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Optical Parameters of the Tilia Cordata Mill. Assimilation Apparatus

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ABSTRACT

Morphometric indicators of trees' assimilative apparatus, including their reflection and light-absorbing properties, largely determine their physiological processes. Leaf initiation and development depend on chlorophyll resulting from photosynthesis, water absorption, its movement through a tree and evaporation. The aim of the paper is to evaluate leaf optical properties of Tilia cordata Mill. It was found that optical coefficients of leaf blades vary depending on the time of sample collection: at the end of the growing season, the leaf blade absorptance (Ab) ranges from 68.9% to 72.4%. During the intensive formation of Tilia flowers, the Ab coefficient decreases to 59.2%. It starts to rise before the beginning of the Tilia fruit maturation. The transmittance, Tr, is also lower at the period of intense flower development. Estimating NDVI (vegetation index) and LAI (leaf area index) from Sentinel-2 satellite imagery showed that the ratio between these indices (NDVI-LAI) changes during the entire growing season. The NDVI-LAI correlation varied up to the strongest one during the entire phenological cycle.

1. INTRODUCTION

A leaf is a unique organ with intense photosynthetic activity developed for centuries of the evolutionary process. Its structure and functional activity are largely determined by the physiological and genetic characteristics of woody plants. They affect leaf optical characteristics: solar radiation absorptance, transmittance and reflectance [1, 2]. Conceptual studies on the relationship of leaf traits to ecosystem processes to better understand the functional adaptation of woody plants is rapidly expanding. In recent years, spectroscopy has been relied on leaf optical properties to identify functional features of phylogenetic associations and biodiversity regularities [3-5]. In addition, as Sokolov [6] claims, the tree foliage phytomass developing nectar-bearing stands should be considered as an apparatus that influences the biological activity of the phytocenosis as a whole. There is a substantial amount of scientific papers related to the assimilation apparatus. Still, Tilia leaf characteristics like solar radiation absorptance, transmittance and reflectance have been studied regardless of its phytomass or nectar-bearing capacity.

Leaves of Tilia are simple, alternate, 2 to 4 inches long and about as wide, broadly egg-shaped to nearly round, the tip abruptly tapered to a sharp point, the base asymmetrical and heart-shaped or one side more angled or straight across. Edges are finely toothed. The upper surface is hairless and deep green, somewhat bronzy in late summer; the lower surface is paler blue-green and hairless except for tufts of short, woolly hairs in vein axils. Fall colour is deep yellow.

Nowadays data on reflectance spectrum of woody vegetation on a specific territory can be received with remote sensing measurements. The study and assessment of ecosystem services through remote sensing has increased substantially over the last two decades, as evidenced by the publication of studies that have applied it. The technological development of satellite images has improved in terms of spatial, spectral, radiometric, and temporal resolution, allowing the space-time observation, classification and monitoring of vegetation on the surface of the Earth [7]. Thus, there were conducted studies of boreal forests in North America within the BOREAS project [8]. However, the examined boreal territories did not include some predominant tree species. Therefore, the research was supplemented by the analysis of pine, spruce and birch [9]. These studies focus on the vegetation and leaf area index (NDVI-LAI) relationship [10], being essential in describing the ongoing temporary changes in carbon, water, and leaf energy exchange [11]. This relationship can vary both depending on the growing season and by year, reflecting changes in environmental conditions [12].

The aim of the given paper is to evaluate leaf optical properties of Tilia cordata Mill.

2. MATERIALS AND METHODS

The objects under study are pure Tilia cordata Mill. plantings growing in the South Ural forest-steppe region.

Studies were conducted in two stages. Firstly, Tilia leaf reflectance to monochromatic flux was determined with laser photometric system "Lafot 93 Yu-34.11.644". The given photometer registers monochromatic flux of rays that are either absorbed, transmitted or reflected from the surface of a sample leaf. Total 1020 leaves from 112 sample trees were studied in different months (July, August) during the active vegetation period. The leaves were sampled in specified order from different parts of trees (the crown of trees was divided into 2-meter sections). Secondly, NDVI and LAI, indicating tree photosynthetic and transpiration activity and other physiological processes, were measured by GIS technology methods and remote sensing from Sentinel-2 satellite imagery processed in the ArcGIS software.

NDVI is equal to:

$$NIR–Red/NIR+Red \quad (1)$$

where, NIR is reflection in the near-infrared spectrum; RED is reflection in the red range of the spectrum [13].

2.1 Statistical analysis

Statistical processing was conducted with Statistica 6.0. Statistical processing of the obtained data included the calculation of such indicators as: mean value; dispersion; standard deviation; the coefficient of variation; mean standard error; asymmetry; excess and experiment accuracy.

The equation relevance was estimated by the correlation coefficient (r).

All the plant experiments were in compliance with relevant institutional, national, and international guidelines and legislation.

3. RESULTS

Leaf optical properties of Tilia cordata Mill. were studied with a laser photometer. Materials for laboratory research were collected in compliance with the mandatory requirements: Leaves were selected from trees in the same natural and climatic conditions during different growing seasons. The laser photometer made it possible to study optical properties of linden leaves: transmittance of the radiant monochromatic flux (Tr), its specular (Rd), diffuse (Rm) reflection and absorption (Ab) (Table 1).

