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CANOPY STRUCTURE AND LIGHT INTERCEPTION IN *Dactylis glomerata*, *Medicago sativa* and *Trifolium repens*: A NEXUS AMONG BIOLOGICAL EFFICIENCY AND FORAGE PRODUCTION

Adrian FILIP[1], Niculae DINCĂ[1], Ana-Maria STANCIU[1], Daniel DUNEA[2]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania
[2]Valahia University of Targoviste, 13 Sinaia Alley, Targoviste, Romania

Corresponding author email: ana.stanciu@agro-bucuresti.ro

Abstract

The study aimed to establish the nexus among biological efficiency and forage production by analyzing the canopy structure and light interception potential in orchard grass (Dactylis glomerata), alfalfa (Medicago sativa), and white clover (Trifolium repens). The measurements were performed in Gherghita Plain, at Pucheni village on large plots in 2023 by using the Delta-T Devices Sunscan Analysis system. The leaf area index (LAI), light parameters, and microclimate indicators were retrieved in each canopy of the studied species at various layers of 10 cm from the bottom to the top of the canopy. Consequently, a close relationship was observed between the biological efficiency, the leaf area distribution, and potential forage production for both grass species and legumes. The results are useful for planning biometrical parameters when developing new performant cultivars.

***Key words**: LAI, extinction coefficient, leaf area distribution, beam fraction, light use efficiency.*

INTRODUCTION

Requirements for qualitative fodder to provide proper conditions for growing valuable livestock are more stringent in the last period. Consequently, it is important to develop new cultivars with better quality indices that ensure improved digestibility and increased adaptation to the climate variability that was significant in the last decade (Dunea and Dincă, 2014). Several forage species were found to be preferred by farmers from which alfalfa, white clover, and orchard grass are often selected because they guarantee crop performances either in pure culture or in mixtures.

Orchard grass (*Dactylis glomerata*) is considered the most valuable species among perennial grasses for its characteristics; like alfalfa, it has superior ecological plasticity due to its high adaptability to environmental factors and improved production and recovery capacity after mowing and grazing.

Due to its high production potential, this species occupies an important place among perennial grasses in the continental and excessively continental climate zones.

Orchard grass, considered one of the most valuable species among the perennial grasses, has the following fodder characteristics:

- particularly broad ecological plasticity, being cultivated in almost all agricultural areas in Romania;
- high degree of consumption and digestibility, especially in the young phenophases;
- high resistance to grazing and this is done when the plants are 10-12 cm;
- it is used both in pure culture and in a mixture with other species of perennial grasses and legumes, in the form of hay or pasture;
- being a species with a high degree of competitiveness, the percentage of participation in the mixture is lower than that of the other species (below 20%);
- the ideal partner for orchard grass is alfalfa, with which it can form a temporary, intensive, long-lasting (5-7 years) forage crop;
- under optimal conditions of vegetation and the application of high doses of nitrogen fertilizers, the orchard grass can achieve at

