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Environmental factors, phenology and nutrition: a technical review on the impacts in soybean culture

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Abstract: Considered one of the oldest leguminous used by humanity, soybean (*Glycine max* (L.) Merrill) originate in China and have numerous applications in animal and human food, due to their high protein and oil content, satisfactory. The soybean complex moves the economy of several countries with employment and income generation. The variation of environmental factors, such as temperature, photoperiod and humidity, influence the growth and consequently the grain production of the crop, so the study of phenology addressing the relationships between climatic factors, seasonal changes and the development cycle is of sum nutrients at the right dose and phase, for proper nutrition and high crop yield.

Keywords: *Glycine max* (L.), phenology, environmental factors, plant nutrition.

Contextualization and analysis

Soybean (*Glycine max* (L.) Merrill) is Brazil's main agricultural commodity and one of the oldest leguminous used by humanity. Its center of origin is in China and currently occupies a prominent place in the world food industry, with a supply of oil for human consumption and soybean meal rich in protein used in animal feed.

Increased investment, especially in technology and rigorous crop management, soybean cultivation in Brazil has been gaining worldwide prominence (Mapa, 2015). The growing use of various technologies, together with the correct crop nutrition are factors responsible for the yield increase (Gonçalves Júnior et al., 2010).

According to Gonçalves et al. (2019), an expression of soybean production potential depends on nutritional supplementation, cultivation techniques, genetic materials selection and environmental factors (sunlight, temperature and water).

Therefore, to know the crop phenology, allow the producer to make a better observation of its demands in vegetative and reproductive periods, either by environmental factors, such as photoperiod, light, and water or nutritional practices (macro and micronutrients).

This study aimed to relate, in a practical way, what are the limiting factors for the grain yield

soybean and show the best nutritional management practices, so that a plant expresses its maximum potential.

Environmental factors that influence soybean crop

The variation of environmental factors such as temperature, photoperiod, and humidity, influence the growth and consequently the grain yield in soybean crop.

Photoperiod and light

Considered a short-day plant, soybean is one of the most photoperiod-sensitive cultivated species, with direct implication in floral induction. According to Hicks (1978), the photoperiod and absorbed solar radiation has a great influence on the morphology and biomass accumulation in soybean, may cause a reduction in the period between seedling emergence and the beginning of flowering. When cultivated in low latitude areas, where the photoperiod is relatively short, or with delayed sowing, there is early flowering and formation of low plants, with reduction of leaf area and lower grain yield (Farias, 2011).

Given this fact, plants with long juvenile period were introduced by soybean breeding programs, less sensitive to photoperiod, expanding the adaptation sites and allowing greater stability of

the cultivars in space and time. Such characteristic is responsible for the adaptation of soybean to low latitude regions.

In these cultivars, even under inductive conditions, until a minimum time, strongly determined by genotype and temperature elapses, the cultivar does not flower, remaining in vegetative period more time than conventional cultivars when exposed to short days, but may occur flowering earlier than some conventional cultivars when subjected to long days.

Figure 1 shows the times when a long-day (LDP) and short-day (LDP) plant, both with a critical photoperiod of 13h, will be induced to flower at different latitudes. With this photoperiodic requirement, LDP blooms later at lower latitudes, since the required photoperiod (13h or more) occurs later than the higher latitude locations. For PDC species, there is a higher precocity when cultivated near the tropics, since the necessary photoperiodic condition (13h or less) occurs earlier than at higher latitudes.

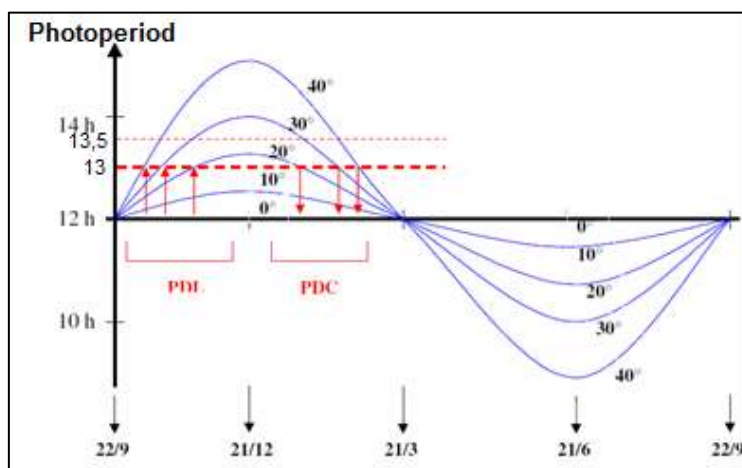


Figure 1. Photoperiod variation at different latitudes and representation of the floral induction time of short day plants (PDC) and long day plants (PDL), both with a critical photoperiod of 13h. Source: Bergamaschi, 2009

