Annals of West University of Timişoara, ser. Biology, 2020, vol. 23 (2), pp.219-234

INVESTIGATIONS ON THE USE OF LEAF AREA IN VARIOUS COMPARATIVE STUDIES IN PLANTS

Bianca-Alexandra BÎLC

West University of Timișoara, Faculty of Chemistry, Biology, Geography, Department of Biology-Chemistry
**Corresponding author's e-mail: bianca.bilc98@e-uvt.ro*
Received 20 July 2020; accepted 23 December 2020

ABSTRACT
The leaf is the most important photosynthetic organ of plants. It participates in many physiological processes, working to intercept light and being responsible for carbon retention. The shape of leaves and their size differ depending on several factors. The parameters that determine the size of the leaf, such as leaf area, are often used to measure the response of plants to different environmental conditions, or to certain stressors. In this paper we wanted to identify the current level at which the study of this parameter is. To conduct this study we used the search engine "Google scholar". Following specific searches we obtained results that helped us to conclude that the leaf area is a parameter of great importance in various types of studies, and despite the fact that in the last 10 years the study on this parameter has had much Researchers' interest in the development of foliar area measurement methods, they can still be studied and optimized to obtain more efficient, cheap and fast methods of determination.
KEY WORDS: *leaf, leaf area, methods, utilizations, dimensions, plants*

INTRODUCTION

The leaf is the most important photosynthetic organ of plants and is involved in many physiological processes. During long-term evolution, plants have developed different forms of leaves to allow them to survive and win fierce interspecific competition in plant communities (Nicotra et al. 2011). The leaves of the plants show great variations in shape, from an elliptical leaf to palmate leaves (Shi et al. 2019a). The leaves work to intercept light and are responsible for fixing carbon (Yang et al. 2009). The shape of the leaves is a specific morphological feature of each plant species, and the ratio between the linear dimensions and the surface of the leaves depends on the amount of indentations at the edge of the leaf blade, among other factors (Pinto et al. 2008). Because plant species and even cultivars within the same species have certain patterns of leaf morphology traits, it appeared the necessity to generate specific models to estimate leaf area (Toebe et al. 2019).

The area of the leaves is often used to measure plant growth, being directly related to photosynthesis and sweating rate, among other physiological processes. In this regard, Blanco & Folegatti (2005) pointed out that the leaf area is a key variable in studies of plant growth, photosynthetic efficiency, evapotranspiration and fertilizer response, but also in measuring the response to irrigation. As stated in Favarin et al. (2002), leaf area is used as an indicator of yield and may be useful for technical evaluations of the crop, such as sowing density, irrigation, fertilization and application of agrochemistry (Toebe et al. 2019). Direct or indirect methods can be used to measure the leaf area of a particular crop. Among the indirect methods, there are mathematical models that link the area of the leaves with the linear dimensions of the leaves, such as length, width or product of both, these models can be generated, validated and applied in different stages of plant development and growth, are non-destructive, and have high precision and low costs (Toebe et al. 2019). Different types of studies have been conducted to generate models that allow the prediction of leaf area depending on leaf size, such studies being performed on the leaves of several species, for example tomatoes (Blanco & Folegatti, 2003), bedding plants (Giuffrida et al. 2011), pumpkin (*Cucurbita pepo* L.) (Toebe et al. 2019), soybeans (Adami et al. 2008), cucumbers (Cho et al. 2007), etc.

The area of the leaves is an important functional feature of the leaves and is related to the length and width of the leaves. In the study of Shi et al. (2019a) four types of representative leaf shapes (elliptical, sectoral, linear and triangular shapes) were studied. The Montgomery parameter was derived from the estimation range for each leaf type the value that should result (Shi et al 2019a). The results obtained show the coefficient of proportionality of leaf area to the product of leaf length and width varies only in a small range, maintaining the allometric relationship for leaf area and thus suggesting the proportional relationship between leaf area and leaf length product × width. The ratio between leaf length and width generally remains stable during leaf evolution (Shi et al. 2019a). This proportionality has been confirmed on different crops with different leaf shapes, such as castor (*Ricinus communis* L.) (Palaniswamy & Gomez 1974), populations of *Parrotia subaequalis* (HT Chang), two species of tulips with their hybrid, species of *Bambusoideae*, *Lauraceae* species, *Oleaceae* species and 12 *Rosaceae* species, where between 150-500 leaves were used for each population or for each species (Shi et al. 2019a, Shi et al. 2019b). To measure the area of the leaf, various methods of estimating it have been developed, by shooting, scanning or using other devices that use measurement algorithms within a delimited contour. These methods have been developed and adapted to various agricultural crops (Perksen, 2007, Erdoğan, 2012). The differences that can be observed between the measured leaf area and the predicted leaf area are statistically small enough, which makes this model a cheap method of measuring the total green area in crop development and growth studies. The leaf area can be easily estimated by measuring only the length and width of the bean leaves. Calculation software, such as MS Excel or

Libreoffice Calc., can be useful for calculating the leaf area using this model, taking into account the measured data (Erdoğan, 2012).

