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General aspects of tomato crops and phosphorus fertilizer application: a review

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Abstract

Efficiently adjusting phosphorus (P) fertilizer application for tomato crops can result in increases in fruit yield and quality and plant nutritional status. The present study is justified by the absence of works analyzing general aspects and responses of tomato crops to water deficit and P rates and sources. This review sought to present information with technical-scientific data about general aspects and important aspects of P fertilizer application to tomato crops. The analysis of secondary data available in the literature and related to this thematic showed the difficulties for the efficient use of P fertilizers and definition of an optimal irrigation water depth. Tomato is a vegetable sensitive to water deficit; thus, the fruit yield and quality and plant nutritional status of tomato plants can be affected by the water volume applied and the irrigation management combined with the quantity of P fertilizer applied.

Keywords: *Solanum lycopersicum* L., phosphorus, irrigation management, fruit quality

Introduction

Tomato is a vegetable of the family Solanaceae that has a high socioeconomic importance and is present in daily meals. It presents natural antioxidant properties due to its concentrations of vitamin C and phenolic and carotenoid compounds, in addition to bioactive and functional compounds, carbohydrates, proteins, and minerals. Moreover, tomato farming ensures employment and income to small and medium farmers and can be grown in open fields and, mainly, in greenhouses.

The world tomato production is estimated in 4.0 million Mg, with a growth of 2.0% in relation to the last survey, according to the Brazilian Institute of Geography and Statistics (IBGE). In Brazil, the planted area is 56.874 hectares and may increase 2.2%, and most national growers are in the states of Goiás and São Paulo, which represent 28.9% and 25.6% of the national production, respectively. The average yields are estimated in 92 394 kg ha^{-1} in Goiás and 78.344 kg ha^{-1} in São Paulo (IBGE, 2021).

The world population growth and the economy development have imposed challenges due to increases in water demand, resulting in a high pressure on the food production sectors. The optimization of natural resources, mainly water and energy, has been pointed out, focused on the creation and development of integrated production systems, as it is estimated that the world population will be approximately 9.5 billion until 2050 (Pinstrup-Andersen, 2017).

Information gathered by the World Water Assessment Programme (WWAP) show a 60% increase in the demand for food, which will require the expansion of agricultural lands. Thus, management practices for the resources, as well as the intensification of production will involve increases in mechanized soil interventions and

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use of agrochemicals, energy, and water (WWAP, 2018). These factors are associated to food production systems, which will be responsible for 70% estimated loss in terrestrial biodiversity until 2050 (Leadley et al., 2014). Thus, changes in the standards of use of natural resources are demands of the society due to environmental socioeconomic concerns (Carvalho et al., 2017).

Thus, water use management is carried out by farmers to improve tomato production based on their experience, in most cases, applying larger quantities of water than those required by the plants, resulting in a decreased water use efficiency (Du et al., 2017). Therefore, a rational irrigation management is important, using techniques that consist of applying only the water volume required by the plants and at the right time.

The greenhouse crop technology has been expanding because of advances in agriculture to ensure the production all year round, mitigate adverse environmental effects, and provide high yields; it is used to protect crops from severe climate conditions, such as rainfall and wind (Dannehl et al., 2014; Ishii et al., 2016; Shamshiri et al., 2018; Ezzaeri et al., 2018). Thus, the quantities of water and nutrients required by tomato plants grown in greenhouses are smaller than those in traditional systems, i.e., open fields (Sun et al., 2013).

The application of adequate rates of phosphorus (P) is needed when focusing on increasing yield and nutritional quality of tomato fruits, as it results in better vegetative development, improving flowering and fruiting (Filgueira, 2013). P is the fifth most accumulated nutrient in tomato plant shoots and has an essential role in energy transformation; it provides better responses when applied at ideal rates, increasing the crop yield (Fayad et al., 2002; Silva et al., 2009).

P is also important for the plant metabolism, cell energy transfer processes, cell division, respiration, and photosynthesis, as it is a structural component of nucleic acids of chromosomes and many coenzymes, phosphoproteins, and phospholipids (Pelá et al., 2009; Souza et al., 2013).

