of a myriad of nutrients, particularly Mg. This phenomenon of nutrient antagonism complicates fertilizer formulation and recommendation because it risks triggering nutrient uptake suppression when one nutrient is oversupplied or appear in excess amounts. In other words, it is not just the quantity of nutrients in the soil that is important, but their amounts relative to one another.

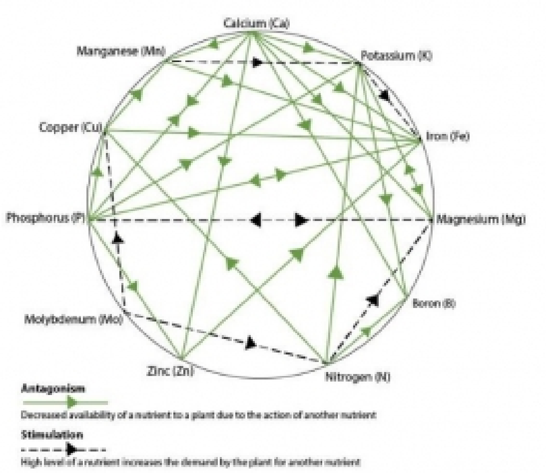

Fig. 2. Nutrient interactions mean the presence of one nutrient can affect the plant uptake of other nutrients in a synergistic or antagonistic manner (image from nutriag.com/article/mulderschart).

This phenomenon of nutrient antagonism is also why we should never over-fertilize our plants partly because it risks oversupplying one or more nutrients which in turn suppress the plant uptake of others. In my experience in helping urban gardeners, the problem of over-fertilization is very common, where gardeners tend to experiment with using various fertilizers too frequently or using excessive quantities. They are also sometimes too impatient when their plants appear not to respond to a certain type of fertilizer, so they then try another fertilizer, and another, and so on – risking oversupply of nutrients and nutrient toxicity.

One of the most effective ways to improve soil fertility is to add organic matter such as from composts, waste materials from our gardens (wood chips, lawn cuttings, or dried leaves and twigs), and certain kinds of food scraps. Organic matter is often regarded to be the lifeblood of soils – with good reasons. Its addition to soils improves a multitude of soil properties related to soil fertility. Addition of organic matter makes the soils less acidic (recall Malaysian soils are generally very acidic), provides plant nutrients in a gradual manner (like a slow release fertilizer) as the organic matter decomposes in the soils, increases soil aeration and drainage, increases the availability of both water and nutrients in the soil, and increases the soil's resistance to erosion.

Building up organic matter in our soils, however, require regular applications. This is analogous to going to a gym to build up or maintain our muscles. Start skipping some gym exercises and our muscles start to shrivel. In the same way, regular applications of organic matter are required to increase or maintain the level of soil organic matter. Applying organic matter in lesser quantities or irregularly and the organic matter level in the soil will gradually decline over time.

But the unfortunate truth is large portions of the organic matter are lost when applied to the soil. This is particularly true for Malaysian soils. Our tropical climate's large rainfall amounts and high air temperatures lead to rapid organic matter decomposition and large organic matter losses by erosion.

There is also a limit to which we can increase the organic matter amount in our soils, even with regular applications. Organic matter levels rise rather rapidly in the first 6 months after application, then gradually slow down and subsequently stagnate at some level, typically no more than about 5% of the total soil weight. Applying large quantities of organic matter may not necessarily lead to high soil organic matter levels and at times actually be counterproductive because applying too much organic matter in our soils can lead to anerobic (oxygen-starved) conditions which leads to poorer, not better plant growth.

How much organic matter can we safely apply then? Generally, no more than 8 kg per one square meter ground area (or roughly, no more than 600 g per medium-sized pot) should be applied at any one time. Re-application should only be done when the organic matter has nearly all decomposed (or no longer visible on the soil surface).

Lastly, watering. Lack of water has a more detrimental effect to plant growth than the lack of nutrients. Even a soil rich in nutrients is of no use to the plant if there is inadequate water. This is because nutrients in the soil or fertilizers must be in solute forms before they can be taken up by the plant roots. The ability of a soil to retain water is therefore crucial. All soils will eventually dry out over time, some faster than others, depending on soil texture, as discussed earlier. Soils lose water via evaporation and drainage, and we, therefore, need to supply enough water to replace the amount of water lost from the soil. Supplying too much water is equally as bad as supplying an insufficient amount of it.

Urban gardeners I have met tend to overwater their plants, but their plants tend not to experience any detrimental effects. This is probably because the soils (particularly, if the gardeners are using potting mix) have good drainage where the excess water is allowed to drain out; thus, avoiding flooding or soil saturation. The problem can arise when the soils have poor drainage or simply too much water is applied in a short time. Soils that are saturated all the time risk causing plant root rot, among others.

Like for nutrients, different plants have unique water requirements. But as a general guideline, plants require about 5 L of water per one square meter ground area (or roughly, 350 mL of water per medium-sized pot) per day. For very hot, dry days, the amount of water to apply can be increased by two times.

The perfect soil may not exist or can be developed. We often have to make do with the soil in our gardens. But the good news is that even problematic soils can be significantly improved through proper management. Applying organic matter to our soils is one very effective way to increase soil fertility, but even then watering and fertilizer applications still need to properly managed. Most of all, it requires our patience. Improving soil fertility takes time. Do not be impatient, and avoid the common mistake of experimenting with too many fertilizers too quickly when results are not forthcoming.