least 3-4 harvests per year, with productions of over 50 t/ha of green mass (Dincă, 2014).
Orchard grass is tolerant of shade and is an ideal companion grass for legumes in mixed permanent pastures (Ecocrop, 2010). It is suitable for mixed sowing with Alfalfa *(Medicago sativa* L.*)* or red clover *(Trifolium pratense* L.*)* for hay or white clover (*Trifolium repens* L.*)* for grazing (Sanada et al., 2010). However, it is in high competition with white clover for water and nutrients when the two species are sown together (Mills, 2007).
Alfalfa (*Medicago sativa* L.) or lucerne is one of the most important fodder crops in temperate climate regions, presenting a superior ecological plasticity due to its adaptability to various ecological, climatic, and soil conditions (Moga et al., 1996). Vegetation factors have an important role in the growth and development of alfalfa plants. Lucerne has a wide ecological plasticity, but its productive potential can only be highlighted in certain pedoclimatic conditions.
Owing to the deep and well-developed root system, alfalfa has a high resistance to drought, even if it is a big consumer of water. It is estimated that for the production of one unit of dry matter, alfalfa consumes 700-800 units of water in irrigated culture and 500-600 units in non-irrigated conditions. The highest productions are achieved in areas with annual precipitation of 500-650 mm, well distributed during the vegetation period. The requirements for heat and solar energy are high for alfalfa. The temperature sum, for alfalfa plants from years II-III of vegetation to reach the beginning of flowering, is about 900°C for cutting I and 800-850°C for cuttings II and III (Dincă, 2014).
White clover (*Trifolium repens*) can be found in a wide range of habitats, including dry meadows, mudflats, wood margins, open woods, river banks, plains, semi-desert regions, and mountains up to the subalpine pastures, but rarely on saline soils. It is a frequent weed on roadsides and in barren areas (UC SAREP, 2006). Because of its stoloniferous growth habit, white clover can colonize bare spaces in swards (FAO, 2011).
The special importance of white clover results from the fact that it resists well to grazing produces fodder rich in proteins and vitamins, has a high perennial potential, determines the reduction of doses of nitrogen fertilizers, makes good use of a wide range of soils, including those with excess acid or of moisture, it is a good melliferous plant (Dincă, 2014). White clover has a high content both in crude protein (20%) and in various nutrients (vitamins, phosphorus, calcium, potassium).
Being a legume that enriches the soil with nitrogen, it can be considered that 1% white clover, in the floristic composition, provides 3 kg of active element nitrogen per hectare per year (Dincă, 2014).
It is less resistant to drought, but it resists frost better than red clover. It easily tolerates long-term flooding and excess moisture, often forming associations on lands with shallow groundwater in varnished or glazed soils. (Dincă, 2014).
Mixtures of orchard grass with alfalfa provided better solar radiation interception by the heterogeneous canopy during the growth season. The interception or absorption coefficients of the photosynthetically active radiation were influenced by a multitude of factors such as the variety of *Dactylis glomerata*, the phenophase, cropping arrangement, cutting cycle, and leaf area index (LAI) (Stanciu et al., 2016).
In this context, the current study aims to extract new information regarding the canopy structure and light interception in three new cultivars that are under preliminary tests, one for each species i.e., *Dactylis glomerata*, *Medicago sativa,* and *Trifolium repens*. All these cultivars are developed by 4AGRO S.R.L. with the support of specialists from the University of Agronomic Sciences and Veterinary Medicine of Bucharest. The main objective was to present the nexus among biological efficiency and forage production.

MATERIALS AND METHODS

Delta-T Device SunScan Analysis System (https://delta-t.co.uk/product/sunscan/), a system that contains the performant BF5 PAR sensor (https://delta-t.co.uk/product/bf5/#overview), was used for field measurements to help us gain a deeper understanding of the canopy structure and light interception potential. The data reported here resulted from the measurements performed on 22 May 2023.

The system includes a linear array of PAR (Photosynthetically Active Radiation) sensors (64 PAR Sensors embedded in a 1 m long probe) and a handheld PDA, which collects and analyses readings from the SunScan Probe. The SunScan system offers a practical and efficient method for in-situ analysis of light dynamics in plant canopies.

Solar radiation can be characterized by three variables in terms of interference with the crop canopy as follows:

- Rg = Global solar radiation expressed in energy units (W/m^2 in the period of time: hour, day, decade, etc.);
- EPAR = useful radiation for photosynthesis expressed in units of energy (J/m^2 or MJ/m^2 in the time period: hour, day, decade, etc.) or the flow of energy;
- QPAR = useful radiation for photosynthesis expressed in several photons (μmol·m^{-2}·s $^{-1}$) or photon flux intensity PPFD (*Photosynthetic Photon Flux Density*).

Figure 1 presents the key indicators forming the radiation fluxes at the canopy level.

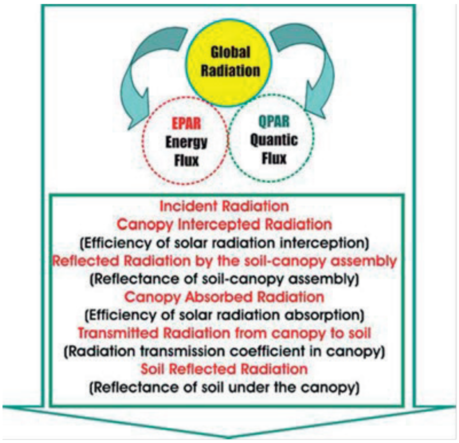

Figure 1. Key indicators for quantifying the solar radiation availability for crop canopies (Dunea, 2015)

Based on the implemented algorithms, the SunScan system provides non-destructive leaf area index measurements with high accuracy proved with comparative studies using a destructive direct measurement technique. An absorption coefficient of 0.85 and an ELADP of 1.5 were used following the previous studies performed in Romania (Dunea et al., 2019). The measurements were made in the Gherghitei Plain, in Pucheni village, at 4AGRO S.R.L. trial fields, in Prahova County in May 2023 (N44.824060, E26.092660) (Figure 2).