Oxisols from alkaline rocks cover approximately 58% of the territorial area of Brazil; these soils are weathered, acid, and present precipitation of P with aluminum (Al) and iron (Fe) in the soil solution, low availability of bases, and high P adsorption capacity to surfaces of iron $Fe(OH)_2$ and aluminum $Al(OH)_3$ oxyhydroxides (Novais & Smyth, 1999; Soares & Casagrande, 2009; Viegas et al., 2010; Souza et al., 2014).

The adsorption of P by these soils is subjected to the effect of minerals present in surface groups as $Fe(OH)_2$ and $Al(OH)_3$, since P is absorbed through chemisorption with establishment of covalent connections to structural and specific surfaces that strengthen the adsorption effect (Souza et al., 2009). Thus, P availability in acid, weathered soils is driven mainly by the P connected to Al, which is a more labile form of P in the soil (Novais & Smyth, 1999).

The amount of nutrients absorbed by tomato plants and their partitioning are associated to plant growth and to biotic and abiotic factors, such as agricultural practices, crops systems, and nutrient rates and sources (Pelúzio, 1991; Fontes & Fontes, 1991; Fontes & Fontes, 1992; Silva et al., 2001). Thus, the adoption of strategies for the decision making on irrigation management and fertilizer applications for tomato production is necessary for the crops to reach satisfactory results, increase plant production, and make tomato growing viable for large, medium, and small farmers.

Development

Origin and history of tomato (Solanum lycopersicum L.)

Tomato is native to regions of the Andes, in the occidental coast of South America, from Ecuador to the north of Chile, and from the Pacific Ocean to the Andes Cordillera and, probably, in the Galapagos Islands (Clement, 2004; Andrade; Souza; Assis, 2009; Higuti et al., 2010). Contrastingly, there were two hypotheses for its place of domestication, one is Peru and the other is Mexico (Bai & Lindhout, 2007; Saavedra et al., 2017). Tomato was taken to Mexico to regions between Puebla and Vera Cruz, before the Spanish colonization, where it started to be domesticated, grown, and bred (Rubatzky & Yamaguchi, 1999; Pelzer, 2008; Paran & Knaap, 2007; Méndez et al., 2011; Silva et al., 2014).

Tomato crops started to be grown in the 16th century and were widespread in the 19th century (Filgueira, 2013; Alvarenga, 2013; Bergougnoux, 2014). They were introduced to Europe by Spain between 1523 and 1554 and to Italy in 1560, being used as an ornamental plant. In other European countries, its use was exclusively for medicinal and ornamental purposes, as it was considered a toxic plant, and only later it was used as food. In the early 20th century, tomato crops increase in the whole world, resulting in the development of processing industries to make tomato concentrates (Costa & Heuvelink, 2005; Almeida, 2006).

Tomato consumption is a habit that was introduced to Brazil in the later 21st century by European immigrants. After the I World War, around the 1930 decade, it was spread and the tomato consumption increased (Alvarenga, 2013). Tomato production in

Brazil started in the state of Pernambuco; however, the development of crops was promoted only in 1950, through the implementation of agroindustries in the state of São Paulo (Brito & Melo, 2010).

Socioeconomic importance of tomato farming

Tomato can be grown all year round and is very important for the economy of Brazil and the world due to its good acceptance and high consumption; it is extensively grown under different conditions: in fields, greenhouses, and gardens (Berni et al., 2018).

Climate changes and economic and social factors negatively affect the economy of Brazil and the world. Thus, the demand for higher yields and improvements in quality of agricultural products, especially vegetables, can be met through technological innovations, such as fertigation, which improves the vegetative development of plants (Santos et al., 2017). Information on the frequency of consumption of fruits and vegetables are important to guide and stimulate strategies for the consumption of these foods (Palm et al., 2009; Figueira et al., 2016).

Tomato is one of the most industrialized vegetables in production volume terms, after batata, generating income and employment for producing regions and making available a rich food with recognized nutraceutical value (Strati & Oreopoulou, 2014; Torbica et al., 2016; Salvador, 2017). It is found in daily meals and can be prepared in several forms, being consumed fresh or processed. Thus, the table tomato and industrial tomato sectors have their specificities, including the management, production practices, cultivars, consumers, processing, and marketing.

Tomato is important in the human diet, providing essential nutrients for human health and well-being (Faurobert et al., 2007; Ilahy et al., 2016; Menezes et al., 2018). The consumption of this vegetable and its derivatives is considered a nutritional indicator of good feeding habits and healthy life styles, and an tomato consumption has been observed for processed and fresh tomatoes (George et al., 2004; Viuda-Martos et al., 2014).