Knowing the values of the leaf area is useful in studies such as those that examine the scaling relationships between leaf flammability and leaf size, thus having the ability to determine which type of leaves are more flammable and have a high potential to increase the spread of vegetation in the sclerophyll dry forest (Murray et al. 2013). And in the case of studies that target the heat exchange between the leaf and the ambient air, the values of the leaf area are also important (Wright et al. 2017). The size of the leaves were on average larger in the equatorial regions and smaller towards the poles. A quadratic regression appropriate to the latitude explained 28% of the global variation, with almost identical trends in single-leaf and compound-leaf species (Wright et al. 2017). Laboratory studies on artificial leaves suggest that the thermal dynamics of the leaves is strongly influenced by the size and two-dimensional shape of the leaves and the thickness of the associated boundary layer. Therefore, warm environments are said to favor selection for small, narrow or dry leaves. Empirical evidence from real leaves in field conditions is rare and is traditionally based on point measurements that do not capture the spatial variation of heat load (Leigh et al. 2017). In a similar way to the size, the shape of the leaf can potentially affect heat transfer: the lamina of a leaf with notched edges or lobes works like many small leaves, making them much more suitable for hot areas, exposed to those that are less notched or an entire leaf for an equivalent area. Despite the apparent benefit of indented leaves in preventing excessively high leaf temperatures, there is little evidence that indented leaf forms occur more frequently in warm environments than elsewhere (Moles et al. 2014, Leigh et al. 2017). The process of calculating the transpiration rate uses the temperature of the leaf from the contributions of the environment (radiation load, air temperature, wind speed) and the properties of the leaf (leaf width, thickness, spectral absorbance and thermal capacity, measured or estimated in the study) (Leigh et al. 2017).

The use of shading nets helps to relieve the thermal stress of vegetable crops. Active photosynthetic radiation and the temperature of the air, leaves and roots decreased with increasing shade. Despite the increase in the leaf area of the plants, there was an increased water content with the simulation of an increased level of shade, which indicates a low water consumption. As the shade level intensified, the total area of the plant's leaves, the area of the individual leaves and the individual weight of the leaves increased, while the number of leaves per plant and the specific weight of the leaves decreased. Morphological changes, such as taller plants and thinner, larger leaves, have probably improved light capture in shady conditions compared to unshaded plants. High levels of shade reduced leaf temperature and excessive leaf perspiration, but led to reduced leaf photosynthesis.

Thus, moderate shade levels (30% and 47%) were the most favorable for the growth and functioning of bell pepper plants (Díaz-Pérez, 2013).

Increased risk of adverse effects caused by exposure to high temperatures, intense solar radiation is as high as the exposure to air pollution. The increase in this risk also occurs due to air pollution in the vicinity of high-capacity main roads and beyond. Trees intercept air particles that are subsequently removed from the crown by resuspension, rain, and leaf abscission (Freer-Smith et al. 2004, Nowak et al. 2013). Using empirical estimates of deposition rate, these reports estimate the total particles removed from trees (usually PM_{10}) on a large-scale or a local scale (Tong et al. 2015). Using deposition rates from the literature, it was calculated whether vegetation walls can cause a 40% reduction for NO_2 and a 60% reduction for PM_{10} (Pugh et al. 2012, Tong et al. 2015). Although the deposition behavior of different particle sizes is well known in atmospheric science, this is usually ignored or overlooked in the planning and design of green space to mitigate air pollution (Tong et al. 2015).

Air pollution poses a serious threat to the health and quality of life of the urban population, reducing the life expectancy of residents in heavily polluted areas by more than a year (WHO, 2003), especially children and people with lung and heart disease. Harmful particles (PM) in air pollution are mainly of anthropogenic origin (Bosko et al. 2005) and comprise a mixture of heavy metals, black carbon, polycyclic aromatic hydrocarbons and other substances suspended in the atmosphere (Bell et al. 2011, Sæbø et al. 2012). A study conducted in Shanghai, China, found that compared to external urban forests, PM concentrations decreased by 9.1%, SO_2 by 5.3% and NO_2 by 2.6% at a distance of 50–100 m in a forest (Yin et al. 2011, Sæbø et al. 2012).

Biomonitoring of pollutants can be achieved by analysis of tree leaves and bark, due to relatively small analyzes costs and because it is easy to collect plant materials for analysis (Sawidis et al., 2011, Sæbø et al., 2012; Ianovici et al, 2020). Previous studies have revealed specific pathways with thick branches and a higher ratio between the total leaf area and the cross-sectional areas of the stems (Sun et al. 2006, Yang et al. 2009). Consistent with the model prediction, the individual leaf area and the total leaf area, grow at a slower rate than the individual mass of a leaf and the whole mass of the plant. While the content of food and free water available, the unit mass of the leaves and the size of the leaves increases (Milla & Reich 2007, Yang et al. 2009).

Also, the leaf area has various functions, just as important in trade, in terms for the plants that are marketed. Plants such as *Monstera deliciosa* are put up for sale only when at least one perforated leaf appears on them. In order to obtain this type of leaf, studies have been performed in order to speed up this process (De Lojo & Di Benendetto, 2014).

MATERIAL AND METHODS

To get the results, we performed systematic searches using the search engine "Google scholar". By using this search engine we had the opportunity to easily access a verry big part of the literature. The results obtained were represented by articles, theses, books and abstracts, from various disciplines and sources, some of them accessible free of charge. By using this platform we had the certainty that the materials underlying the study will be relevant to the academic environment.

