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How nutrition and health interact in coffee farming

Guilherme Amaral de Souza
Market Development Cons. in the Southern and Southwestern Market | MG

Lucas de Ávila Silva
Market Development Cons. in Alto Paranaiba / MG

National coffee production has gone through several updates, from management methods to post-harvest processes. These facts are due to the incessant search for cost reduction in farming, always focusing on improving productivity and quality of the final product.

Expenses with processes related to harvesting are the most expensive in the coffee production chain. Next, fertilization and pest and disease control operations appear, representing 23 and 14% of the effective operating cost per bag, respectively (data from 227 properties that are part of the Educampo project in the Brazilian savannah, Forests and Southern Minas Gerais regions).

Thus, in order to obtain success, coffee farmers must pay attention not only to soil management (correction and fertilization), but also to the chemical control of pests and diseases. It is worth mentioning that the prominent coffee diseases are: rust, cercosporiosis, Phoma leaf spot and brown eye spots. These diseases are responsible for significant productivity losses, intense defoliation and stunting of the affected plants (Patricia & Oliveira, 2013; Barbosa Junior et al., 2019). In addition, they can influence the quality of grains and beverages (Pozza et al., 2010).

How do diseases occur in coffee plants anyway?

Not only in the coffee tree, but in all plants, for a certain disease to occur, three factors are necessary that make up the "Disease Triangle", where the environment must be favorable to the presence and survival of the pathogen (causing agent) and the host (plant) must be susceptible for infection by the pathogen to occur.

Glossary

Acclimatization: Increase in the plant's tolerance to stress as a result of previous exposure to stress. May involve gene expression.

Adaptation: Inherited level of resistance acquired through a selection process over many generations. Compare with acclimatization.

Abiotic stress: Environmental condition that requires the full genetic potential related to light, water, gases, content and availability of nutrients in the soil, temperature and toxins (heavy metals and salinity);

Biotic stress: Environmental condition that prevents the full genetic potential related to pests and diseases

Systemic acquired resistance: Increased plant resistance to a range of pathogens after infection by one pathogen in one location.

(Taiz et al., 2017)

Disease control does not mean eradicating them from the area, but managing them so that they remain below the level of economic damage (Patricio & Oliveira, 2013).

The resistance of plants against disease is a genetically controlled mechanism, however, it can be influenced by some factors, among them, the mineral nutrition of plants. Fertilizers can change the characteristics of the soil, plant and phytopathological organism, increasing or reducing the severity of infections (Garcia Junior, 2002; Belan et al., 2015; Patricio & Oliveira, 2013). Thus, well-nourished plants tend to be more vigorous and resistant to infections.

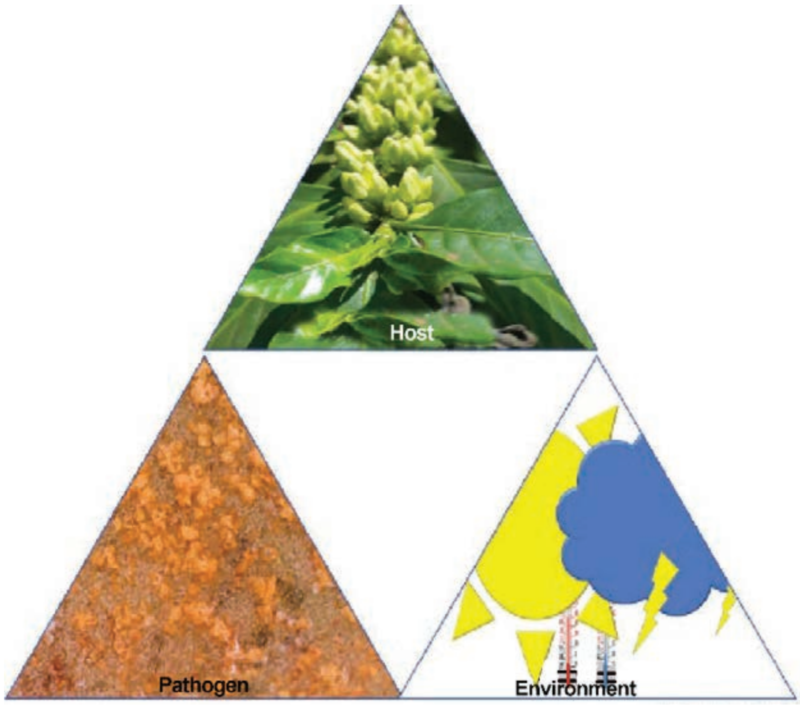

Figure 1. Disease triangle. Adaptation: Guilherme Souza (2019).