Tomato became an example of fruits that promote the maintenance of human health (Kelebek et al., 2017; Liu et al., 2015; Shah et al., 2015) due to its high nutritional value; bioactive and functional compounds; and natural antioxidant properties due to presence of vitamin C, phenolic compounds, and carotenoids compounds, especially lycopene, which is responsible for the red color of tomato fruits and their derivatives (Martínez-Valverde et al., 2002; Eyiler & Oztan, 2011; Had et al., 2014).

In addition, tomatoes present large quantities of carbohydrates, proteins, lipids, and minerals (Chong et al., 2014; Jorge et al., 2014). These compounds from different phytochemical classes are associated to possible benefits to human health, which include the capacity to protect organisms from neoplasms (prostate, lung, and stomach), as well as cardiovascular and neurodegenerative diseases (Firuzi et al., 2011; Had et al., 2014; Ilahy et al., 2016).

Botanical aspects and morphological characteristics

Tomato plants belong to the kingdom Plantae, genus *Solanum*, subgenera *Eulycopersicum* and *Eriopersicon*, class Dicotiledonae, order Turbiflorae, family Solanaceae, which includes batata, eggplant, pepper and sweet pepper, and the species *Solanum lycopersicum* (Nuez, 1995; Raemaekers, 2001; Filgueira, 2013; Alvarenga, 2013). However, there was a change in the tomato scientific name from *Lycopersicon esculentum* Mill to *Solanum lycopersicum* L. after discussions among researchers, taxonomists, and geneticists (Spooner et al., 2005; Peralta et al., 2006).

The first scientific name of tomato was given in 1964 by Tournefort, who ranked it, genetically, as *Lycopersicon*, which means "wolf peach" in Greek. The binominal system used by Linnaeus in 1753 reclassified tomato in the genus *Solanum*. Contrastingly, in 1754, Miller described and reclassified it as *Lycopersicon* and described several species, including the cultivated tomato, which was called *L. esculentum* (Peralta & Spooner, 2001; Peralta et al., 2006), as shown in the Code of Nomenclature for Cultivated Plants (Brickell et al., 2004).

Tomato crops are perennial; however, they are grown as an annual crop. The plants present herbaceous-shrub character, flexible stem, and hairy and abundant lateral branching in their natural architecture, which can be altered or modified by pruning and crop systems, usually ground systems for the industry, and trellising systems for fresh consumption (Filgueira, 2013). Tomato plants present different forms of development (ground, semi-erect, and erect), and two growth habits (determined and indeterminate).

Tomato plants with determined growth habit are represented by cultivars adapted mainly for ground crops, presenting absence of apical dominance and stems or single floral apical branching; whereas plants with indeterminate habit are represented by most cultivars of table tomato, with apical dominance and emission of floral branches every three emitted leaves (Filgueira, 2013; Alvarenga, 2013). However, the cultivation practices affect plant development and fruit quality (Marim et al., 2005).

Tomato has a root system with a main or pivoting root, and secondary and adventitious roots. Pivoting roots may reach 40 cm effective depth when there are no barriers, as occurs in transplanted seedlings, whereas secondary roots are more ramified and superficial, with rapid development, and can reach depths greater than 0.50 m (Alvarenga, 2013).

The plant growth occurs from the axillary gem of the last leaf, from which a secondary stem is developed. The subsequent stem branching has similar development and is responsible for producing inflorescence every three leaves. A typical stem base of a tomato plant has 2 to 4 cm diameter and is covered by glandular hairs (Lapuerta, 1995).

The leaves are petiolate, imparipinnate, and compost, inserted in several stem nodes in an alternate form, with leaf blade fractioned into 7, 9, or even 11 leaflets, with the stem containing secretory glands and hairs. A typical tomato leaf has 0.5 m length and a little less than this in width (Lapuerta, 1995). Tomato seeds are abundant, presenting light brown color, 3 to 5 mm length, 2 to 4 mm width, and embryo wrapped in the endosperm. The 1000-seed weight ranges from 2.5 to 3.5 g (Dam et al., 2006).

