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# Early growth of pecan cultivars under organic production

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**ABSTRACT.** Organic pecan production may offer not only a chance to increase economic returns-due to its increased product value-but also to avoid pesticide applications. This contributes to the growth of residue-free food and protects the environment. However, there is limited data on the performance of pecan cultivars in ecologically-based systems, especially regarding growth and susceptibility to scab (*Venturia effusa*) during the early developmental stages of orchards. This study aimed to evaluate the early growth of pecan cultivars in an organic production system in Pelotas, Rio Grande do Sul State, Brazil. The cultivars evaluated were Melhorada, Imperial, Success, Importada, Barton, Farley, Shawnee, Chickasaw, Desirable, Cape Fear, Choctaw, Elliot, Mahan, Sioux, Stuart, and Sumner. Their phenology, vegetative growth, and susceptibility to scab were assessed from 2018 to 2022. Sumner, Stuart, Desirable, Success, and Imperial exhibited the highest early growth under experimental conditions. Chickasaw, Desirable, Sioux, and Cape Fear were the most precocious cultivars in terms of bud break, while Barton, Farley, Stuart, and Sumner were the latest. In terms of scab susceptibility, Cape Fear, Chickasaw, Choctaw, Mahan, and Sioux were the most susceptible cultivars, whereas Barton, Elliot, and Stuart were the least susceptible under experimental conditions. In the early stages, Barton, Elliot, Success, Stuart, Sumner, Desirable, and Imperial were the standout cultivars in the organic production system.

**Keywords:** agroecology; *Carya illinoinensis*; pecan; *Venturia effusa*.

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## Introduction

Pecan crop has gained recognition, and cultivation areas have significantly increased, mainly in southern Brazil, in recent years. Rio Grande do Sul State accounts for 70% of the national pecan nut production and is its largest producer, followed by Santa Catarina and Paraná. It is estimated that around 6.85 thousand hectares are planted with pecan trees in Rio Grande do Sul, with an estimated production of 5.17 thousand tons (Bilharva et al., 2018; Boscardin & Costa, 2018; Agribusiness Outlook, 2023). Data from EMATER/RS in 2023 indicates that 1,502 pecan producers aim to meet both internal and external demands for pecan nuts in the state.

This temperate fruit tree has attracted the interest of farmers and consumers, which can be attributed to the nut's consumption, directly associated with health benefits. Pecans are excellent sources of proteins, minerals, carbohydrates, and fiber (Feng & Kong, 2022; Ferrari et al., 2022; Tong et al., 2022; Rahaman et al., 2023).

Moreover, there is a growing consumer demand for sustainable food production. Increasing awareness of production systems that employ agricultural practices, which do not harm the environment, use natural resources wisely, maintain good biological quality, and are pesticide-free, is evident (Reganold & Wachter, 2016; Mie et al., 2017). Consequently, there is a need to explore alternative agricultural systems based on Agroecology principles, such as organic production.

Organic systems adhere to principles that consider environmental, social, and economic aspects. These systems require effective management to influence quality and productivity positively. Agricultural practices to improve soil quality and the selection of disease and pest-resistant cultivars are strategies employed in alternative systems compared to conventional ones (Mie et al., 2017; Knapp & Van Der Heijden, 2018). In southern Brazil, some producers focus on organic pecan production, and research has been conducted on the crop as an alternative to conventional systems. However, scientific studies focusing on organic pecan production are scarce.

Initially, Brazil introduced several pecan cultivars native to the United States. Over time, new genotypes have been grown and selected (Poletto et al., 2022). Understanding the phenological stages of cultivars is crucial to plan management practices such as pruning, fertilization, and irrigation (Fronza et al., 2018; Oliveira et al., 2018; De Marco et al., 2021).

Phytosanitary issues, such as pest attacks and diseases caused by fungi, bacteria, and other pathogens, can threaten pecan crops (Lazarotto et al., 2014; Zhang et al., 2019). Scab, caused by the fungus *Venturia effusa* (a.k.a., *Fusicladium effusum*), is a major disease affecting pecans. It is prevalent in pecan cultivation areas worldwide and can lead to significant production losses (from 50 to 100%) and impact quality, causing stress to the plants (Rossman et al., 2016; Walker et al., 2016; Reuveni et al., 2022).

Although pecan trees were introduced in Brazil about a century ago, few studies on the early developmental stages of plants during orchard establishment have been conducted to evaluate growth and performance (Lange Junior et al., 2020a).