To perform the searches we used the terms specific to the topic in English. The first search was for the keyword "leaf size". We continued by choosing the specific time interval for which we wanted to perform the search and then unchecked the boxes related to the inclusion of mentions and patents to obtain only the values related to the number of articles published on this topic. Next, for all searches, we followed the number of articles published on those topics in the period 2010-2020. The next step was to do a specific search with the keywords for each year from the period 2010-2020, in order to assess the increase or decrease of interest in publishing research or study articles on the literature.

In the next stage we performed a parallel search to identify the number of items that involve the use of foliar area depending on the environment in which they were made, urban or rural. Following the searches we wanted to make a deeper subclassification of the use of the parameter depending on the environment where it was used, but also the purpose of the study for which it was used. For each search made between 2010-2020 we conducted searches using the same keywords for the period 2000-2010, to see the evolution of interest in these topics over the last 20 years. Thus, we obtained percentages of increasing or decreasing the interest for the different topics, based on the increase or decrease of the number of published articles.

All values were tabulated using MS Word, and the graphs made in the paper were made using MS Excel.

RESULTS AND DISCUSSIONS

The problems of the last two decades have materialized in a large number of studies on their understanding and solution. If we consider a particular case, the studies in which the parameter "foliar area" is involved we can observe that it has a special importance, as evidenced by the large number of studies in which it is used (Table 1). If we perform a search by the parameter "leaf size" the results returned by the search engine are mostly articles that study molecular biology, plant physiology and genetic studies. Instead, if we perform a simple search by the key words "leaf area" we will obtain several studies related to problems of biomonitoring, bioaccumulation of compounds, climate change, pollution, but also studies that analiyze the effects on agriculture, and the influence of factors such as light, temperature, humidity on plant development, the leaf area playing an important role in this studies in understanding these problems.

TABLE 1. Number of items searched by using the keywords ”leaf size” and ”leaf area”

	Obtained results	
	2000-2010	**2010-2020**
leaf size	1.480.000	1.420.000
leaf area	1.610.000	1.290.000

Table 1 shows that studies using the leaf area parameter are more numerous in the period 2000-2010 compared to those related to its leaf size, but we can also see that the number of studies targeting these parameters shows a slight decline in the last two decades in the publication of articles. Carrying out more specific searches, for determined periods (Fig. 1), in the interval 2010-03.06.2020, the decrease of the interest in publishing articles that include the “leaf area” parameter is highlighted. For the period 2010-2020, the highest number of published articles was registered in 2012, more precisely 150.000 articles, and the lowest value was registered in 2020, a number of 31.100 articles by the middle of the year. If we take in consideration the year 2019 (64.900 results) to calculate a percentage of the decrease of interest in terms of publishing articles on this topic, we get a difference of 56,73%.

The studies of research and studies of review showed variations in the interest of publishing articles involving the “leaf area” parameter (Table 2). In 2010, 115.000 research articles were published, much more compared to 2019, when only 55.400 articles on this topic were published and much less in 2020 (only 39.700 articles published up to mid-year). While interest in research articles that include this parameter has decreased, interest in publishing articles on the study of literature that includes this parameter has remained relatively the same, with approximately 63.800 articles published in 2010 compared to 2019 when they were published, 50.100.

In total, in the period 2000-2010, 1.380.000 research articles were published containing the parameter "leaf area", these values registering a slight decrease in the last 10 years, respectively 2010-2020, the value of these published articles being of approximately 1.330.000 items (Table 3). Even though research articles show a slight decline of approximately 3,62%, the number of review articles is increasing, in the last 10 years a number of approximately 1.100.000 articles have been published compared to 606.000 articles published in the period 2000- 2010.

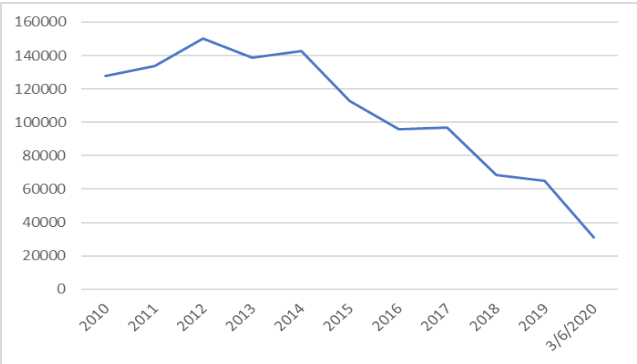

FIG. 1 Graph of the evolution of the publication of articles that include the parameter "leaf area" in the period 2010-03.06.2020

TABLE 2. Values obtained for the differentiated search for articles that include the "leaf area" parameter according to the type of article, "leaf area research" or "leaf area review"

Year	Obtained results	
	leaf area research	leaf area review
2010	115.000	63.800
2011	120.000	69.600
2012	136.000	78.000
2013	129.000	81.100
2014	119.000	81.000
2015	108.000	77.500
2016	94.300	70.100
2017	92.100	73.700
2018	70.200	69.300
2019	55.400	50.100
03-06-2020	39.700	26.700

TABLE 3. Values of the number of articles published in the last two decades with the increase/decrease percentages recorded for each parameter ("-" - decrease , „"+" – increase)