Tomato flowers are hermaphrodite, small, and yellowish, with a raceme-type shape (bunches) that can be ramified or not, which characterizes it as an autogamous plant with cross pollination frequency of up to 5%, increasing the self-pollination rate; however, pollinating insects, such as bees, can cause this crossing (Silva & Giordano, 2000; Fontes & Silva, 2002; Alvarenga, 2013; Nick & Borém, 2016). The upper inflorescence is simple, bifurcate, or ramified (Nuez et al., 1998).

The flowers are hypogynous, with floral parts inserted below the ovary in a plain or occasionally convex receptacle, with five or more sepals and petals arranged in a helicoidal form containing the same number of stamens, and a bi or plurilocular ovary, with anthers together forming a cone involving the stigma (Alvarenga, 2013).

The shape of tomato fruits is connected to the group of their cultivar (Melo et al., 2007). The fruit color stands out among the overall characteristics: yellow, pinkish, orange, and mainly red when the fruit is mature (Minami & Haag, 1989; Alves Filho, 2006).

The fruit is classified as a fleshy juicy berry with divided locules, which is the characteristic that defines the tomato variety (Holcman, 2009). Internally, it is divided in locules in which the seeds are immersed in the placental mucilage, depending on the cultivar. The fruits are classified as bilocular, trilocular, tetralocular, or plurilocular (Melo, 1989). The weight of each fruit varies from 25 g (cherry type) to more than 400 g (salad type) (Filgueira, 2013).

Tomato is classified in Brazil based on the groups Santa Cruz, Salada or Caqui, Saladinha, Italiano or Saladete, and Cereja (Cherry) (Alvarenga, 2013); however, Filgueira (2013) classified it into the groups Santa Cruz, Salada or Caqui, Italiano, Cereja, and Agroindustrial.

Agronomic aspects

The maximization of the plant production in tomato crops, reaching high yields and economic profitability, is obtained when production factors (soil fertilizer application, plant mineral nutrition, water management, genetic, and health) are rationally used and at adequate levels. Tomato crops require three months of rainfall to overcome difficulties for their growth and development (Lopes & Stripari, 1998).

Droughts and low air humidity periods can decrease the number of floral buttons and flowers, and cause cracks in fruits, whereas long rainfall and relative air humidity periods facilitate the emergence of fungal diseases and, consequently, fruit rotting (Dam et al., 2006). Tomato crops are adapted to different climate conditions, including hot and wet tropical climates, which requires a long growth season, as the growth speed is connected to air temperature and plant age (Selina & Bledsoe, 2002).

The ideal air temperature for most tomato varieties is from 21 to 24 °C, with tolerance to the amplitude of 10 to 38 °C. Air temperatures lower than 10 °C cause decreases in growth rate, deficient pollination, water and nutrient absorption paralysis, yellowing of leaves, hardening of stems, and make fruits to crack and become purplish due to anthocyanin accumulation; whereas air temperatures higher than 38 °C may cause abortion of flowers, decrease in germination percentage, premature death of seedlings, fruit abortion and late blight in fruits, tissue damages, and fruits presenting problems with scald (Marouelli & Silva, 2000; Dam et al., 2006; Alvarenga, 2013).

The ideal temperature for the seed germination is from 15 to 25 °C (ideal), with relative air humidity between 60 to 80%. These climate factors are important for the crop by having high effect on the different phenological stages of the tomato development. Moreover, a high relative air humidity can favor the occurrence of diseases, which limits the crop development (Dam et al., 2006; Alvarenga, 2013).

Tomato is demanding in daily thermo-periodicity, requiring mild diurnal temperatures (between 6 and 8 °C), and nocturnal temperatures ranging from 15 to 20 °C. Photoperiod is indifferent for tomato crops, which can be grown in short days in the winter and in long days in the summer. However, excess rainfall is another agroclimatic factor that affect the crop by favoring the emergence of fungal and bacterial diseases (Filgueira, 2013).

Tomato crops develop well in most soils, since the soil presents an appropriate capacity for water retention, aeration, and low salinity. Therefore, the soil characteristics should be analyzed before planting, including chemical, physical, and biological properties, and areas with soaking problems, irregular topographies, sand banks, gravel, and rocks should be avoided (Silva et al., 2006; Martins et al., 2017).