Wahua & Miller (1978) found that soybean crop is very sensitive to shading, with up to 100% reduction in yield when the crop received about 93% of shading.

The crop is not efficient in harnessing light, because the carbon fixation is by C3 cycle way, and has a high compensation point, i.e., it needs relatively high amounts of light to produce photoassimilates. With light below the compensation point, the plant breathes more carbon than fix, losing the dry matter that had already produced (Rosolem, 2006).

Water

The soybean water demand is in the range of 450 to 700 mm throughout the cycle, being the emergence and the filling of the grains, considered the most critical. To perform well, in addition to adequate water volume, the crop needs good rainfall distribution throughout the production cycle (Pardo et al., 2015), given its low water use efficiency (Yang et al., 2003).

When subjected to severe water deficit, especially during the grain filling phase, soybeans show decreased in oil and oleic acid content and increased stearic acid content (Bellaloui et al., 2013), which prejudice the seeds quality.

Therefore, considering the current scenario, where most areas do not have irrigation, the risks in the production process are high, because during the harvest and off-season periods the prolonged periods of drought have been increasingly frequent (Gonçalves, 2017).

Soybean phenology and influence of environmental factors

The phenology study in soybean crop is important, considering the approach between climatic factors, seasonal changes and the cycle of plant development (Ventura et al., 2009).

Soybean development can be divided into two periods: vegetative (designated by the letter V), which goes from sowing to flowering and reproductive (R), which includes the period between flowering and physiological maturation (Mundstock, 2005).

The letters corresponding to each stage are followed by numerical indices, which identify specific stages of development, except in the VE (emergence) and VC (cotyledon) stages. Therefore, the node is the stem part used to determination of vegetative stages, being the first valid node, the one of the leaves with one leaflet.

Vegetative stages

After soybean sowing, to start the germination process, the seed begins to absorb water, in the order of up to 50% of its weight. Depending on the environmental conditions, between five and ten days after sowing, the seedling emerges, and from the moment, the hypocotyl is emitted above the ground line, the plant is in the LV stage. In this phase, all nutrient demands by the seedling are obtained through cotyledons (Mundstock, 2005).

Once the two cotyledons are fully open and the first pair of true leaves (single-leafed) have their edges apart (untouched), the plant enters in the VC stage. In these two initial stages, the highest demands of the crop are for water and adequate temperature, so that the germination process occurs. This is influenced by temperature, which when low, affects the germination percentage and delays the initial development of the crop, being the temperature of 32°C, considered optimal (Castro et al., 1983).

The plant is in V1 stage when the single-leafed leaves (opposite at the first leaf node) are fully developed, that is, when the leaflet edges no longer touch. In this phase, the development of roots

According to Mundstock & Thomas (2005), water deficit in the vegetative phase can affect crop yield traits, mainly reducing grain yield, the number of pods per plant and the number of grains per plant.

begins with the consequent appearance of the first nodules of Biological Nitrogen Fixation (BNF) and the beginning of the photo assimilates production.

The plant reaches stage V2 when the first trifoliate leaf is fully developed. In this phase, the BNF itself begins.

Plant needs at these early stages of development two to five mm of water per day, temperature between 20 °C to 30 °C and nutrients to formation of vegetative structures (Embrapa, 2007).

The following vegetative stages are characterized by the emission of a new leaf where the leaflet edges do not touch (Neumaier, 2005). The changes between phases occur from three to five days, depending on the edaphoclimatic conditions (Figure 2).