Table 1. Leaf optical properties of small-leaved linden, %

Item No.	Leaf selection time	Ratios of			
		Specular reflection	Transmittance	Diffuse reflection	Absorptance
1	July	7.3±0.84	1.9±0.80	24.8±0.33	66.0±1.42
	August	6.4±0.80	2.4±0.89	18.9±0.40	72.4±1.00
2	July	9.4±1.14	3.4±0.82	28.0±0.21	59.2±1.08
	August	8.3±0.97	3.6±1.00	19.2±0.39	68.9±1.09
3	July	8.4±1.07	2.8±1.15	26.6±0.16	62.2±0.34
	August	7.3±0.94	4.8±1.15	19.0±0.33	69.0±1.17
4	July	9.0±0.99	2.8±1.40	24.0±0.40	64.2±1.10
	August	8.1±1.06	2.3±0.94	19.2±0.58	70.4±0.66
5	July	9.5±0.99	3.5±1.63	26.9±0.90	60.0±1.33
	August	8.9±1.10	3.4±1.02	18.5±0.47	69.2±1.02

Optical coefficients of leaf blades vary depending on the time of sample harvesting. At the end of the growing season, the amount of light flux absorbed (Ab) ranges from 68.9% to 72.4%. During the intensive formation of Tilia flowers, the Ab coefficient decreases to 59.2%. This is due to changes in the physicochemical properties of leaves during their life cycle [14].

Leaf optical properties of linden trees in different months are significantly different: $t_{fact}=2.82 \geq t_{theor}=1.98$, proving obvious differences in the photosynthetic apparatus of trees in different periods of vegetation.

To calculate NDVI and LAI, the following Sentinel-2 satellite imagery were decoded:

S2A_MSIL1C_20180722T071619_N0206_R006_T40UEF_20180722T092930 (July 22, 2018);

S2A_MSIL1C_20180829T072611_N0206_R049_T40UDF_20180829T094331 (August 29, 2018).

The data was processed with ArcGIS 10.5 (Figures 1-2).

The leaf area index (LAI) is an important parameter for assessing the environment. It affects the light propagation in the vegetation cover and, consequently, its measurable reflection coefficient.

The input NDVI and LAI values for the growing season months were determined using the "Spatial Analyst" tools (Table 2).

The NDVI and LAI correlation is shown in Figure 3.

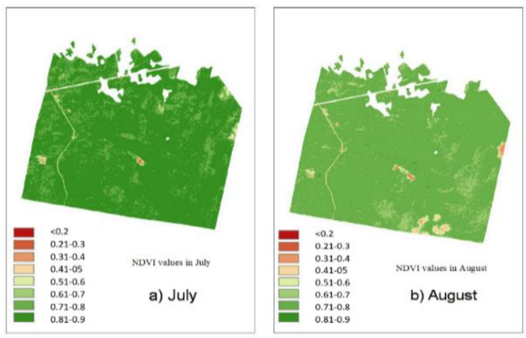


Figure 1. NDVI values

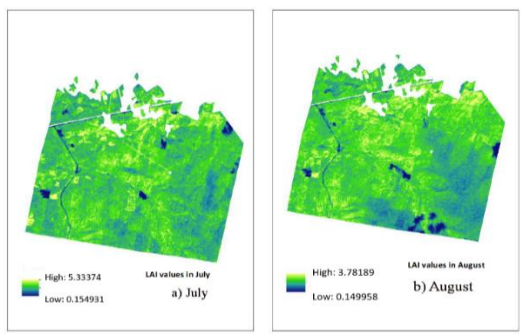
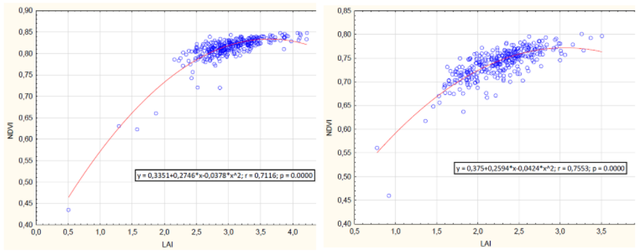


Figure 2. LAI values

Table 2. Statistical processing of the obtained data

Indicator	Mean value	Disp.	Std. dev.	Variation coef.	Std. error mean	Asym.	Excess	Experiment accuracy, %
July LAI	3.1938	0.2076	0.4556	14.2666	0.0252	–1.4681	8.7401	0.7902
July NDVI	0.7669	0.0018	0.0422	5.5052	0.0023	–7.9593	74.2652	0.3049
August LAI	2.2664	0.1428	0.3778	16.6714	0.0209	–0.0798	0.8746	0.9233
August NDVI	0.7391	0.0012	0.0343	4.6383	0.0019	–2.4976	15.0782	0.2569



a) July b) August

Figure 3. Graphs of NDVI - LAI correlation

The NDVI-LAI correlation coefficients (r) in the sample areas varied from 0.7116 to 0.7553, indicating a high relationship between these two indices (Figures 4-5).