Figure 2. Area of experiments located in Puchenii Mari village in Prahova County, Romania (Geoportal ANCPI) - approximately 1.5 ha

The canopy assessments were carried out in the large plots with the three forage species, collecting information on the value of the leaf area index (LAI) from 10 cm to 10 cm above the ground, resulting in several canopy unit layers (Figure 3).

Figure 3. Delta-T Devices SunScan Analysis System deployed in the alfalfa canopy and the orchard grass field

RESULTS AND DISCUSSIONS

Orchard grass (*Dactylis glomerata*)
Following the measurements performed in 5 points on the diagonal of the large parcel cultivated with orchard grass, we have obtained the profile of the leaf area distribution within the uniform canopy in pure culture (Figure 4).

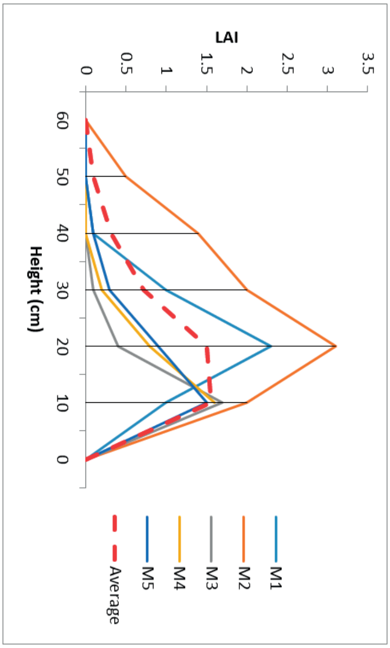

Figure 4. Leaf area distribution in the canopy of orchard grass per unit of canopy layer (0-60 cm by increments of 10 cm); M1-M5 measurements on the diagonal of the plot

A larger proportion of LAI was found in the 0-10 cm and then on 10-20 cm in the orchard grass canopy. The total leaf area reached on average a 4.2 value. In literature, Mills (2007) found that by the end of every regrowth cycle, the adjusted LAI of the tested pastures was ≥4.1 (critical LAI) and ranged from 4.1 to 11.8. In our tests, the measurements in the orchard grass canopy showed a total LAI that ranged from 2.2 to 9.

White clover (*Trifolium repens*)
The white clover had an average total LAI of 7.9 (Figure 5). The highest LAI is located in the 0-10 cm layer, and the canopy height did not exceed 40 cm (Phelan et al., 2013).

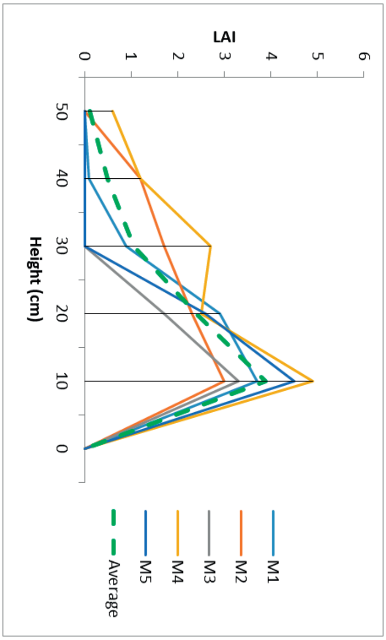

Figure 5. Leaf area distribution in the canopy of white clover per unit of canopy layer (0-40 cm by increments of 10 cm); M1-M5 measurements on the diagonal of the plot