Studies on pecan phenology, vegetative growth, and tolerance to scab are crucial to understanding the adaptive and productive responses of trees grown in an ecological system. Therefore, this study aimed to evaluate the early growth and scab tolerance of pecan cultivars grown in an organic production system in Pelotas, Rio Grande do Sul State, Brazil.

## Material and methods

The experiment was conducted at the Estação Experimental Cascata (EEC), which is part of Embrapa Clima Temperado in Pelotas, Rio Grande do Sul State, Brazil (latitude 31°37'9" S; longitude 52°31'33" W; altitude 170 m). According to the Köppen System, the climate in the region is classified as Cfa, i.e., humid subtropical (Alvares et al., 2013). Pluviometric precipitation is evenly distributed throughout the year, with summer maximum temperatures ranging from 34 to 36°C and winter minimum temperatures between -2 and 0°C. The soil is classified as Argisol with a textural characteristic of the B horizon (Santos et al., 2006).

The experimental area was established in August 2018 with the following 16 pecan cultivars: Barton, Cape Fear, Chickasaw, Choctaw, Desirable, Elliot, Farley, Imperial, Importada (Pitol II), Mahan, Melhorada (Pitol I), Shawnee, Sioux, Success, Sumner, and Stuart. The experiment was designed as a randomized complete block with three replicates and three samples of each cultivar per unit. The spacing was 10 x 10 m, and plants were arranged in a triangular pattern. All pecan cultivars in the experiment were grafted onto unidentified rootstocks.

The plants were managed under an organic production system, meaning no synthetic chemical fertilizers or pesticides were used. The orchard was not irrigated.

The experimental area received turkey manure biennially, alternated yearly with organic compost at a ratio of 5 kg per linear meter. Additionally, green fertilization was alternated with *Avena strigosa*, *Crotalaria juncea*, *Mucuna pruriens*, and *Vicia sativa* L.

Evaluations were conducted from 2018 to 2022, covering the following agronomic variables:

a) Phenology: Evaluations, based on field monitoring, characterized stages of pecan development and duration using the Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie (BBCH) scale adapted by De Marco et al. (2021). Observed periods included dormant bud (00), swollen bud (01), beginning of budbreak (07), open bud (09), open leaves (17), and the emergence of staminate and pistillate inflorescences (54), starting after winter pruning, usually conducted in July and August;

b) Plant height (m): Plant height and canopy diameter, both perpendicular and parallel to the cultivation row, were measured with a measuring tape, with results expressed in meters (m);

c) Diameters of canopy-cultivar and rootstock stems: Diameters at the canopy-cultivar stem (grafting) and the rootstock stem were measured 10 cm above and below the grafting points using a Carbografite® digital caliper (150 mm), with results in millimeters (mm);

d) Absolute growth rate (AGR): $AGR = (V2 - V1) / (T2 - T1)$, as proposed by Lange Junior et al. (2020b), where V is the variable and T is the time for each period, expressed as height in cm per day;

e) Canopy volume: Mean canopy volume was calculated using plant height (H), canopy diameter towards the row (DR), and canopy diameter towards the spacing between rows (DS) with the formula $CV = (\pi/6) \times H \times DR \times DS$ (Cantuárias-Avilés et al., 2011), expressed in cubic meters ($m^3$);

f) Leaf scab: Diseases were monitored through regular visual analysis of each pecan plant in the experimental area. Scab severity levels were determined based on leaf symptoms, following the method proposed by Hunter and Roberts (1978): 1 = no symptoms on leaflets; 2 = up to 20% of leaflets with traces; 3 = 11 to 25%; 4 = 26 to 50%; 5 = 51 to 100%.

Leaflets showing symptoms were collected for diagnostic confirmation of the disease at the Laboratory of Phytopathology at Embrapa Clima Temperado.

Resulting data were subjected to analysis of variance, and treatment means were compared using the Scott-Knott test at a 5% significance level.

## Results and discussion

The onset of budbreak occurred in September and October across all cultivars during the years under evaluation (Figure 1). In the first year of the 2018-2019 season, there was variation among cultivars; 50% of them, including Cape Fear, Elliot, Sioux, Chickasaw, Choctaw, Desirable, Mahan, and Shawnee, began the phenological stage in the second fortnight of September, while Farley, Barton, Imperial, Importada, Melhorada, Success, Sumner, and Stuart initiated budbreak in October.