Keywords	Obtained results for the period		Increase/decrease percentages
	2000-2010	2010-03.06.2020	
leaf area	1.610.000	1.290.000	- 19,87%
leaf area research	1.380.000	1.330.000	- 3,62%
leaf area review	606.000	1.100.000	+ 81,51%
leaf area urban	168.000	204.000	+ 21,42%
leaf area rural	131.000	115.000	- 12,22%
leaf area climate change	90.200	172.000	+ 90,68%
leaf area pollution	120.000	137.000	+ 14,16%
leaf area pollution urban	30.600	31.300	+ 2,28%
leaf area pollution rural	20.700	17.700	- 14,50%
leaf area climate change pollution	42.700	18.600	- 56,45%
leaf area biomonitoring	9.060	16.900	+ 86,53%
leaf area biomonitoring urban	4.540	11.100	+ 144,49%
leaf area biomonitoring rural	2.430	5.650	+ 132,51%
leaf area measurement	281.000	461.000	+64,05%

Despite the fact that there is a general decrease in the use of this parameter, it seems that the leaf area it is still important in several types of studies where it is associated with other different parameters.

For example, in the last 10 years, 204.000 articles have been made that target this parameter in studies conducted in the urban environment. There was an increase of 2,28% in the publication of articles related to the utility of foliar area in the study of pollution in urban areas, being published 31.300 articles (Table 3). Also, the "leaf area" parameter is important in biomonitoring studies made in urban areas, therefore there is an increase of interest of about 144,49% in the last 10 years compared to the last decade (Table 3).

The importance of this parameter in climate change monitoring studies should not be ignored either. The studies that target the climate changes and use the foliar area as an important parameter, recorded an increase of interest of approximately 90,68% in the number of articles published in the last decade.

"Leaf area" is a parameter with great implications in pollution studies, this being supported by the large number of articles published in this regard, namely 120.000 articles in the period 2000-2010, respectively 137.000 articles in the period 2010-2020, registering an increase of approximately 14,16% (Table 3).

Most studies targeting the pollution in the rural area, in association with the parameter "leaf area" have a decreasing trend. The only type of studies that seemed to be growing are represented by those of biomonitoring in rural areas, which show an increase in the number of published articles by approximately 132,51% (Table 3).

Of particular importance is the parameter "leaf area" in studies that determine the concentrations of pollutants from various sources. There are approximately 17.400 published articles aimed at the study of suspension particles, using the leaf area. There are also 30.200 articles that study the influence and effects of heavy metals on plants by determining their concentrations in plants, but also the effects they have on plant development, the leaf number, leaf area and total leaf area (Table 4).

TABLE 4. Values obtained for searches by different types of pollutants in the period 2000-2010 and for the period 2010-2020

Search by polluting nature	Obtained results for the period	
	2000-2010	2010-03.06.2020
leaf area particulate matter	19.300	17.800
leaf area particulate matter research	20.700	17.400
leaf area particulate matter review	19.000	17.800
leaf area heavy metals	24.400	30.200
leaf area heavy metals accumulation	22.200	18.000

The “leaf area” parameter is also used in studies to identify the effects of chemical elements and various compounds that can act on plants either naturally, by their presence in the environment, or by artificial methods, introduced by man, intentionally or accidentally. Such studies are conducted in order to understand the environmental conditions necessary for plants to show optimal development. The influence of these compounds can also be manifested on the productivity of the plant or its resistance under stress conditions, these influences were associated with the value of the parameter "leaf area".

In Table 5, we can see very high values of the number of published articles regarding the association of the value of the leaf area with various elements. Of the items searched in the list of this study, nitrogen was the most studied item, with approximately 485.000 articles published in the last decade. Nitrogen receives special attention due to its use in many combinations with other elements for example potassium (K) or/and phosphorus (P) as a fertilizer (Ata-Ul-Karim et al. 2014). In areas with large populations, such as China, or with less fertile soils, the environment is constrained by heavy grain production, so there is a need to know the minimum and maximum thresholds that can be used to obtain good crops in the future. Studies of this type have used the rate of increase in the value of the leaf area to determine the optimal values, values that enhance the growth and development of the plant and do not adversely affect the environment (Ata-Ul-Karim et al. 2014). By performing the proportions and dilution curves of nitrogen in accordance with the percentage of growth of the leaf area in different stages of plant growth, it was possible to identify applicable values of the amount of nitrogen needed per hectare of crop, but also of the influences that the content of water has it in association with the percentages of fertilizers used for different plants (Moosavi, 2012, Ata-Ul-Karim et al. 2014).

Sodium is the second most studied element in association with the leaf area in our list of elements compiled (Table 5). For the association between these two keywords we obtained 149.000 articles published in the last 10 years. This large number of published articles is due to the interest for the influence of sodium (Na) in osmolarity processes and related to the delay of plant senescence. To determine the influence of Na, the values of the leaf area, the leaf size, as well as the water content of the leaves after one month, respectively two after the treatment of the culture with Na were compared. The results consisted in an expansion of the leaf parameters due to osmoregulatory functions, observing effects on the delay of the senescence process (Battie-Leclau et al. 2013).

Iron (Fe) is the element that occupies the third position in the search list (Table 5), for their association with the parameter "leaf area" the search engine returned 95.200 articles which were published in the last decade. This large number of published articles is due to the fact that Fe is an essential microelement in plant growth. The effects of this and other microelements, such as manganese, have been studied by reference to the leaf area under different light conditions (Matsoukis et al. 2015). The activity of these microparticles resulted in an increase in plant biomass and chlorophyll. For *Arabidopsis thaliana*, zerovalent iron nanoparticles activated plasma H^+-ATPase activity. The increase in ATPase activity caused a decrease in apoplastic pH, an increase in leaf area, but also an increase in the opening of the stomata opening (Kim et al. 2014).