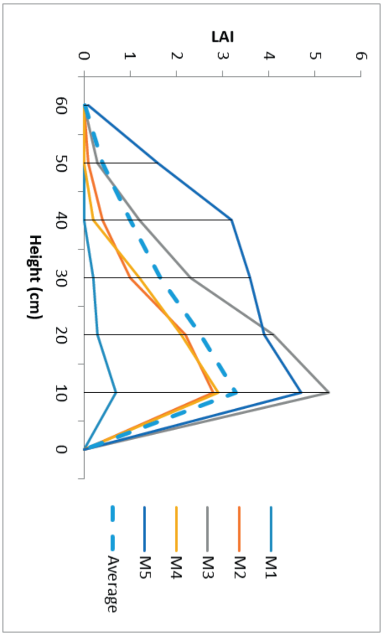

Figure 6. Leaf area distribution in the canopy of alfalfa per unit of canopy layer (0-60 cm by increments of 10 cm); M1-M5 measurements on the diagonal of the plot

Alfalfa (*Medicago sativa*)

Figure 6 presents the leaf area distribution in the canopy of alfalfa per unit of canopy layer. The total LAI reached an average value of 8.88. The profile of the leaf area is different compared to the other two species, showing a higher leaf area in the 10-30 cm layers. The total LAI ranged between 1.2 and 13.2 showing important variabilities because of the uneven development of the canopy. In literature, Hammond et al. (2023) found that during the growth season, the measured LAI of alfalfa varied from 0.23 to 11.28 and canopy height varied from 6 cm to 65 cm. Our results are in agreement with this report.

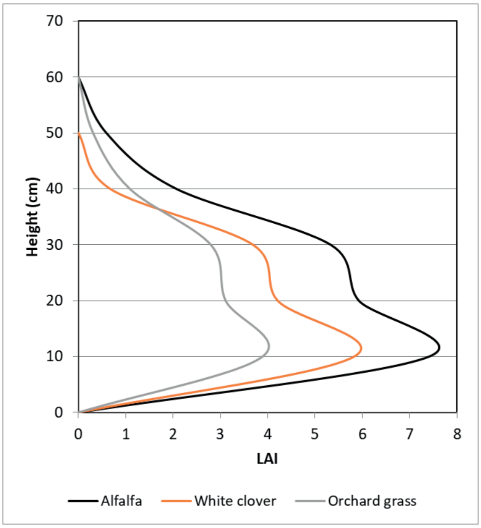

Figure 7. The cumulative LAI (L_h) counted from the top of the canopy down to the specific height (the leaf area density profiles were obtained using a parabolic function for each tested homogenous canopy ($L_h = LAI-[(LAI/h_t^3) \cdot h^2 \cdot (3h_t - 2h)]$ (Kropff and van Laar, 1993)

Figure 7 shows the cumulative LAI for various canopy layers obtained for each species using a parabolic function. The results meet the averaged lines provided by the real measurements (Figures 4-6). The highest value was found in alfalfa, then in white clover, followed by the orchard grass. The leaf area density has importance on the profile of direct absorbed flux of radiation, and the diffuse flux of the species over height. Such information can be useful in determining the CO_2 assimilation rate of sunlit and shaded leaves at various heights in the homogenous canopy.

Regarding the measured light parameters for each tested species, Table 1 presents briefly the key findings.

Table 1. Key radiative parameters determined in each canopy

Indicator	Trans mitted	Spread	Incident	Beam fraction
Orchard grass	233.1	1.51	1757.6	0.803
White clover	263.5	1.42	1805.2	0.806
Alfalfa	292.3	1.04	1857.7	0.801

The highest transmitted radiation was retrieved in the alfalfa canopy, while the lowest one was found in orchard grass. The same trend was available for the spread parameter.

Figure 8 shows the radiative parameters ratio based on LAI for alfalfa. It is obvious that starting from an LAI of 3.5, the PAR absorption becomes relatively constant, and the reflectance diminishes with leaf area increment (Goudriaan, 1977).

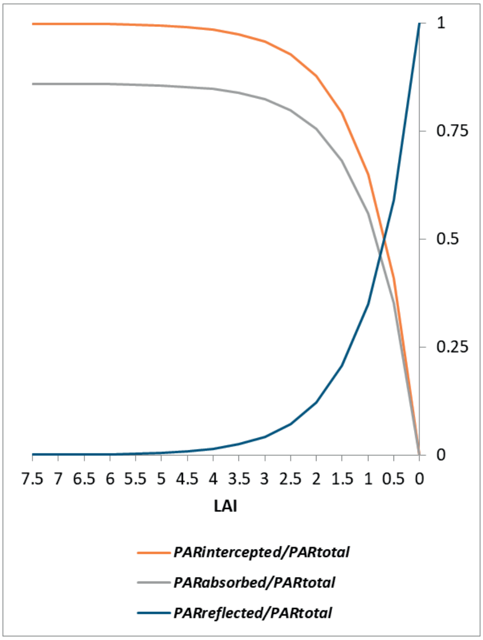

Figure 8. Radiative parameters ratio based on LAI for alfalfa (Intercepted PAR/Total PAR; Absorbed PAR/Total PAR; Reflected PAR/Total PAR)