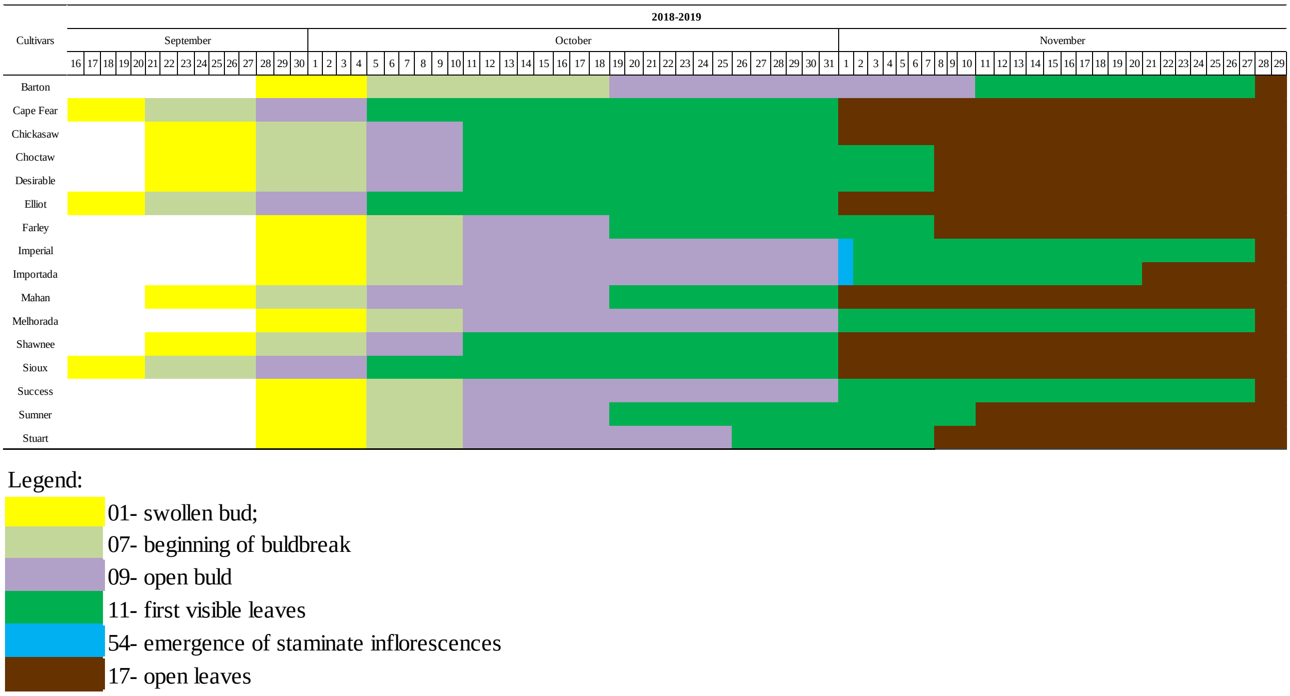


**Figure 1.** Phenological characteristics of pecan cultivars under organic system in southern Brazil during the 2018-2019 season. Pelotas, Rio Grande do Sul State, Brazil.

In the 2019-2020 season, budbreak commenced 11 days earlier than in the previous year (Figure 2), with Cape Fear starting on September 9th. However, by the second fortnight of September, 75% of the cultivars had also initiated budbreak. That year, the latest cultivars to start were Barton, Sumner, and Stuart, beginning in early October. During this period, Cape Fear had already reached the first visible leaves stage, more advanced than the other cultivars.

The number of cultivars reaching the reproductive development stage increased, with 68.75% of them, including Barton, Cape Fear, Chickasaw, Choctaw, Desirable, Importada, Imperial, Melhorada, Success, Sumner, and Stuart, developing staminate inflorescences. Additionally, the first pistillate flowers emerged in Chickasaw, Desirable, Success, and Sumner, representing 25% of the cultivars in the orchard.

In the last season under evaluation (2021-2022) (Figure 3), developmental stages among pecan plants varied. By mid-September, Chickasaw, in the open bud stage, was more advanced than the others.

Field monitoring and phenological stage characterization are effective management tools that determine the physiological state of each cultivar (Casagranda et al., 2023). Phenology aids in efficient decision-making during cultural treatments in the orchard, aiming to enhance plant development and production (Oliveira et al., 2018; Han et al., 2018; De Marco et al., 2021).

In the final two seasons, budbreak occurred earlier than in the first season, which started at the end of September. This variation could be due to the plants adapting to field conditions in the first year and being influenced by climatic factors, possibly chill hours (Table 1), which varied annually.