What strategies do plants have against pathogen attacks?

Throughout the evolutionary process, plants managed to develop some strategies against pest and disease attacks. Defense mechanisms are diverse and vary by species and environment.

The main strategies developed are:

a) Physical barriers, for example: waxes, cutin, suberin and lignin that form barriers that make it difficult for pathogens to penetrate;

b) Secondary metabolites, for example: terpenes, phenols, phytoalexins and nitrogen compounds that are chemical compounds produced by plants that can act as resistance mechanisms.

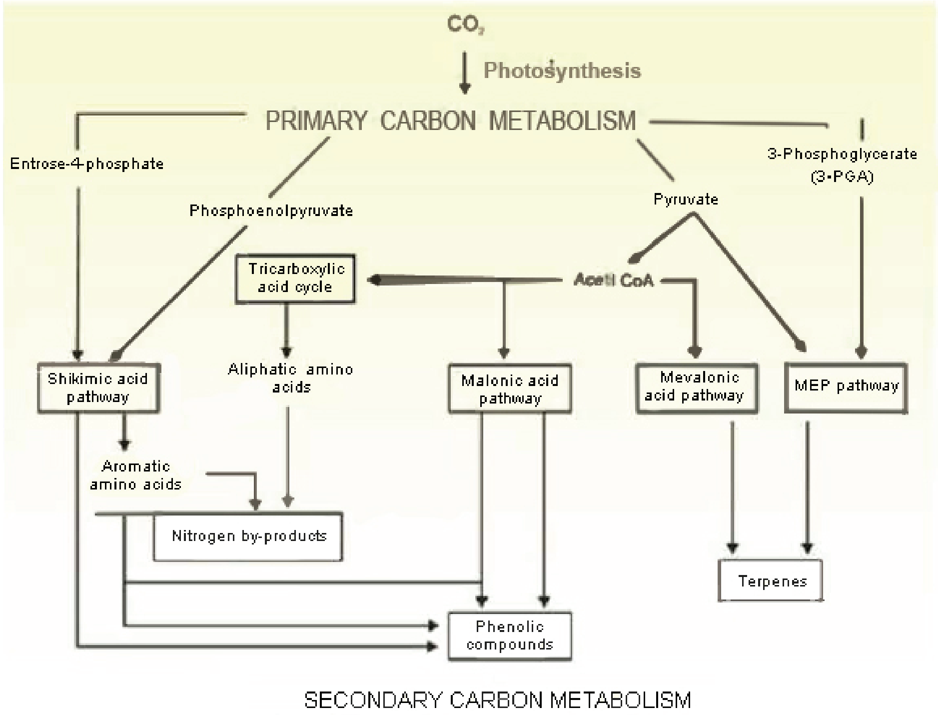

Figure 2. Simplified scheme of secondary metabolite synthesis pathways and their interrelationships with primary metabolism (Yamada, 2004).

In general, the knowledge of the metabolic pathways that compose secondary metabolism is fundamental for understanding agronomic practices that can help manage pests and diseases. It is worth noting that some compounds produced are considered toxic even to the plants that produce them (Yamada, 2004). Therefore, to avoid damage to plants, these metabolites are stored in isolated cellular compartments such as vacuoles, resin canals, trichomes, among others. After the pathogens attack, these toxins begin to act and become active only at the damaged site, i.e., minimally affecting the primary metabolism of the attacked plants (Taiz et al., 2017).

How does mineral nutrition relate to plant health?

Each nutrient has a role within the metabolism and physiology of plants (Table 1), therefore, in the recommendations, balance between the elements should always be prioritized. On the other hand, there is a fine line between deficiency and toxicity that determines adequate nutritional balance.

In general, well-nourished plants tend to be more vigorous, productive and stress-tolerant than plants with a nutritional imbalance.

After the application of fertilizers, whether soil or foliar, the elements are absorbed. Therefore, nutrients are directed to the composition of primary metabolism, i.e., to the growth and development of plants. In this step, the formation of amino acids, proteins, cell membranes, among others occurs (Huber et al., 2012; Pozza & Pozza, 2012).