The ideal soil pH for tomato crops is from 5.5 to 6.8, and the soil should present availability of nutrients for a good plant development. Tomato is commonly grown under pH between 5.0 to 7.5; a pH lower than 5.5 decreases the availabilities of magnesium (Mg) and molybdenum (Mo), and a pH above 6.5 causes deficiency of zinc (Zn), manganese (Mn), and iron (Fe) (Braga, 2012; Yara, 2019).

Tomato production under organic system is a great opportunity of business, but presents some specificities associated to seeds, choice of genotypes (hybrid × open pollination), water shortage, nutritional management, and plant phytosanitary protection (Sediyama et al., 2014; Mansour et al., 2014). These specificities are dependent on the production environment (open field or protected environment) and climate conditions. In conventional systems, the soil management and preparation consist in liming, plowing, harrowing, furrowing, and organic and mineral soil fertilizer application (Luz et al., 2007).

The cycle of most tomato cultivars ranges from 95 to 125 days, depending on the climate conditions, soil fertility, irrigation intensity, attack of pests, diseases, and planting season (Silva et al., 2006). The plants present three phenological stages: the first is from sowing to the beginning of flowering; the second is from the beginning of flowering to the beginning of fruit harvest; and the third is until the end of the harvest (Alvarenga, 2013).

Some cultural practices, such as prevention, mitigation, and control of diseases, the high nutritional demand of plants, and the high cost of hybrid seeds, in general, increase production costs, making it a high-risk activity (Andreote & Van Elsas, 2013; Fahad et al., 2015; Ahammed et al., 2015; Machado et al., 2018).

The weeding is usually carried out to maintain clear the area close to the tomato plant rows to avoid competition with weeds and soil cover plants. Soil cover plants should be left between the tomato rows, weeding when necessary to avoid competition for light and facilitate the application of pesticides to the lower leaves. The stems should be tied, avoiding injury and strangulation as the plant grow. Buds from the axils of plants should be removed, leaving one or two stems per plant; this should not be carried out on wet plants, as it can cause the dissemination of diseases and pests (Beaker et al., 2016).

Tomato mineral nutrition

Plants obtain mineral nutrients from the soil mainly in the form of inorganic ions. These elements are part of all organisms and are translocated to the different plant parts with biological functions (Taiz et al., 2017). Thus, fertilizer applications can provide mineral nutrients to improve plant production.

Nitrogen (N) and potassium (K) are the most accumulated nutrients in tomato plants (Lucena et al., 2013). N is responsible for metabolic processes in the plants, such as synthesis of several amino acids, nucleic acids, cell division and stretching, phytohormones control, photosynthesis, enzymes, and proteins (Hawkesford et al., 2012; Huang et al., 2015). Adequate applications of nitrogen fertilizers result in higher growth of plant vegetative organs and increase canopy photosynthetic capacity, which is determinant for the crop to express its maximum production potential (Almanza-Merchán et al., 2016).

K is absorbed by plants as a monovalent cation, which is mobile in plant tissues (Coskun et al., 2017). It is responsible for physiological processes, such as photosynthesis; enzymatic activation (dehydrogenase, oxidoreductase, transferase, synthetase, kinase, and aldolase); synthesis, transfer, conversion, and storage of carbohydrates; osmoregulation; cell turgor; and ion homeostasis in plant cells (Hawkesford et al., 2012; Sousa et al., 2014; Shabnam & Iqbal, 2016). It is essential for assimilation of N, activating enzymes that act on reduction of nitrate until its incorporation into carbon chains (Coskun et al., 2017), reducing nitrate-nitrogen ($N^{-}NO_3^{-}$) and ammoniacal nitrogen concentrations to non-ionized form ($N^{-}NH_4^{+}$) in plant tissues (Hagin et al., 2008).

An adequate combination of N and K fertilizer application can ensure balance between growth phytohormones and improvements in photosynthetic processes, resulting in higher growth and yield (Kumar et al., 2017).

The order of absorption of micronutrients in tomato plants is Fe, Zn, boron (B), Mn, and copper (Cu) (Rodrigues et al., 2002). Mo is absorbed in small quantities by most crops (Castellane, 1982). B is related to production of hormones, nucleic acids, sugar translocation, metabolism, and translocation of carbohydrates; its deficiency can result in dark injuries and cracks in tomato fruits and stems (Malavolta et al., 1989). Zn is important for plant development, as it acts on the functioning of growth regulators, such as auxin, which affect internode elongation (Yara, 2019).