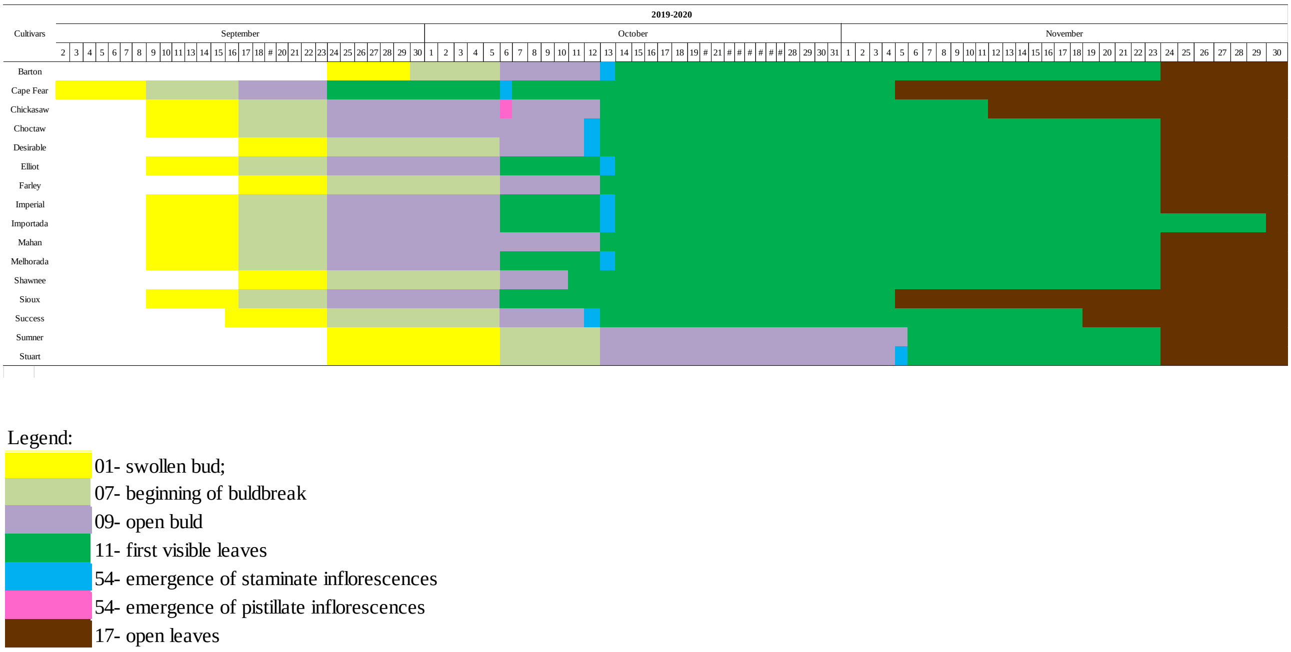


**Figure 2.** Phenological characteristics of pecan cultivars under organic system in southern Brazil during the 2019-2020 season. Pelotas, Rio Grande do Sul State, Brazil.