In the phases between V3 to VN (nth developed leaf), the plant demand is approximately 5 mm of water per day and nutrients for the development of vegetative structures. The occurrence of water deficit in this period reduces the emission of new branches and consequently, there is a reduction in the number of nodes and plant size. In addition, low-temperature stresses lengthen the crop cycle.

During the vegetative phase, if the plant is exposed to low temperatures, especially at night, symptoms of false virus can occur. Grigolli et al. (2017) found that soybean plants subjected to cold heat stress present false virus injuries.



Figure 2. Vegetative stages of soybean crop. Source: Adapted from Stoller, 2017.

Reproductive stages

The reproductive stages comprise four distinct phases of plant development, namely: R1 and R2, corresponding to flowering; R3 and R4, the development of the pod; R5 and R6, grain development and, R7, R8 and R9; plant maturation (Table 1).

Phases R1 and R2 are very sensitive to stresses by temperature and water, and if there is a lack of water or high temperatures during flowering, there will be a low flowering. The crop needs in this period are five to seven millimeters of water per day and a high nutrients demand.

Temperatures below 13°C prevent flowering of plants, while floral induction is optimal when the temperature is between 21°C and 27°C (Parker & Borthwick, 1943; Embrapa, 2007).

Regarding the grain filling phase, according to Ritchie et al. (1977), phase R5.1 corresponds to 10% of granation; R5.2, 11 to 25%; R5.3, 26 to 50%; R5.4, 51 to 75% and R5.5, 76 to 100%, as shown in Figure 3.

Phases R3 and R4 require seven to nine millimeters of water per day, in addition to temperatures around 25 °C. If water deficit occurs, there will be the abortion of pods with a consequent reduction in grain yield.

In phase R5 there is a peak of water consumption (eight millimeters of water per day), since the translocation of nutrients from leaves to grains and removal of nutrients from soil solution. Water deficiency limits carbon assimilation and can shorten the crop cycle by reducing the allocation period of reserves for reproductive structures (Maehler et al., 2003).

Finally, the final stages of development, close to the harvest period, are hampered by the high occurrence of rainfall, which can affect grain quality.

Table 1. Soybean reproductive stages

STAGES	NAME	DESCRIPTION
R1	Flowering initiation	An open flower on any stem node
R2	Full Flowering	A flower open on one of the last two nodes of the stem, with a fully developed leaf
R3	Pod formation start	Pod with 5 mm on one of the last four stem nodes with fully developed leaf
R4	Fully Developed Pod	Pod with 2 cm on one of the last four stem nodes with fully developed leaf
R5	Grain Filling Start	Grain with 3 mm in the pods of the last four stem nodes
R6	Full Grain	Pod containing green beans filling the pod cavities of one of the last four stem nodes
R7	Maturation start	A normal mature-colored stem pod
R8	Full maturation	95% of mature colored pods