The P stored in seeds is used for germination and beginning of growth, which are affected by exchanges between externally available P and existing P in the plant (Grant et al., 2001). This nutrient is required in large quantities due to the grown area, crop demand, and high nutrient adsorption from the soil (Candian et al., 2017). Thus, P fertilizers can be applied by broadcast or to the planting furrows with incorporation into the soil in the conventional system (pre-planting and piling), or applied to the soil surface in no-tillage system (Marcolan, 2013).

P limitations at the beginning of the vegetative cycle can cause restrictions in plant development, from which the plant cannot recover, even when the supplying of P is increased to adequate levels (Grant et al., 2001). P is mainly absorbed (80% and 90%) by plants as dihydrogen phosphate or phosphate diacid ($H_2PO_4^-$) and hydrogen phosphate or phosphate acid (HPO_4^{-2}). It is mobile in plant tissues and responsible for metabolic processes of enzymes, participates in cell division, photosynthesis, and respiration (Shabnam & Iqbal, 2016), is part of organic compounds that involve phospholipidic phosphorylation and cell membrane (step photochemical), and is essential for protein synthesis, such as adenosine triphosphate (ATP) and adenosine diphosphate (ADP) in the Calvin cycle (reducing carbon stage) (Taiz et al., 2017).

Nutrient absorption by tomato crops is low until the emergence of the first flowers. Then, it increases until reaching the maximum absorption at the fruit formation stage and growth (from 40 to 60 days after planting), and decreases during the fruit maturation. Thus, the quantity of nutrients extracted is small; however, a fertilizer application is required due to the low nutrient absorption efficiency by these plants. It is estimated that the rate of uptake of P from fertilizers by tomato plants is approximately 10%; the residual P stays in the soil and can be absorbed by weeds, withheld by soil particles (fixation), or taken by erosive processes (Giordando et al., 1994).

Irrigation management in tomato crops

The agricultural sector is the activity that most demands water, and this demand is expected to increase in the next decades (WWAP, 2018). Thus, greater attention of public managers to sustainable development of resources water is required (Agência Nacional de Águas – ANA, 2016). Considering this scenario and the connections to the populational growth, economic development, and water demand by other sectors of the society, the use of natural resources will increase, as well as the volume of effluents, resulting in decreased water quality and increased environmental impacts.

In Brazil, the historical series have shown significant annual increases in irrigated areas in the last decade. The growth of irrigated agriculture is explained by the expansion of agriculture to regions with unfavorable climates, government incentives for regional developments, and benefits from the practice through availability of financing (ANA, 2021).

According to data from the Food and Agriculture Organization of the United Nations (FAO), Brazil is among the ten countries with the largest area intended for irrigation, occupying the sixth position, with 8.2 Mha. The leading countries are China and India, with approximately 70 Mha, followed by the USA (26.7 Mha), Pakistan (20.0 Mha), and Iran (8.7 Mha) (FAO, 2020).

Drip irrigation systems present high water application uniformity and control of root zone development, resulting in higher plant growth due to adequate soil moisture and ensuring the existence of a subsurface drainage reduction potential, increasing crop yield (Hanson et al., 2006; Bajracharya & Sharma, 2005).

Researches have shown higher yields and nutritional quality for tomato fruits, with higher economy of water (up to 30%) when using drip irrigation than other irrigation systems (Coletti & Testezlaf, 2003; Favati et al., 2009; Choudhary et al., 2010; Ozbahce & Tari, 2010; Marouelli et al., 2012; Kusçu et al., 2014). Koetz et al. (2010) evaluated tomato crops under drip irrigation and found increases in physical-chemical characteristics of fruits, mainly, fruit diameter and weight.

Moreover, Marouelli et al. (2013) evaluate the effect of sprinkler and drip irrigation systems on organic table tomato production and found that the drip system reduced the occurrence of late blight (*Phytophthora infestans*) and the percentage of rotten fruits.

Conclusion

Tomato crops have high demand for nutrient and water, and this demand becomes greater in practically all phenological stages, depending on the crop environmental conditions. The use of adequate rates of inputs, water, and nutrients through irrigation system and fertilizer application enables the exploration of the production potential of tomato plants, resulting in improvements in fruit quality and yield. The application of adequate phosphorus rates improves the tomato vegetative development and production.

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