Part of the nutrients act on secondary metabolism (shikimic acid and malonic acid pathway), responsible for plant defense (Taiz et al., 2017). It is worth remembering that these defense mechanisms are effective against pathogens and also against herbivores (Amtmann et al., 2008; Huber et al., 2012; Taiz et al., 2017).

Table 1. Functions of nutrients and ways plants absorb them.

Nutrient	Main form of absorption	Main Functions
Nitrogen (N)	NO_3^- / NH_4^+	Constitution of amino acids; proteins; nucleic acids.
Phosphorus (P)	$H_2PO_4^-$ / HPO_4^-	Nucleic acid composition; ATP formation; phospholipids.
Potassium (K)	K^+	Enzyme activation; ionic and water balance; stomatal control.
Calcium (Ca)	Ca^{2+}	Membrane constitution; cell wall; enzyme signaler.
Magnesium (Mg)	Mg^{2+}	Chlorophyll constitution; enzyme activator; photosynthesis; respiration; DNA and RNA synthesis; ribosome stability.
Sulphur (S)	SO_4^{2-}	Protein constitution; amino acids; coenzymes.
Boron (B)	H_3BO_3	Membrane stability; cell elongation; sugar transport; nucleic acid synthesis; Olen grain germination and pollen tube growth.
Chlorine (Cl)	Cl^-	Evolution of H2O in FSII; ionic balance; ATPase of membranes.

Copper (Cu)	Cu^{2+}	Enzymes of the antioxidant system; photosynthesis; respiration; Olen grain sterility.
Iron (Fe)	Fe^{2+}	Enzyme activation; photosynthesis; respiration; chlorophyll synthesis; nitrate reductase.
Nickel (Ni)	Ni^{2+}	Enzyme activator; urease; hydrogenase.
Manganese (Mn)	Mn^{2+}	Photosynthesis; phosphorylative enzymes and of the antioxidant system; RNA synthesis.
Molybdenum (Mo)	MoO_4^{2-}	Biological nitrogen fixation; nitrate reductase; nitrogenase; enzymes antioxidant system (heat stress).
Zinc (Zn)	Zn^{2+}	Auxin synthesis; protein synthesis; activation of enzymes of the antioxidant system; chlorophyll.

Adapted from Marschner (1995); Malavolta (2006); Taiz et al. (2017).

As it is a relatively new topic, much has progressed in recent years, reflecting significantly in the increase of work in coffee farming (Pozza et al. 2001; Garcia Junior, 2002; Carvalho et al., 2008; Lima, 2009; Catarino et al., 2016; Chaves et al., 2018; Silva Junior et al., 2018, Perez et al., 2019).

In Table 2, it is possible to verify how some coffee diseases behave towards nutrients. However, in this bulletin, we will focus on the plant's acclimatization mechanisms to withstand/tolerate the attack of pathogens.

Did you know?

Glyphosate kills some plants by blocking a step within the shikimic acid metabolic pathway. The shikimic acid pathway is responsible for the formation of amino acids phenylalanine, tyrosine and tryptophan.

(Yamada, 2004)

Table 2. Behavior of the main diseases of coffee due to nutrients.

Disease	Disease Incidence	Nutrients	Sources
Rust	Increase	↑ N; ↑ K; ↓ Ca; ↑ Zn	Pozza et al. (2001); Garcia Júnior, (2002); Santos et al. (2008); Carvalho et al. (2008); Lima (2009); Pérez et al. (2017); Chaves et al. (2018); Vasco et al. (2018); Pérez et al. (2019)
	Decrease	↓ K; ↓ B	
Cercosporiosis	Increase	↑ P ; ↓ Ca; ↑ Zn	
	Decrease	↑ N; ↑ P ; ↑ K	
Phoma leaf spot	Increase	↑ N ; ↓ Ca; ↓ S; ↓ B; ↓ K; ↑ Zn	
	Decrease	↑ K	
Spots caused by Pseudomonas syringae pv.	Increase	↑ N	
	Decrease	↑ K	

In coffee, the application of high doses of N and K is common and nutritional imbalance often occurs. When applying high doses of N, the metabolic flux of the Krebs cycle is greater, in order to direct the assimilation of N into primary compounds/amino acids. Thus, secondary metabolism is compromised and there is a decrease in activity in the shikimic acid pathway, i.e., a reduction in the formation of phenols, lignin, tannins, among others (Yamada, 2004; Taiz et al., 2017). Thus, plants are more susceptible to attacks by pests and diseases, as the formation of defense compounds is deficient.