Source: Adapted from Fehr & Caviness, 1977

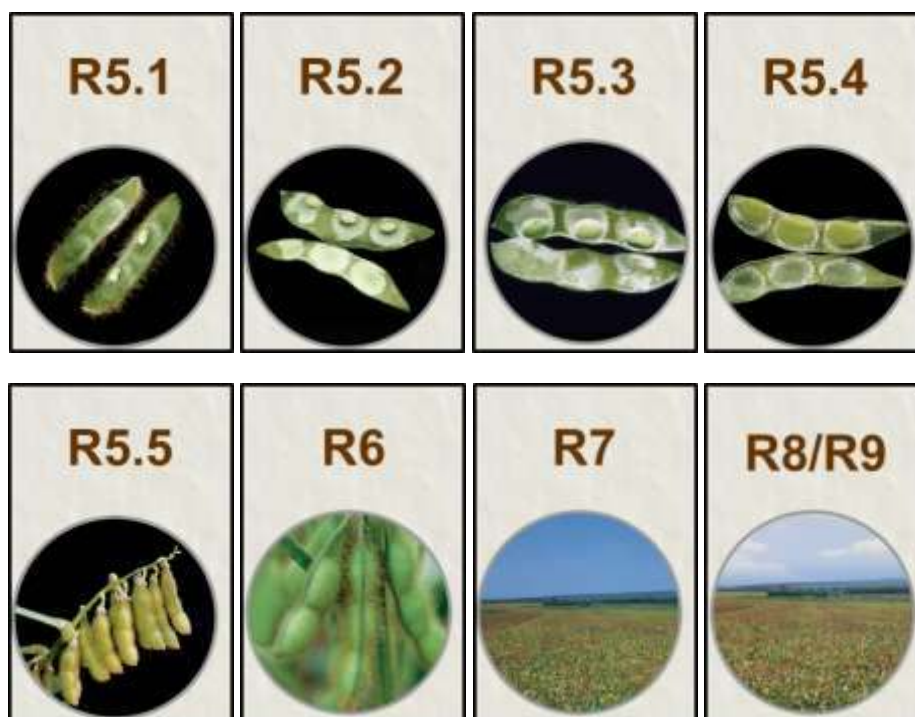


Figure 3. Soybean reproductive stages. Source: Adapted from Stoller, 2017.

Soybean nutritional management

From the 1970s, with the cultivars use of long juvenile period, the expansion of soybean cultivation to the cerrado began in originally acidic soils with low natural fertility. Without correction, soybean yield was lower than 10 bags per hectare,

and strategies for soil acidity correction were needed (Zancanaro et al., 2014).

Fertilizers are highly influential production factors in crop yields and crop expenditures account for almost half of the total production cost. According to Casarin & Stipp (2009), the proper use of fertilizers goes through a process that has been

called “4C Management”, defining the right source, at the right dose, applying at the right time and with the right location.

This type of management is one of the foundations of Good Practices for the Efficient Use of Fertilizers (BPUFs), which aims to provide the right conditions for balanced nutrient supply to crops, minimizing losses. Soil management is a work whose results only appear in the medium and long term and must be performed continuously (Zancanaro et al, 2014), given the high nutrient demand of the crop (Table 2).

According to Embrapa Soja (2011), the nutritional requirement for the production of one ton of soybean per hectare is: 83 kg N; 15.4 kg P; 38 kg of K; 12.2 kg Ca; 6.7 kg Mg; 15.4 kg S; 77 g of B;

515 g of Cl; 26 g Cu; 460 g of Fe; 130 g of Mn; 7 g Mo and 61 g Zn.

Nutrient uptake by the crop is measured by the amount accumulated in the leaves and stems of the plant. According to Cordeiro et al. (1979), absorption is increasing until reaching a maximum accumulation point. From then on, the accumulation rate is decreasing due to nutrient translocation to the grains in formation. There is a higher velocity period of absorption that corresponds to the beginning of plant's flowering. The period between flowering and pod filling is the “critical period” of the crop, where adverse factors such as water deficit (drought), nutritional deficiency, pest attack and disease can drastically reduce grain yield (Sfredo, 2008).

Table 2. Estimates of total extraction and exportation of macronutrients ($\text{kg}\cdot\text{ha}^{-1}$) and micronutrients ($\text{g}\cdot\text{ha}^{-1}$), as a function of expected productivity.

Nutrientes	Productivity Achieved / Productivity Expectations					
	$3.0 \text{ t}\cdot\text{ha}^{-1} / 50 \text{ sc}\cdot\text{ha}^{-1}$		$3.6 \text{ t}\cdot\text{ha}^{-1} / 60 \text{ sc}\cdot\text{ha}^{-1}$		$4.2 \text{ t}\cdot\text{ha}^{-1} / 70 \text{ sc}\cdot\text{ha}^{-1}$	
	Extraído	Exportado	Extraído	Exportado	Extraído	Exportado
	$\text{Kg}\cdot\text{ha}^{-1}$					
N	249	153	299	184	349	214
P₂O₅	46	30	55	36	65	42
K₂O	114	60	137	72	160	84
S	46	16	55	19	65	23
Ca	37	9	44	11	51	13
Mg	20	6	24	7.2	28	8
	$\text{g}\cdot\text{ha}^{-1}$					
Mo	21	15	25	18	29	21
Zn	183	120	220	144	256	168
Mn	390	90	468	108	546	126
Cu	78	30	94	36	109	42
B	231	60	277	72	323	84

Source: Broch & Ranno (2013).