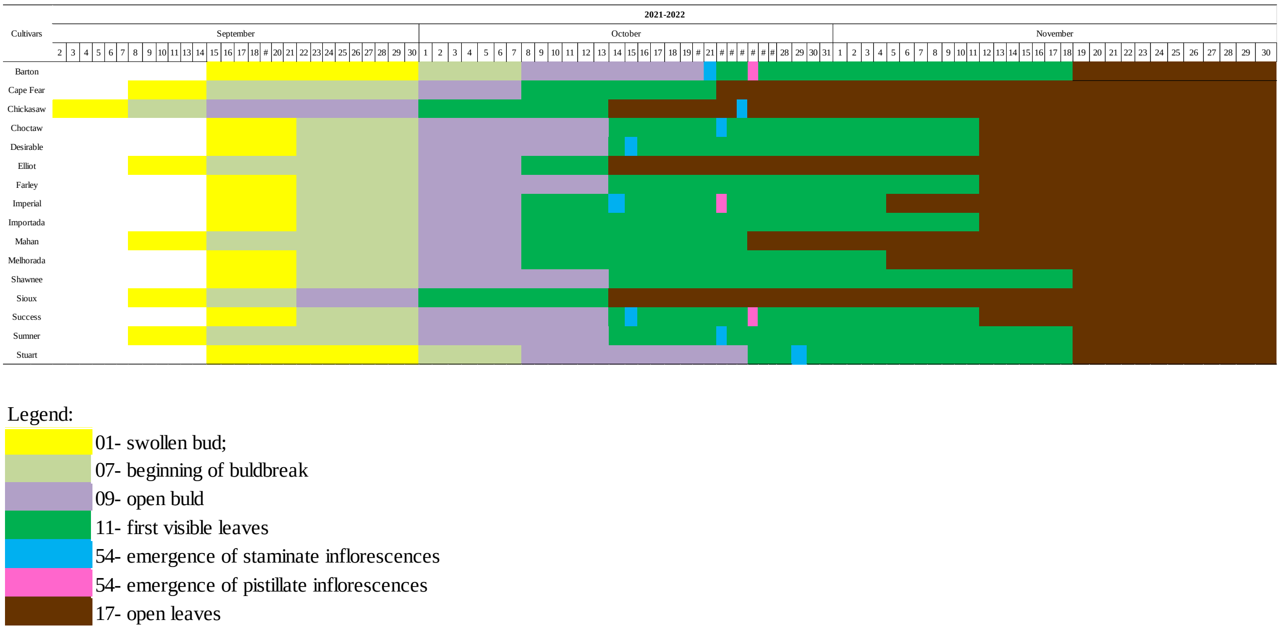


**Figure 3.** Phenological characteristics of pecan cultivars under organic system in southern Brazil during the 2021-2022 season. Pelotas, Rio Grande do Sul State, Brazil.

**Table 1.** Data on accumulated chill hours (below 7.2°C) at the Cascata Experimental Station from 2018 to 2022. Pelotas, Rio Grande do Sul State, Brazil.

| Year | Chill hours |
|---|---|
| 2018 | 378 |
| 2019 | 482 |
| 2020 | 411 |
| 2021 | 463 |
| 2022 | 466 |

Source: Agrometeorology Laboratory at the Embrapa Clima Temperado (2022).

Insufficient chill hours can affect a plant's ability to exit dormancy, impact budding uniformity, and pose pollination challenges. More accumulated chill hours in winter reduce the heat required in spring for more uniform flower sprouting, benefiting pollination and production (Melke, 2015; Wells, 2017; Crosa et al., 2021).

In terms of staminate and pistillate flower emergence, Barton, Imperial, and Success displayed both inflorescences. Climatic factors like temperature, precipitation, light, and wind directly influence pecan trees, affecting not only budbreak timing but also the intensity and distribution of flowering (Lange Junior et al., 2020b). Although edaphoclimatic conditions directly impact pecan productivity and development, genetic factors are crucial for water and nutrient foraging in deep soil layers. Rainfall intensity during critical flowering and shell-filling periods is essential for optimal productivity (Casagranda et al., 2023).

There was variability in when and how long all cultivars reached the developed leaves stage (Stage 17). Generally, cultivars reached this stage in early November, with some, like Barton, Shawnee, Sumner, and Stuart, being later than others.

Throughout the first three seasons of evaluating phenological characteristics of pecan cultivars, variations were observed both among cultivars and annually, likely due to fluctuating chill hours and temperatures. De Marco et al. (2021) emphasized the significance of a phenological scale in assessing orchard management and defining developmental stages across different regions.

Oliveira et al. (2018) and Han et al. (2018) also stressed the importance of understanding plant phenology to manage species effectively, enhancing development and boosting production. Additionally, recognizing the developmental stages of pecan cultivars aids in planning orchard treatments and understanding cultivar behavior and adaptation over the years in response to climate variations in different regions.

The height growth among the cultivars was notably distinct, with Imperial, Success, Stuart, Choctaw, Importada, Sumner, Desirable, Chickasaw, Mahan, and Barton reaching heights of 3.71, 3.69, 3.61, 3.47, 3.25, 3.23, 3.35, 3.03, 3.01, and 3.0 m, respectively. They showed similar average growth rates, except for Melhorada, which was 1.78 m shorter than Imperial (Table 2). The intrinsic genetic characteristics significantly influence the vegetative development and can impact productivity (Casagranda et al., 2023). Moreover, the application of tipping and biofertilizers has been shown to promote early-stage growth in pecan orchards (Lange Junior et al., 2020a).

**Table 2.** Plant height, grafted plant diameter, rootstock diameter, absolute growth rate, and canopy volume of pecan cultivars under organic production. Pelotas, Rio Grande do Sul State, Brazil.