The relationships between nutritional P and diseases are antagonistic, while some studies show the reduction of diseases with an increase in P levels, in others this does not happen. In an extensive review on the effects of nutrition and the development of diseases, Walters and Bingham (2007) suggest that these negative effects are due to the sequestration of Ca in the apoplast by P, altering the activity of enzymes such as polygalacturonase. Thus, the alteration of cell membranes that are more susceptible to fungal attack occurs. On the other hand, when P-phosphite is used, there is an intense correlation with the increase in defense compounds, improving the health of coffee plants (Nojosa et al., 2009; Silva Júnior et al., 2018).

Among the elements, K is the one that presents the most consistent results when it comes to reducing the incidence of pests and diseases. Belan et al. (2015) using X-ray microanalysis techniques to analyze the distribution of nutrients in the tissue of coffee leaves infected with spots caused by Pseudomonas syringae pv., Phoma leaf spots, Cercosporiosis and rust found that the K concentration gradient was greater around asymptomatic tissues of the lesions and decreased within the lesions. On the other hand, according to the authors, the levels of

Ca were higher at the edges of lesions, i.e., in necrotic tissues, decreasing in asymptomatic tissues.

Both K and Ca can accumulate in the conducting vessels (xylem and phloem) and in the cortex of plants and inhibit the growth and penetration of pathogens through a physio-chemical barrier, thus maintaining the integrity of the membranes (Amtmann et al., 2008; Sugimoto et al., 2010).

Ca can also inhibit the activity of the polygalacturonase enzyme, which is responsible for dissolving the middle lamella in case of attacks by certain fungi and bacteria (Hawkesford et al., 2012).

Mg is directly linked to the synthesis of phenolic compounds and lignin (Hawkesford et al., 2012). In addition, it activates enzymes such as peroxidase (PDX) that fight reactive oxygen species (ROS) produced as a result of the infection process (Moreira et al., 2013).

It is widely known that S has agricultural pesticide characteristics, so much so that it was used as a fungicide for several years. In the secondary metabolism pathways, mainly in the elemental form (SO), S can increase the production of phytoalexins, which is a very efficient organic compound for plant pathogen tolerance (Walters & Bingham, 2007; Belan et al., 2015). This is because there is a change in the metabolism of glucosinolate production (Walters & Bingham, 2007). Another point that