When high radiation intensity occurs, the direct fractions do not exceed 80% of the total incident radiation, so the diffused component is important for the absorption capacity of the canopy (Kropff and van Laar, 1993).

Figure 9 presents the simulation of the light absorption (PAR) in the canopy of the tested species in pure culture using a parabolic leaf area distribution. The resulted profiles vary with species and canopy height showing the attenuation of radiation absorption within the canopy with the cumulative LAI. Alfalfa reached a maximum value of PAR absorbed around 3.5 Joules m^{-2} ground s^{-1} cm^{-1} height, while the lowest was for the orchard grass with approximately 2.5, respectively. White clover did not reach 3 Joules m^{-2} ground s^{-1} cm^{-1} height.

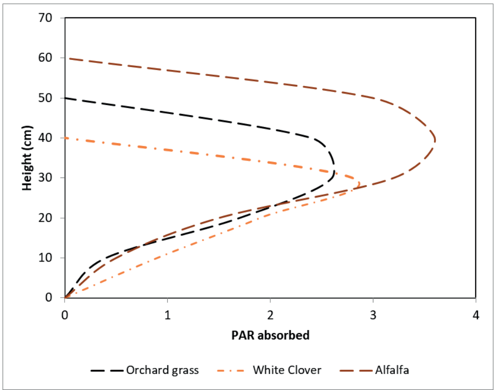

Figure 9. Absorbed PAR profiles in each canopy height layer of the tested species (Joules m^{-2} ground s^{-1} cm^{-1} height) based on a constant input of diffuse radiation

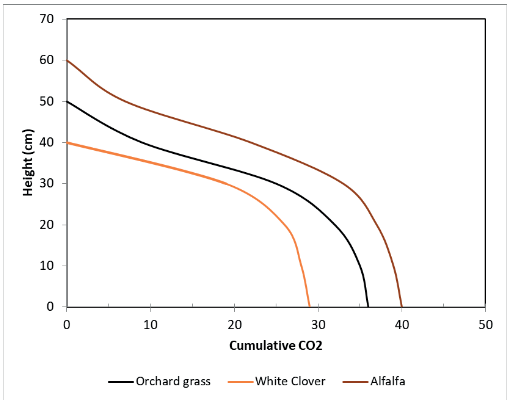

Figure 10. Cumulative CO_2 assimilation profile in the canopy counted from the top (kg CO_2 ha^{-1} ground h^{-1})

Figure 10 shows the simulation of the Cumulative CO_2 assimilation profile in the canopy counted from the top in relationship with canopy height. The maximum value was obtained in alfalfa (~40 kg CO_2 ha^{-1} ground h^{-1}), while the lowest was in white clover (~30 kg CO_2 ha^{-1} ground h^{-1}), respectively.

Bhagsari and Brown (1986) found that the relationship between leaf size and specific leaf weight was inconsistent in alfalfa. CO_2 exchange rates for some genotypes with various leaf sizes may not show significant differences in the photosynthetic potential. They established negative correlations between leaf area and CO_2 exchange rate, which may be one of the causes for the absence of consistent relationships between the exchange rate and yield.

More studies should be performed to characterize in detail the biological efficiency of various cultivars and at different phenophases in conjunction with the weather fluctuations (Dunea et al., 2015), soil and nutrition conditions by employing remote sensing technologies as well (Abdulhussein and Mihalache, 2022).

CONCLUSIONS

The paper presents the relationships between biological efficiency and forage production by analyzing the canopy structure and light interception potential for three important forage species. The amount of PAR intercepted by a canopy is dependent on LAI and canopy architecture, particularly the extinction coefficient as a measure of light interception into the canopy. Such information is relevant for improving the breeding of new cultivars by finding measures of improving LAI and plant height.

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