Other metals have been studied due to the fact that there have been consequences of changes in environmental conditions, for example in the study "Pepper (*Caspicum annum* L.) how the culture is affected by the level of shading: Microclimate, Plant growth, Gas exchange and The level of nutrient concentration in the leaf ", Díaz-Pérez (2013) evaluated the effects of shading level on microclimate, plant growth, leaf gas exchange and mineral nutrient content of bell pepper culture. *Camelot*, *Lafayette*, *Sirius* and *Stiletto* bell peppers were grown at 0%, 30%, 47%, 62% and 80% shading levels. As the shade level intensified, the total area of the plant's leaves, the area of the individual leaves and the individual weight of leaves increased, while the number of leaves per plant and the specific weight of leaves decreased. In addition to the main observations of the study on changes in leaf area under shading conditions, he also made observations on changes adjacent to the variation of leaf area due to changes in lighting conditions. For example, the values of chlorophyll index (CI), normalized with the specific weight of leaves were related to the nitrogen concentration of leaf (N) and increased with increasing shade. Concentrations of nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), sulfur (S), aluminum (Al) and boron (B) in the leaf increased with increasing levels of shading. Thus, following the observations made and the values obtained Díaz-Pérez (2013) showed that moderate levels of shading (30% and 47%) were the most favorable for the growth and functioning of bell pepper plants (Díaz-Pérez, 2013).

Values not as high as those of nitrogen, sodium or iron, but also considerable were obtained for elements such as uranium, barium and vanadium (Table 5). For searches made by the phrase "leaf area uranium" we obtained 13.200 articles published in the period 2010-2020. The interest given to the study of this element in association with the leaf area is due to the stressor effects it has alone or in combination with cadmium (Table 5) (Horemans et al. 2011). Also, studies aimed at the association between uranium and foliar area are biomonitoring studies especially around uranium mining areas (Gieré et al. 2012).

Barium (Ba) is also an element that is studied in relation to the leaf area, following the search made by combining these two keywords we obtained 10.500 results (Table 5). Barium is a toxic element for most plants, and to identify the effect of Ba on plants, the growth parameters, the bioaccumulation of Ba and the concentration of macronutrients were followed after treatment with Ba. The main symptoms of toxicity of this element are interventional chlorosis followed by the appearance of necrotic spots in the leaf area (Monteiro et al. 2011).

TABLE 5. Table with values of the number of items found after searches by chemical elements

	Chemical elements and various compounds	Results obtained between 2010-03.06.2020
leaf area	Nitrogen	485.000
	Sodium	149.000
	Iron	95.200
	Silver	86.300
	Copper	68.100
	Potassium	55.700
	Zinc	45.600
	Magnesium	28.800
	Cadmium	26.300
	Nickel	24.000
	Manganese	23.100
	Mercury	23.100
	Arsenic	19.500
	Aluminium	19.200
	Cobalt	18.500
	P_2O_5	17.900
	Titanium	17.800
	Selenium	17.700
	Chromium	17.700
	Platinum	17.700
	K_2O	17.100
	Uranium	13.200
	Barium	10.500
	Vanadium	10.300

Vanadium completes the list of searches (Table 5) in terms of chemical elements in association with the leaf area, an association for which we obtained 10.300 articles published in the last decade. Vanadium is present in the soil as a result of pollution with petrochemical waste, chemical pollution, but also pollution resulting from road traffic. Contamination of plants with vanadium leads to chlorosis, small plant size (roots, stems, shoots), but also smaller size of the leaf area as the concentration of the element increases in the soil (Sánchez et al. 2014).

The importance of studying the parameter in agriculture should not be ignored either. Interest in this field has increased in the last decade compared to the previous decade. For the search "leaf area agriculture" we obtained 105.000 articles for the period 2010-2020, with 4,5 more articles published than in the period 2000-2010 (Table 6). Studies on the importance of foliar area for tests performed on crop plants show an increase in the number of articles published in the last 10 years, publishing 85.900 articles on this topic.

TABLE 6. Number of articles with implications in agriculture published in the last 20 years

Keywords	Obtained results	
	2000-2010	2010-03.06.2020
leaf area agriculture	22.900	105.000
leaf area crop plants	63.900	85.900
leaf area annual plants	207.000	253.000
leaf area biennial plants	16.700	17.300
leaf area perennial plants	41.600	20.400

From table 6 we can see that annual plants are more used for studies, for the chosen period being published a number of 253.000 articles, much more compared to the number of studies conducted on biennial or perennial plants, where we obtained 17.300 articles after searching, respectively 20.400.

Studies in the field of agriculture are closely related to the relationship of plants with fertilizers, environmental conditions (light, humidity, temperature, etc.), the interaction between plants with them, but also the influence that these factors have on plant growth and development.

Obtaining a fast and efficient method for determining the biophysical parameters of crops is significantly important in agricultural and ecological applications. By using the leaf area, the total green area of the crops can be estimated. The methods that are based on estimating the value of the leaf area are quite precise, cheap and often non-invasive methods (Li et al. 2015, Ianovici et al. 2015). Also, knowing this parameter (leaf area) is important for tests aimed at carbon exchange and light absorption at the leaf level for different plants. The differences obtained between the values given by the estimation model and the values observed for the foliar area of the plants are very small, so this procedure can be used to estimate as accurately as possible the total green area of the crop plants (Erdoğan, 2012).