Nitrogen

It is the nutrient most required by soybean crop. It can be absorbed as ammonium (NH_4^+) or nitrate (NO_3^-), which is the predominant form. When absorbed, NO_3^- is reduced to NH_4^+ , so that N is transformed into amino acids and proteins. About 90% of the total N of the plant is in organic form, such as free amino acids, proteins, amines, purines, coenzymes, among others (Sfredo & Borkert, 2004).

Soil N is present in organic matter and is dependent on the dynamics of microorganisms, the amount of plant residues, the rapid return and carbon utilization efficiency of the microbiota (Baudoin et al., 2003), all influenced by climatic conditions (Hungary et al., 2007).

However, the use of nitrogen fertilizers has generated discussions in the scientific environment.

According to Hungary et al. (2007), the use of nitrogen fertilizers in the crop is undesirable, due to the high cost, being polluting and, mainly, to reduce the nodulation and the efficiency of the symbiotic N_2 fixation process in legumes.

Fontoura & Barth (2013) verified the productivity of a commercial soybean cultivar as a function of urea application and found the non-viability of application due to the high costs and low yield response. Therefore, nitrogen fertilization would only be effective and profitable, under conditions where N_2 fixation does not meet the total N demand for high yield soybean and when its price relative to N is sufficient to make the investment economically viable (Salvagiotti et al., 2008).

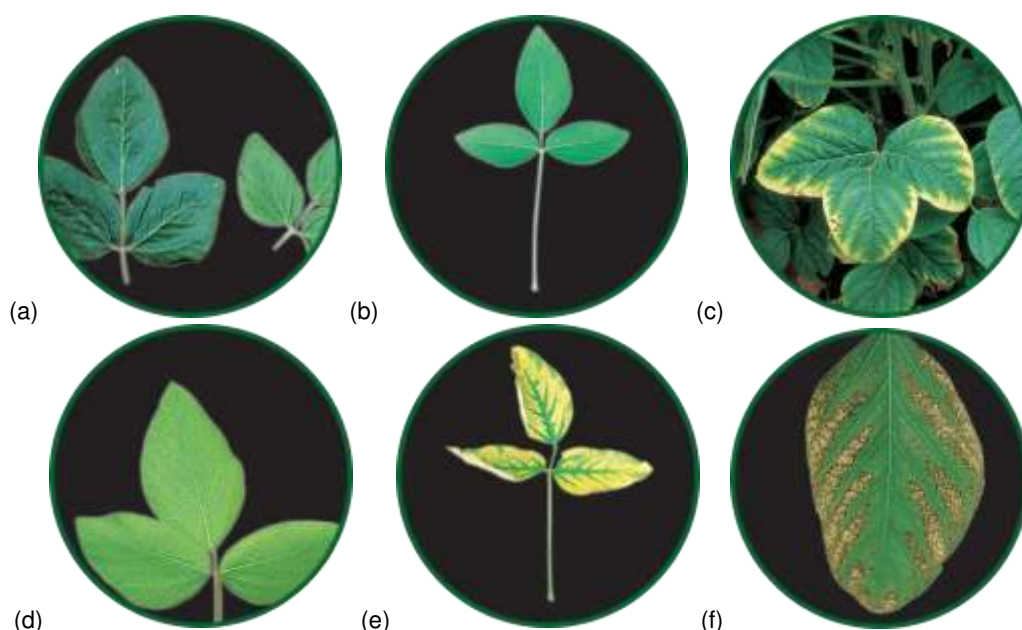


Figure 4. N (a), P (b), K (c), S (d), Ca (e) and Mg (f) soybean deficiencies. Source: Adapted from Stoller, 2017.

The most viable source of N supply to soybeans is symbiotic fixation or biological nitrogen fixation (BNF), where diazotrophic bacteria belonging to the genus *Bradyrhizobium* (*Bradyrhizobium japonicum* and *B. elkanii*) are exposed to the roots, forming nodules.

In stages V1 and V2, the activity of the enzyme nitrogenase (responsible for the transformation of nitrogen into ammonia) can already be detected, reaching its maximum point in the full flowering stage, declining from the grain filling (Vargas et al., 1993).

Most of the accumulated N is fixed in the beans and the second most is in the pods. In N deficiency (Figure 4, a), there is total and uniform chlorosis in older leaves, followed by necrosis (Malavolta et al., 1980), resulting in low protein levels in the grains (Sfredo & Borkert, 2004).