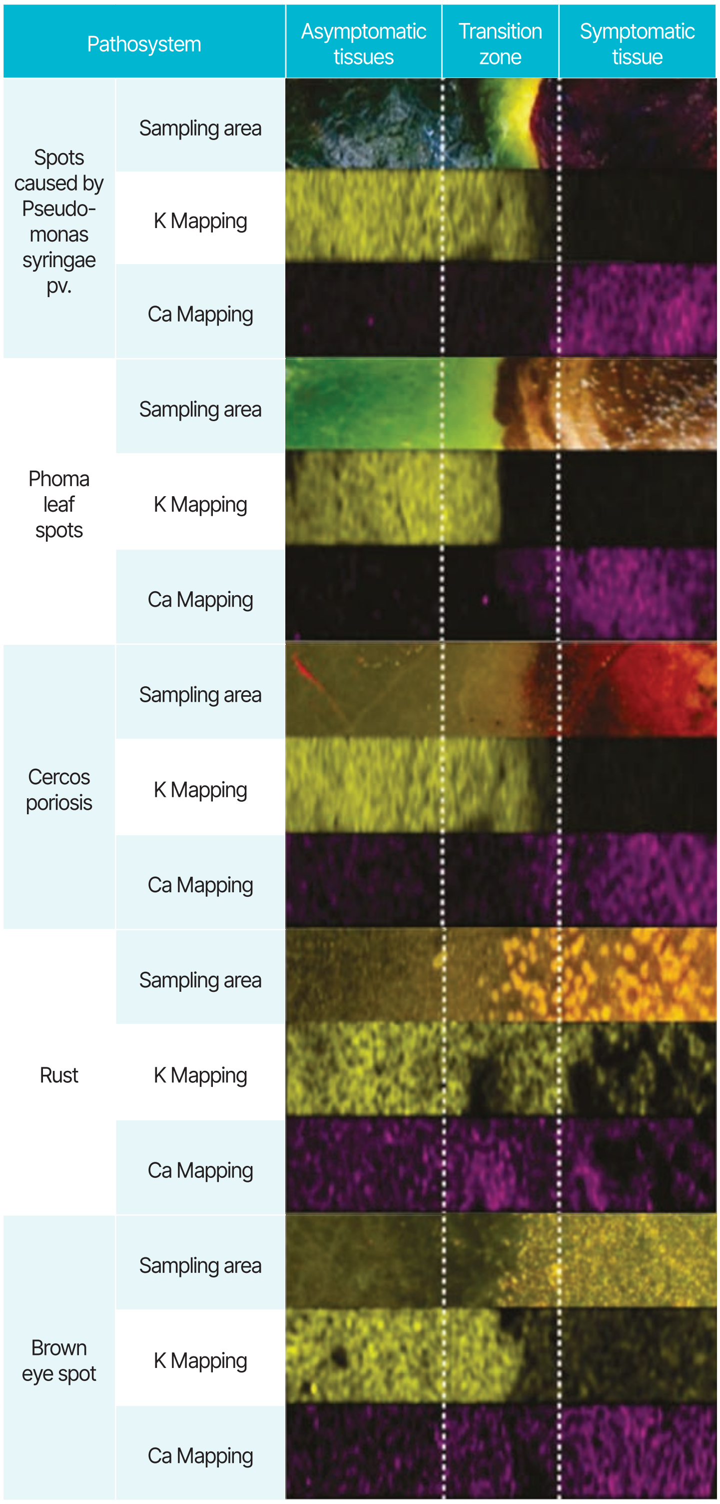

Figure 3. X-ray microanalyses for K and Ca mapping in coffee plant tissues with lesions of foliar diseases: Pseudomonas syringae pv., Phoma leaf spot, cercosporiosis, rust and brown eye spot (translated and adapted from Belan et al., 2015b).

is worth mentioning that necrotrophic fungi, such as rust, need higher levels of S to reproduce (Walters & Bingham, 2007).

Micronutrients act mainly as catalysts in biochemical reactions, enzyme activation, synthesis of compounds such as phenols, phytoalexins, lignin, among others (Broadley et al., 2012; Taiz et al., 2017).

B, along with Ca, is responsible for maintaining the integrity of the plasma membrane (Vasco et al., 2018). On the other hand, within the resistance of plants against pathogen attacks, it plays a fundamental role in phenolic compound pathways (Broadley et al., 2012).

Among the micronutrients, Cu is widely used, thanks to its fungistatic and bacteriostatic effects. In the plant, Cu acts in the formation of lignin, composition of melanin, phytoalexins, quinones and other phenolic compounds that have an effect on the inhibition and development of pathogens. Furthermore, Cu comprises enzymes of the antioxidant system, such as superoxide dismutase (SOD), which is responsible for eliminating the peroxide ions formed after cells are extruded by microorganisms (Broadley et al., 2012; Taiz et al., 2017).

Mn is one of the main nutrients that provide plants with resistance against pathogens. This is because it is directly linked to the processes of lignin and cell wall formation, thus making it difficult for microorganisms to penetrate. At the same time, it acts on enzymes of the antioxidant system that fight free radicals and mitigate damage caused by pathogens (Yamada, 2004; Broadley et al., 2012; Taiz et al., 2017).

Zn, as well as Cu and Mn, plays a major role in the enzymes of the antioxidant system, in addition, it can bind to sulfur and phosphate compounds, ensuring the integrity of the membranes (Yamada, 2004). Thus, it reduces cellular juice leaks and limits K leaching (Neves et al., 2011). In plant defense metabolism, Zn also acts in the synthesis of phytoalexins (Yamada, 2004).