In addition to crop plants, other plants for biomonitoring purposes are also studied in association with the foliar area. From the list of plants searched (Table 7) we can see that the largest number of published articles is for the genus *Citrus* (33.500 articles).

The most studied crop species in association with the "leaf area" parameter is *Zea mays* (24.700 articles), followed by *Triticum aestivum* with 19.700 published articles. *Oriza sativa* and *Hordeum vulgare* are on the next positions in the top of the most studied cereals chosen for searches with 18.900 published articles, respectively 17.900 (Table 7).

The species of *Phaseolus vulgaris*, *Nicotiana tabacum*, *Cucumis sativus*, *Solanum lycopersicum*, *Gliciene max*, *Solanum tuberosum*, *Letuca sativa*, *Beta vulgaris*, *Helianthus annuus* and *Brassica oleracea* are relatively studied plants for them obtaining values of the number of articles published in 2010-2020. , in the range of 17.700 and 17.000 (Table 7).

Species such as those of the genera *Quercus*, *Tilia*, along with *Lemna*, *Salix* and *Taraxacum officinale*, along with other plants for use in biomonitoring have returned, after the search associated with the leaf area, different values of the number of published articles, values presented in Table 7.

TABLE 7. Values of the number of articles for different plant species published in the period 2010-2020, in association with the leaf area parameter

	Plant	Obtained results between 2010-03.06.2020
leaf area	*Citrus*	33.500
	Quercus	28.300
	Zea mays	24.700
	Arabidopsis thaliana	20.100
	Triticum aestivum	19.700
	Oryza sativa	18.900
	Acer	18.500
	Fagus	18.400
	Hordeum vulgare	17.900
	Phaseolus vulgaris	17.700
	Nicotiana tabacum	17.600
	Cucumis sativus	17.400
	Solanum lycopersicum	17.300
	Glycine max	17.300
	Solanum tuberosum	17.200
	Lactuca sativa	17.100
	Beta vulgaris	17.100
	Amaranthus	17.100
	Helianthus annuus	17.100
	Gossypium	17.000
	Brassica oleracea	17.000
	Avena sativa	16.600
	Tilia	16.200
	Ocimum basilicum	16.100
	Punica granatum	15.200
	Solanum melongena	14.800
	Coffea arabica	14.200
	Lemna	13.400
	Cucurbita pepo	12.400
	Robinia pseudoacacia	12.400
	Canabis sativa	12.100
	Taraxacum officinale	11.200
	Platanus	10.500
	Salix alba	9.850
	Aesculus	8.440
	Hedera helix	6.320
	Ambrosia artemisiifolia	4.300

Due to the large number of studies on plants in which the values of the foliar area are of major importance, the need to optimize the methods for determining their exact values have led to increased interest in this regard to the subject. Studies to optimize these methods were also carried out by Erdoğan (2012) in which he calculated the required determination constant R^2 to estimate as accurately as possible the value of the leaf area for genotypes, other than *Vicia faba,* grown in the Mediterranean climate, using the values of length and width (Erdoğan, 2012).

Not only the interest in foliar area measurement methods has increased but also the interest in using this value in determining the influence that exogenous factors have on plants. Thus, in the period 2000-2010, 281.000 articles were published in this regard. In the next 10 years the number of articles published increased by about 64,05% (Table 5), more precisely 461.000 articles were published.

To measure the area of the leaf, various methods of estimating it have been developed, by shooting, scanning or using other devices that use measurement algorithms within a delimited contour. These methods have been developed and adapted to various agricultural crops (Perksen, 2007). The differences that can be observed between the measured leaf area and the predicted leaf area are statistically small enough, which makes this model a cheap method of measuring the total green area in crop development and growth studies. The leaf area can be easily estimated by measuring only the length and width of the leaves (Erdoğan, 2012). A study of this kind was conducted by Ianovici et al. (2015) to demonstrate that leaf area and fractal size are sensitive parameters that can be used effectively for habitat biomonitoring. Also, the study conducted on several species, presents methods for measuring fast, cheap and non-invasive the leaf area (Ianovici et al. 2015).

CONCLUSION

The leaf area is a parameter with multiple valences and with a special importance for conducting many studies. The need to determine the values of the leaf area arose from the use of this parameter so intensely in studies on various topics. Knowing the value of this parameter helps us to evaluate the condition of the plant, the influence of exogenous factors on living conditions through the effects they have on plants. Optimizing the already existing methods of measuring the leaf area, but also the development of new algorithms and methods for determining the values of the leaf area as accurate, cheap and fast are problems that still need to be addressed. Due to the implications of the foliar area in studies in so many fields, it shows us how important a single leaf of a plant is and how much information it can give us about the general condition of the plant as a whole, the environment in which it lives and the needs that the plant has.

REFERENCES

- Adami M., Hastenreiter F.A., Flumignan D.L., de Faria R.T. 2008. Estimativa de área de folíolos de soja usando imagens digitais e dimensões foliares. Bragantia. 67(4): 1053-1058.