| Cultivar | Plant height (m) | Grafted plant diameter (mm) | Rootstock diameter (mm) | Absolute growth rate (cm day$^{-1}$) | Canopy volume (m$^3$) |
|---|---|---|---|---|---|
| Barton | 3.00 a | 42.12 b | 49.26 b | 0.15 b | 2.66 c |
| Success | 3.69 a | 56.00 a | 60.99 a | 0.17 b | 12.54 a |
| Importada | 3.25 a | 50.39 a | 58.13 a | 0.17 b | 6.67 b |
| Melhorada | 1.93 b | 30.32 b | 30.32 b | 0.13 b | 0.62 c |
| Imperial | 3.71 a | 54.29 a | 63.22 a | 0.23 a | 8.87 b |
| Sumner | 3.23 a | 55.34 a | 68.31 a | 0.20 a | 10.49 a |
| Mahan | 3.01 a | 37.45 b | 51.40 b | 0.21 a | 3.49 c |
| Chickasaw | 3.03 a | 38.55 b | 41.37 b | 0.21 a | 4.19 c |
| Shawnee | 2.32 b | 49.38 a | 58.07 a | 0.24 a | 4.65 c |
| Elliot | 2.50 b | 39.19 b | 47.64 b | 0.18 b | 4.49 c |
| Sioux | 2.85 b | 42.70 b | 46.41 b | 0.17b | 5.49 c |
| Choctaw | 3.47 a | 46.13 a | 47.18 b | 0.24 a | 4.58 c |
| Cape Fear | 2.48 b | 31.69 b | 35.48 b | 0.19 b | 3.23 c |
| Stuart | 3.61 a | 54.89 a | 58.87 a | 0.27 a | 8.66 b |
| Desirable | 3.35 a | 50.77 a | 58.99 a | 0.24 a | 7.34 b |
| Farley | 2.71 b | 38.77 b | 40.54 b | 0.21 a | 4.52 c |
| CV (%) | 16.56 | 16.00 | 17.23 | 21.3 | 34.73 |

*Means followed by the same letter on columns do not differ statistically from each other by the Scott-Knott's test at 5% probability.

Regarding the diameters of grafted plants and rootstocks, variations among cultivars were minimal. The Success cultivar exhibited the largest diameter at 56.0 mm, comparable to Importada, Imperial, Sumner, Shawnee, Stuart, and Desirable. Similar trends were observed in rootstock diameters. Although Success did not have the highest rootstock diameter, it remained among the top performers, with diameters ranging between 49.2 and 68.61 mm. In contrast, Melhorada showed poorer performance, with its grafted plant diameter and rootstock diameter 46.48 and 47.94% smaller, respectively, than those of Imperial. Additionally, Melhorada had the lowest canopy volume at 0.62 m$^3$, aligning closely with Barton and other cultivars, with a notable 11.92 m$^3$ difference from Success, the top performer.

The absolute growth rate in plant height varied from 0.13 to 0.27 cm day$^{-1}$ among the cultivars, aligning with findings by Lange Junior et al. (2020a) from different tipping and biofertilizer treatments, which varied between 0.0683 and 0.1162 cm day$^{-1}$. Notably, canopy volumes varied significantly, with Success and Sumner exhibiting the highest volumes at 10.49 and 12.54 m³, respectively, indicating superior growth performance. However, it is important to note that these cultivars are still in their vegetative growth phase at four years old.

In the initial 2018-2019 season, symptom levels (Table 3) among cultivars showed minimal variation. However, 37.5% of the cultivars, including Chickasaw, Choctaw, Imperial, Mahan, Shawnee, and Sioux, displayed Level 3 symptoms (11 to 25% of leaflets showing disease traces). In the subsequent year, symptom severity varied, with 31.25% of cultivars reaching Levels 4 and 5. Cultivars like Cape Fear, Chickasaw, Choctaw, Mahan, and Sioux exhibited these higher severity levels, while 43.75% of cultivars, including Desirable, Farley, Imperial, Importada, Melhorada, Shawnee, and Sumner, showed intermediate scab symptoms. Cultivars such as Barton, Elliot, Success, Stuart, and Sumner demonstrated higher disease tolerance, with fewer leaf symptoms. In the final evaluation year, Barton, Elliot, and Stuart maintained low scab symptom levels.

**Table 3.** Evaluation of scab severity caused by *Venturia effusa* in pecan cultivars under organic production. Pelotas, Rio Grande do Sul State, Brazil.