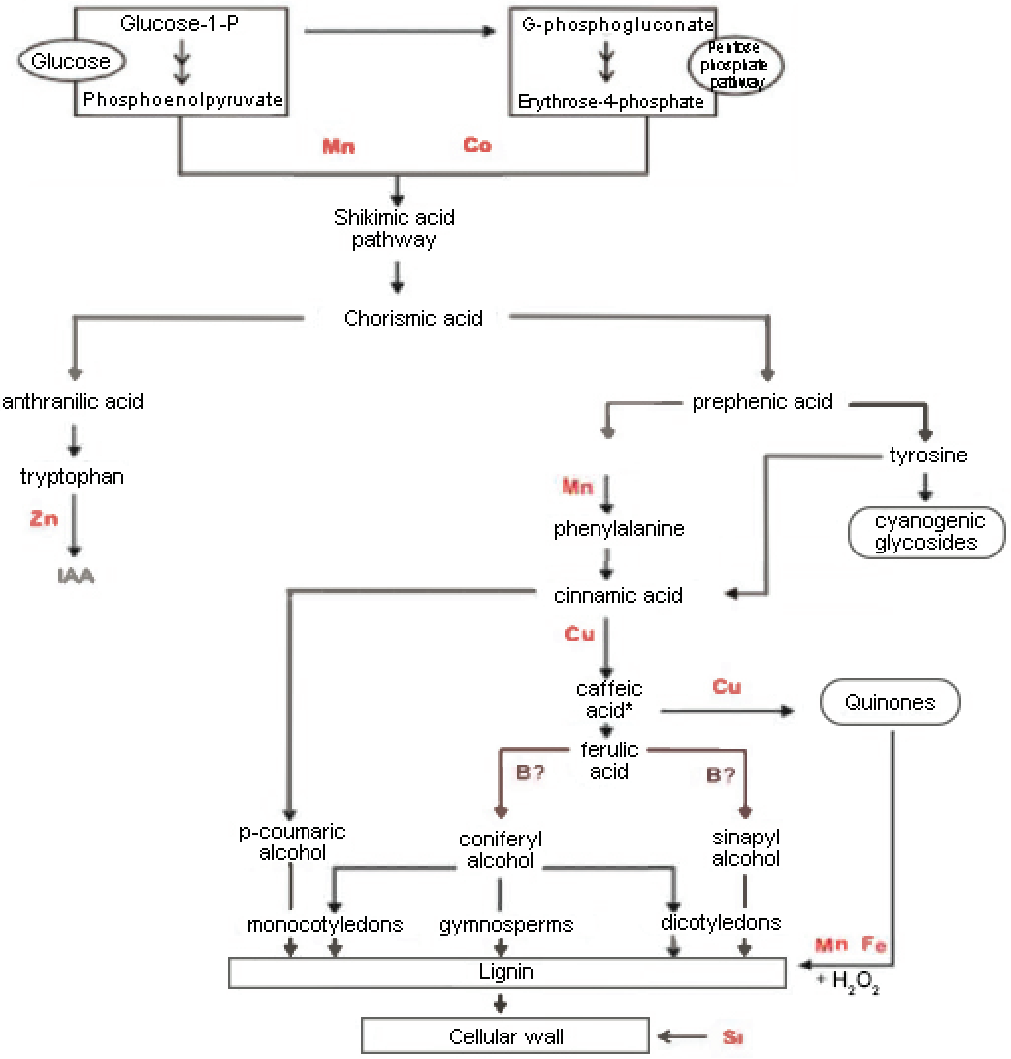

Figure 4. Role of micronutrients in the shikimic acid pathway and synthesis of organic compounds related to plant defense (Yamada, 2004).

In view of all the facts presented, it appears that the mechanism of interaction between nutrition and diseases is quite complex and demands a lot from the environment, from management factors to the correct application of agricultural pesticides. ICL presents nutrition solutions that help in the nutritional status and balance of your crop. Finally, the popular phrase holds true: *"it is better to invest in the supermarket than in the pharmacy:*

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Meet our team

Guilherme Amaral de Souza

An agronomist with a degree from Universidade Federal de Lavras (UFLA) and a PhD in Soils and Plant Nutrition from Universidade Federal de Lavras and a sandwich course from Cornell University / USDA — USA.

He works as a market development consultant (CDM) in the South and Southwest of Minas Gerais

For questions or suggestions:
guilherme.souza@icl-group.com.br

Lucas de Ávila Silva

An agronomist with a degree from Universidade Federal de Vicosa (UFV), with a master's degree in Soils and Plant Nutrition and a PhD in Plant Physiology from the same institution, with a sandwich course from the National University of Ireland - Galway.

He works as a market development consultant (CDM) in Alto Paranaíba/MG.

For questions or suggestions:
lucas.silva@icl-group.com.br

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