- Ata-Ul-Karim S.T., Zhu Y., Yao X., Cao W. 2014. Determination of critical nitrogen dilution curve based on leaf area index in rice. Field Crops Research. 167: 76–85.
- Battie-Laclau P., Laclau J.P., Piccolo M.C., Arenque B.C., Beri C., Mietton L., Muniz M.R.A., Jordan-Meille L., Buckeridge M.S., Nouvellon Y., Ranger J., Bouillet A.P. 2013. Influence of potassium and sodium nutrition on leaf area components in *Eucalyptus grandis* trees. Plant and Soil. 371: 19-35.
- Bell M.L., Morgenstern R.D., Harrington W. 2011, Quantifying the human health benefits of air pollution policies: Review of recent studies and new directions in accountability research. Environmental Science & Policy. 14(4): 357–368.
- Blanco F.F., Folegatti M.V. 2003. A new method for estimating the leaf area index of cucumber and tomato plants. Horticultura Brasileira. 21(4): 666–669.
- Blanco F.F., Folegatti M.V. 2005. Estimation of leaf area for greenhouse cucumber by linear measurements under salinity and grafting. Scientia Agricola. 62(4): 305–309.
- Bosco M.L., Varrica D., Dongarrà G. 2005. Case study: Inorganic pollutants associated with particulate matter from an area near a petrochemical plant. Environmental Research. 99(1): 18–30.
- Cho Y.Y., Oh S., Oh M.M., Son J.E. 2007. Estimation of individual leaf area, fresh weight, and dry weight of hydroponically grown cucumbers (*Cucumis sativus* L.) using leaf length, width, and SPAD value. Scientia Horticulturae. 111(4): 330–334.
- De Lojo J., Di Benedetto A. 2014. Biomass accumulation and leaf shape can be modulated by an exogenous spray of 6-benzylaminopurine in the ornamental foliage plant, *Monstera deliciosa* (Liebm.). The Journal of Horticultural Science and Biotechnology. 89(2): 136–140.
- Díaz-Pérez J.C. 2013. Bell Pepper (*Caspicum annum* L.) Crop as Affected by Shade Level: Microenvironment, Plant Growth, Leaf Gas Exchange, and Leaf Mineral Nutrient Concentration. HortScience. 48(2): 175-182.
- Erdoğan C. 2012. A Leaf Area Estimation Model for Faba Bean (*Vicia faba* L.) Grown in the Mediterranean Type of Climate. Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi. 7(1): 58-63
- Favarin J.L., Neto D.D., GarcÌa y GarcÌa A., Villa Nova N.A., da GraÁa Guilherme Vieira Favarin M. 2002. EquaÁıes para a estimativa do Ìndice de area foliar do cafeeiro. Pesquisa Agropecuária Brasileira. 37(6): 769-773.
- Freer-Smith P.H., El-Khatib A.A., Taylor G. 2004. Capture of Particulate Pollution by Trees: A Comparison of Species Typical of Semi-Arid Areas (*Ficus Nitida* and *Eucalyptus Globulus*) with European and North American Species. Water, Air, & Soil Pollution. 155: 173–187.
- Gieré R., Kaltenmeier R., Pourcelot L. 2012. Uranium oxide and other airborne particles deposited on cypress leaves close to a nuclear facility. Journal of Environmental Monitoring. 14(4): 1263-1273.
- Giuffrida F., Rouphael Y., Toscano S., Scuderi D., Romano D., Rivera C.M., Colla G., Leonardi C. 2011. A simple model for nondestructive leaf area estimation in bedding plants. Photosynthetica. 49(3): 380–388.
- Horemans N., Vanhoudt N., Janssens M., Van Chaze B., Wannijn J., Van Hees M., Vandenhove H. 2011. On the nature and timing of oxygen radical production following exposure of *Arabidopsis thalianaleaves* to uranium, cadmium or a combination of both stressors. Radioprotection. 46(6): S491–S496.
- Ianovici N, Batalu A., Hriscu D., Datcu AD. 2020. Phytomonitoring study on intra urban variations of leaves of some evergreen and deciduous trees. Ecological Indicators. DOI:10.1016/j.ecolind.2020.106313
- Ianovici N., Vereș M., Catrina R.G., Pîrvulescu A.M., Tănase R.M., Datcu D.A. 2015. Methods of biomonitoring in urban environment: leaf area and fractal dimension. Annals of West University of Timișoara, ser. Biology, 18(2): 169-179.
- Kim J.H., Oh Y., Yoon H., Hwang I., Chang Y.S. 2014. Iron Nanoparticle-Induced Activation of Plasma Membrane H+-ATPase Promotes Stomatal Opening in *Arabidopsis thaliana*. Environmental Science & Technology. 49(2): 1113–1119.
- Leigh A., Sevanto S., Close J.D., Nicotra A.B. 2017. The influence of leaf size and shape on leaf thermal dynamics: does theory hold up under natural conditions? Plant, Cell & Environment. 40(2): 237–248.
- Li W., Niu Z., Wang C., Huang W., Chen H., Gao S., Li D., Muhammad, S. 2015. Combined Use of Airborne LiDAR and Satellite GF-1 Data to Estimate Leaf Area Index, Height, and Aboveground Biomass of Maize During Peak Growing Season. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 8(9): 4489–4501.
- Matsoukis A., Gasparatos D., Chronopoulou-Sereli A. 2015. Micronutrient Content in Relation to Specific Leaf Area, Light Regime and Drenched-Applied Paclobutrazol in *Lantana camara* L. Current Agriculture Research Journal. 3(2): 101-104.