Phosphor

According to Sfredo & Borkert (2004), phosphorus (along with nitrogen and potassium) is the most readily redistributed element via phloem to other parts of the plant, especially new growing organs.

Absorbed in the form of phosphate (H_3PO_4), P is essential for energy storage and supply processes, structural component of macromolecules, and key element of various metabolic pathways and biochemical reactions (Holford, 1995).

Fertilizers are the main sources of phosphorus supply to the soil, such as simple superphosphate, triple superphosphate, mono ammonium phosphates, among others.

Firmano et al. (2009) found that the application of P mitigated the effects of water deficit and that in plants supplemented with P there was a tendency of stability in the root system biomass. Deficient plants are small and have bluish green leaves (Figure 4, b).

Potassium

Among the nutrients required by the crop, potassium is the second most absorbed and the one that presents the highest concentrations in soybean plants (Mascarenhas et al., 2004). Assists in the nodulation process of symbiotic bacteria, germination and is closely linked to seed quality (Aratani et al., 2007).

According to Prado (2008), more than 60 enzymes depend on K for their normal activity. The nutrient is required in larger quantities when soybeans are in full vegetative growth, where the maximum absorption speed occurs 30 days before the phenological stages R1 and R2 (Silva et al., 2010).

Absorbed in the form of K^+ , the nutrient is important in all aspects of crop growth and production and has a great influence on nutritional balance (Malavolta, 1980). It has enzymatic action and is responsible for the opening and closing of the stomata, besides osmotic regulation of tissues (Langer et al., 2004).

According to Sfredo & Borkert (2004) potassium deficiency causes internodal chlorosis, followed by necrosis at the edges and apex of older leaves (Figure 4, c).

Nutrient supplementation promotes greater efficiency of physiological parameters in the absence of water restriction and improves

photosynthetic recovery of plants after rehydration in cultivars sensitive to water deficit (Catuchi et al., 2012).

Sulfur

Sulfur is present in the plant predominantly in organic form (cystine, cysteine, methionine, proteins, glycosides and vitamins). Nitrogen and sulfur assimilations are well coordinated, ie the deficiency of one element represses the assimilatory pathway of the other (Epstein & Bloom, 2006).

Absorption occurs mainly in the form of sulphate (SO_4^{2-}) and can be absorbed as organic S, SO_2 (air) and wettable S (defensive) by leaves. The main sources are agricultural plaster (economically most viable), simple superphosphate, elemental sulfur (S0), or NPK formulations with S addition.

The main physiological drains of sulfur are the newer upper leaves (Silva et al., 2010) where the first symptoms of deficiency (Figure 4, d), in the form of uniform chlorosis similar to N deficiency (Sfredo & Borkert, 2004).

Calcium

Liming is the main means of supplying Ca to the soil, which is absorbed as Ca^{2+} and transported via xylem unidirectional. In plants, it is found in the forms of pectate, oxalate or adsorbed to proteins.

In deficiency cases (Figure 4, e), the first symptoms are observed in the new plant tissues, as the root and shoot growth points are affected. There is atrophy of the root system and death of the apical bud. The primary leaves have their emergence delayed and when they emerge, they become cup-shaped; collapse of the petiole by the disintegration

of the cellulosic wall (Sfredo & Borkert, 2004) and, in the reproductive phase, the fall of flowers and pods may occur.

Magnesium

A constituent of chlorophyll, magnesium is fundamental in photosynthesis processes, besides acting as enzyme activator, among them those related to carbohydrate synthesis and others involved in nucleic acid synthesis.

The nutrient is absorbed as Mg^{2+} and like calcium, liming is the main means of providing this nutrient.

In Mg deficiency (Figure 4, f), the older leaves have internodal chlorosis (light yellow) and pale green veins (Sfredo & Borkert, 2004).

Micronutrients

Generally, micronutrients are required as enzymatic cofactors, participating in some prosthetic group, coenzyme or even metal activators, constituents of the cellular structure, of molecules of one or more organic compounds.

Micronutrient fertilization is not always visualized in yield, but directly influences plant vigor and tolerance to pests and diseases, in addition to the quality of the harvested product (Fancelli, 2003).