| Cultivar | Scab severity level | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2018-2019 | | | | | 2020-2021 | | | | | 2021-2022 | | | | |
| | Nov | Dec | Jan | Feb | Mar | Nov | Dec | Jan | Feb | Mar | Nov | Dec | Jan | Feb | Mar |
| Barton | 1 ns | 1b | 2b | 2b | 2b | 2b | 2d | 2d | 2d | 2d | 1b | 2c | 2d | 2d | 3c |
| Cape Fear | 1 | 2a | 2b | 2b | 2b | 2b | 4b | 5a | 5a | 5a | 2a | 2c | 4b | 5a | 5a |
| Chickasaw | 1 | 1b | 2b | 3a | 3a | 3a | 5a | 5a | 5a | 5a | 1b | 4a | 5a | 5a | 5a |
| Choctaw | 1 | 2a | 3a | 3a | 3a | 2b | 3c | 4b | 4b | 4b | 2a | 4a | 5a | 5a | 5a |
| Desirable | 1 | 1b | 2b | 2b | 2b | 2b | 2d | 3c | 3c | 3c | 1b | 2c | 3c | 3c | 4b |
| Elliot | 1 | 1b | 2b | 2b | 2b | 2b | 2d | 2d | 2d | 2d | 1b | 1d | 2d | 2d | 3c |
| Farley | 1 | 1b | 2b | 2b | 2b | 2b | 2d | 3c | 3c | 3c | 1b | 2c | 3c | 4b | 4 b |
| Imperial | 1 | 1b | 2b | 3a | 3a | 2b | 2d | 3c | 3c | 3c | 1b | 2c | 4b | 5a | 5a |
| Importada | 1 | 1b | 2b | 2b | 2b | 2b | 2d | 3c | 3c | 3c | 1b | 4a | 5a | 5a | 5a |
| Mahan | 1 | 2a | 3a | 3a | 3a | 2b | 2d | 4b | 4b | 4b | 1b | 1d | 4b | 5a | 5a |
| Melhorada | 1 | 1b | 2b | 2b | 2b | 2b | 2d | 3c | 3c | 3c | 1b | 2c | 4b | 4b | 4b |
| Shawnee | 1 | 1b | 2b | 3a | 3a | 2b | 2d | 3c | 3c | 3c | 1b | 1d | 3c | 4b | 4b |
| Sioux | 1 | 1b | 3a | 3a | 3a | 3a | 4b | 5a | 5a | 5a | 2a | 3b | 5a | 5a | 5a |
| Success | 1 | 1b | 2b | 2b | 2b | 2b | 2d | 2d | 2d | 2d | 1b | 1d | 3c | 4b | 4b |
| Sumner | 1 | 1b | 2b | 2b | 2b | 1c | 2d | 3c | 3c | 3c | 1b | 2c | 2d | 3c | 4b |
| Stuart | 1 | 1b | 2b | 2b | 2b | 2b | 2d | 2d | 2d | 2d | 1b | 1d | 2d | 2d | 3c |

*1 = no symptoms in leaflets; 2 = up to 10% of traces; 3 = from 11 to 25%; 4 = from 26 to 50%; and 5 = from 51 to100%. **Means followed by the same letter on columns do not differ statistically from each other by the Scott-Knott's test at 5% probability.

Symptom severity varied across pecan cultivars. It could be attributed not solely to genetic differences but also to varying climatic conditions (Figures 4 and 5) during the evaluated seasons. This is particularly evident in the last two seasons, where environmental conditions were conducive to the pathogen's development. For the disease to manifest, the pathogen requires both a genetically susceptible host and an environment that supports its proliferation. These factors combined likely account for the observed differences in disease symptoms among the various cultivars over the course of the study.

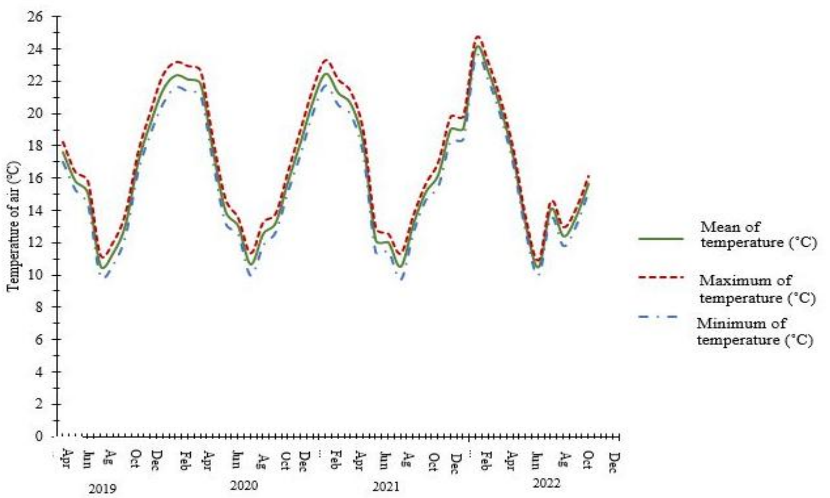


**Figure 4.** Mean and maximum temperatures (°C) in Pelotas, Rio Grande Sul State, Brazil (2019-2022). Source: Embrapa Clima Temperado (2022).