- Milla R., Reich P. B. 2007. The scaling of leaf area and mass: the cost of light interception increases with leaf size. Proceedings of the Royal Society B: Biological Sciences. 274(1622): 2109–2115.
- Moles A.T., Perkins S.E., Laffan S.W., Flores-Moreno H., Awasthy M., et al. 2014. Which is a better predictor of plant traits: temperature or precipitation? Journal of Vegetation Science. 25(5): 1167–1180.
- Monteiro F.A., Nogueirol R.C., Melo L.C.A., Artur A.G., da Rocha F. 2011. Effect of Barium on Growth and Macronutrient Nutrition in Tanzania Guineagrass Grown in Nutrient Solution. Communications in Soil Science and Plant Analysis. 42(13): 1510–1521.
- Moosavi S.G. 2012. The effect of water deficit stress and nitrogen fertilizer levels on morphology traits, yeld and leaf area index in maize. Pakistan Journal of Botany. 44(4): 1351-1355
- Murray B.R., Hardstaff L.K., Phillips M.L. 2013. Differences in Leaf Flammability, Leaf Traits and Flammability-Trait Relationships between Native and Exotic Plant Species of Dry Sclerophyll Forest. PLoS ONE. 8(11): e79205.
- Nicotra A.B., Leigh A., Boyce C.K., Jones C.S., Niklas K.J., Royer D.L., Tsukaya H. 2011. The evolution and functional significance of leaf shape in the angiosperms. Functional Plant Biology. 38(7): 535.
- Nowak D.J., Hirabayashi S., Bodine A., Hoehn, R. 2013. Modeled PM2.5 removal by trees in ten U.S. cities and associated health effects. Environmental Pollution. 178: 395–402.
- Palaniswamy K.M., Gomez K.A. 1974. Length-Width Method for Estimating Leaf Area of Rice1. Agronomy Journal. 66(3): 430.
- Perksen E. 2007. Non-destructive leaf area estimation model for faba bean (*Vicia faba* L.). Scientia Horticulturae. 113(4): 322–328.
- Pinto A.C.R., Graziano T.T., Barbosa J.C., Lasmar F.B. 2008. Modelsos para estimative da area foliar de *Curcuma alismatifolia* e *Vurcuma zedoaria*. Bragantia. 67(2): 549-552.
- Pugh T.A.M., MacKenzie A.R., Whyatt J.D., Hewitt C.N. 2012. Effectiveness of Green Infrastructure for Improvement of Air Quality in Urban Street Canyons. Environmental Science & Technology, 46(14): 7692–7699.
- Sæbø A., Popek R., Nawrot B., Hanslin H.M., Gawronska H., Gawronski S.W. 2012. Plant species differences in particulate matter accumulation on leaf surfaces. Science of The Total Environment. 427-428: 347–354.
- Sánchez T., Martín S., Saco D. 2014. Some Responses of Two *Nicotiana tabacum L.* Cultivars Exposed to Vanadium. Journal of Plant Nutrition. 37(5): 777–784.
- Sawidis T., Breuste J., Mitrovic M., Pavlovic P., Tsigaridas K. 2011. Trees as bioindicator of heavy metal pollution in three European cities. Environmental Pollution. 159(12): 3560–3570.
- Shi P., Liu M., Ratkowsky D.A., Gielis J., Su J., Yu X., Wang P., Zhang L., Lin Z., Schrader J. 2019b. Leaf area–length allometry and its implications in leaf shape evolution. Trees. 33: 1073–1085.
- Shi P., Liu M., Yu X., Gielis J., Ratkowsky D. 2019a. Proportional Relationship between Leaf Area and the Product of Leaf Length and Width of Four Types of Special Leaf Shapes. Forests. 10(2): 178.
- SUN S., JIN D., SHI P. 2005. The Leaf Size–Twig Size Spectrum of Temperate Woody Species Along an Altitudinal Gradient: An Invariant Allometric Scaling Relationship. Annals of Botany. 97(1): 97–107.
- Toebe M., de Souza R.R., Mello A.C., De Melo P.J., Segatto A., Castanha A.C. 2019. Leaf area estimation of squash '*Brasilerinha*' by leaf dimensions. Ciência Rural. 49(4): e20180932
- Tong Z., Whitlow T.H., MacRae P.F., Landers A.J., Harada Y. 2015. Quantifying the effect of vegetation on near-road air quality using brief campaigns. Environmental Pollution. 201: 141–149.
- World Health Organization. 2003. Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide. Report 2003 on a WHO working group. Bonn; 2003.
- Wright I.J., Dong N., Maire V., Prentice I.C., Westoby M., Díaz S., Gallagher R.V., Jacobs B.F., Kooyman R., Law E.A., Leishman M.R., Niinemets Ü., Reich P.B., Sack L., Villar R., Wang H., Wilf P. 2017. Global climatic drivers of leaf size. Science. 357(6354): 917–921.
- Yang D., Niklas K. J., Xiang S., Sun S. 2009. Size-dependent leaf area ratio in plant twigs: implication for leaf size optimization. Annals of Botany. 105(1): 71–77.
- Yin S., Shen Z., Zhou P., Zou X., Che S., Wang W. 2011. Quantifying air pollution attenuation within urban parks: An experimental approach in Shanghai, China. Environmental Pollution. 159(8-9): 2155–2163.