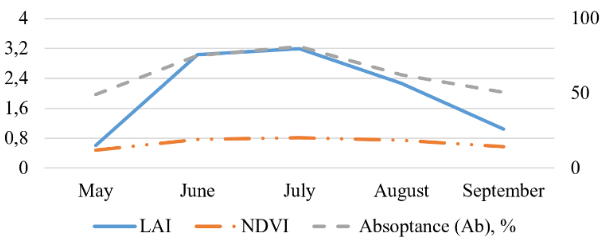


Figure 4. Absorption coefficient, NDVI and LAI values during the growing season

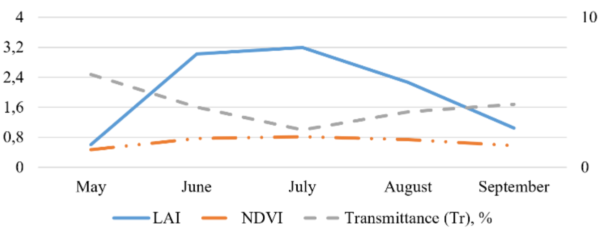
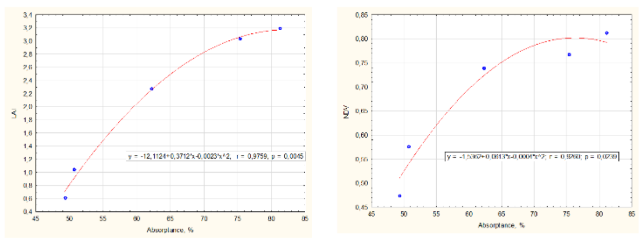


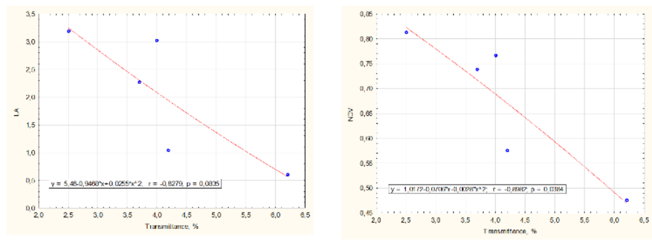
Figure 5. Transmission coefficient, NDVI and LAI values during the growing season

The correlation of the indicators is shown in Figures 6-7.



a) b)

Figure 6. Dependence of the absorption coefficient on: a) LAI; b) NDVI



a) b)

Figure 7. Dependence of the transmission coefficient on: a) LAI; b) NDVI

During the abundant formation of linden flowers, the Ab coefficient decreases, it stars rising before the fruit maturation. The transmission index, Tr coefficient, during the abundant formation of flowers is lower.

4. DISCUSSION

The NDVI and LAI values, leaf optical properties of woody plants obtained by different remote sensing methods provided more detailed data on forest stands [11, 15]. Though leaf anatomy and morphology vary greatly, their biochemical and biophysical properties demonstrate common absorption characteristics in the optical spectrum, that was detected by modern high-precision aviation spectrometers [16].

Studies were based on NDVI and LAI values that were also used to evaluate forest litter, playing an equally important role in the carbon process of forest ecosystems [17] and undergrowth [5]. The NDVI and LAI relationship was analyzed in relation to other indicators of the forest stand: biomass [18], net primary production [19], vegetation health [20], and changes in climatic conditions [21]. There were comparative studies of natural and artificial forests in China in terms of their ecological functions, primarily related to carbon uptake [22], analysis of vegetation restoration in areas covered by forest fires in Spain [23], estimation of urban plantation condition and health [24, 25]. Vegetation cover was examined to differentiate forests by species (coniferous and deciduous) and land categories (plantations, cropland, hayfields, pastures, open forests, etc. [26].

The conducted research has proved a high NDVI and LAI correlation and its dependence on field and laboratory data, revealed by other authors as well [27-29]. In particular, work [27] presents the results of studies carried out in winter time in the north of Europe, but works [28] and [19] in the tropical forest in northern India and in the Tripura region (India). The results of studies conducted over 20 years in the Himachal Pradesh region in work [30] show that the parameters of NDVI and LAI have a close correlation with complex indicators of air quality and the presence of pollutants in them. In general, our conclusions are consistent with the results of a number of scientific studies [8, 9, 31].

5. CONCLUSIONS

Optical coefficients of leaf blades change depending on the time of sample harvesting. At the end of the growing season, the leaf blade absorptance (Ab) ranges from 68.9% to 72.4%. During the intensive formation of Tilia flowers, the Ab coefficient decreases to 59.2%. It starts to rise before the beginning of the Tilia fruit maturation. The transmittance, Tr, is also lower at the period of intense flower development. Estimating NDVI (vegetation index) and LAI (leaf area index) from Sentinel-2 satellite imagery showed that the ratio between these indices (NDVI-LAI) changes during the entire growing season. It was found that the indicators of NDVI (in the range from 0.4 to 0.85) and LAI (in the range from 0.5 to 4.5) throughout all stages (July, August) of the study were interdependent (p=0.716-0.7553) parameters, which allows using only one of them in further work, and the second one can be calculated according to the developed equations.

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