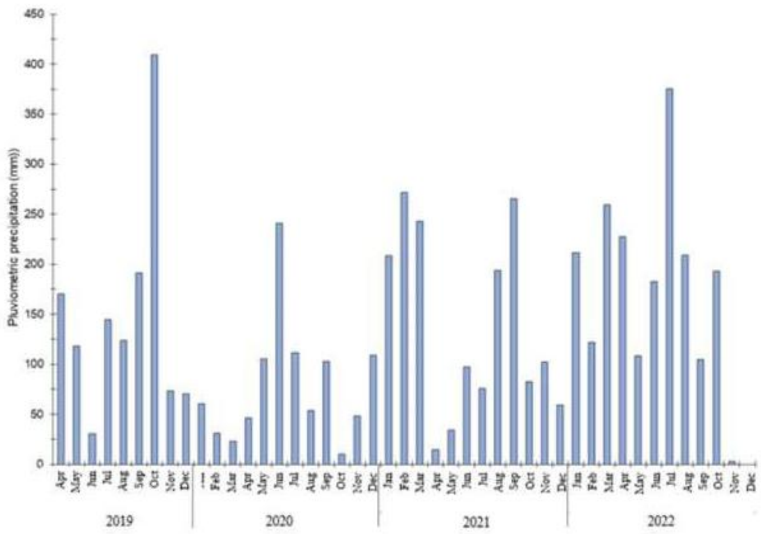


**Figure 5.** Rainfall (mm) from 2019 to 2022. Pelotas, Rio Grande Sul State, Brazil. Source: Embrapa Clima Temperado (2022).

Scab significantly impacts the health and productivity of pecan orchards, with potential losses varying due to different climatic conditions and management practices. In regions such as the southeastern USA, parts of South America, and South Africa, where rainfall is common during the growth season, scab can lead to substantial yield reductions (Bock et al., 2017; Conde-Innamorato et al., 2022). Reuveni et al. (2022) noted that in areas where pecans are cultivated, rain typically coincides with warm temperatures from spring through late autumn. Conversely, in countries with a Mediterranean climate like Israel, winters are cold and rainy, followed by mild, drier springs and summers, influencing the disease dynamics.

Regarding cultivar susceptibility, Barton, Elliot, Success, and Stuart demonstrated lower susceptibility to scab over three years of study, showing mild severity levels compared to other cultivars. In contrast, Shawnee exhibited high susceptibility (5.4), a finding supported by Walker et al. (2018), who observed significant disease symptoms in this cultivar in Brazil, indicating its high vulnerability to scab. Similarly to our findings, Bock et al. (2020) recognized Elliot's lower susceptibility, underscoring its consistent tolerance across different seasons.

In experimental settings, cultivars like Cape Fear, Chickasaw, Choctaw, Mahan, Imperial, and Sioux exhibited a high susceptibility to scab, as evidenced by severe symptom manifestation. Conversely, Barton, Elliot, and Stuart demonstrated notable tolerance to the disease. Within an organic production framework, choosing cultivars with lower susceptibility to scab is a strategic approach. Effective cultural practices extend beyond selecting resistant or tolerant varieties to include cultivating healthy seedlings, implementing low-density planting, conducting regular pruning, and ensuring balanced nutrition.

The variability in phenology, growth, and response to disease among pecan cultivars enriches our understanding of their adaptability and suitability for agroecological systems, particularly in southern Brazil. Emphasizing the development of disease-tolerant cultivars and the adoption of strategic orchard management practices can help reduce the incidence and severity of plant diseases. This is crucial as the spread of crops into new areas often coincides with the emergence of biological disorders (Savian et al., 2021). Moreover, ongoing research into the phenology, pest presence, and disease incidence is essential to better understand the reproductive behaviors of these cultivars and predict their long-term productivity.

## Conclusion

In the climate of southern Rio Grande do Sul State, Brazil, this study identifies Chickasaw, Cape Fear, Sioux, and Elliot as the most precocious pecan cultivars in terms of budbreak, while Barton, Stuart, and Sumner are the most delayed. Although all tested pecan cultivars are vulnerable to scab to some degree, Cape Fear, Chickasaw, Choctaw, Imperial, Mahan, and Sioux exhibited the highest severity levels of the disease. Conversely, Barton, Elliot, Success, and Stuart showed less susceptibility to scab compared to the other cultivars studied. In terms of early growth, Sumner, Stuart, Desirable, Success, and Imperial stood out, demonstrating the most significant early growth rates among the cultivars tested.

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