Molybdenum (Mo) and cobalt (Co) are important nutrients in biological nitrogen fixation (BNF), Mo being an enzymatic cofactor of the enzymes nitrogenase and nitrate reductase and Co, a leghemoglobin component present in nodules (Sfredo et al., 1997).

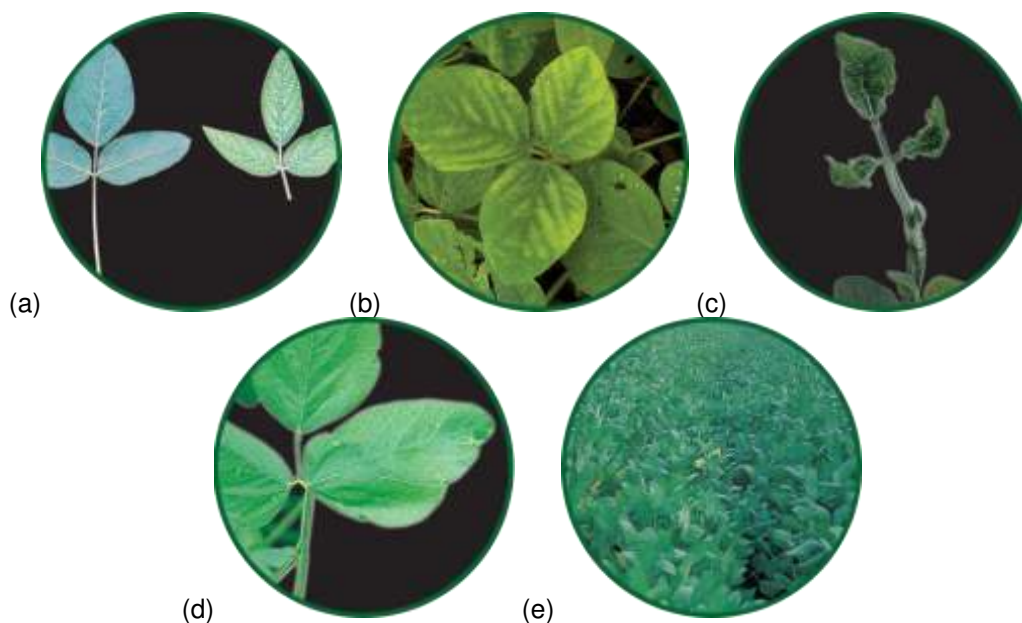


Figure 5 - Zinc (a), Manganese (b), Boron (c), Copper (d) and Cobalt / Molybdenum (e) soybean deficiency. Source: Adapted from Stoller, 2017.

Manganese (Mn) is the most abundant micronutrient in soil; however, 90% is complexed to organic compounds. Moreover, according to Malavolta (2006) its availability is directly related to the pH of the medium. Among its functions, the nutrient acts on photosynthesis, nitrogen metabolism, cyclic compounds as precursor of aromatic amino acids, hormones (auxins), phenols and lignins (Heenan & Campbell, 1980).

The symptoms caused by micronutrient deficiency (Figure 5) are varied. Zinc (Zn) deficiency reduces the size of young leaves and makes them lanceolate, presenting chlorotic areas, bending of the main branch and low yield of pods. Manganese (Mn) deficiency is noticeable in young leaves, where small yellowish leaves are seen between the ribs and plants with reduced growth. Boron (B), on the other hand, presents slow development of the growth points, the petioles of the younger leaves become small, deformed and bluish green in color, low flowering and sharp fall of pods. Copper (Cu) deficiency has necrosis on the tips of young leaf petioles and they look dry. In cobalt (Co) and molybdenum (Mo) deficiency, symptoms are observed in new leaves that become chlorotic, there is a fall in flowers and pods and a reduction in vegetative and root growth, seed weight and consequently in production (Stoller, 2017). **Conclusions**

The classification of soybean development in stages (phenology), allows greater precision and uniformity for the correct identification of the phase that the plant is in.

Environmental factors (water availability, photoperiod, light incidence, and temperature) directly affect the crop yield traits and influence the cultivar's choice for a region.

Providing nutrients at the place, dose and phase correct is essential for the plant to express its maximum potential and ensure high grain yield.

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