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Leaf Area and Dry Matter Accumulation Dynamic in two Biological Types of Common Bean (*Phaseolus vulgaris* L.)

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Abstract

In most of the comparative studies of cultivars the determination of production capacity is mainly based on the elements of production. These elements as quantitative indicators are highly influenced by environmental factors. Elements of production are expressions of different photosynthetic activity of cultivars, which are determined by morphophysiological traits, climatic factors and cultivation technology. Knowledge of the physiological bases of beans production would help to better explain the physiological mechanisms and the different potentials of cultivars. For this purpose, four common bean cultivars and lines, representing two different of biological types (growth habit) were studied. Based on the dry matter accumulation (W) and the leaf area, some physiological growth indicators have been calculated. The data obtained argue that there are significant differences between the two biological types of beans based on the leaf area index (LAI) and the dry matter accumulation (DMA) during the plant life cycle of common bean. In the determinant growth habit, differences between cultivars were observed at the end of the reproduction period, where "Lapardha" cultivar had a greater LAI than "Kallmet", a fact which is reflected in a higher rate of dry matter accumulation. The same phenomenon is also observed when comparing semideterminant lines, where L13-2 had a LAI and dry matter accumulation higher than L232. This prolonged photosynthetic activity results due to the emergence of new leaves, and the different architectural construction of cultivars and lines in the study, which is manifested even in the highest production indicators.

Keywords: Leaf area index, dry matter, plant architecture, line, cultivar, biological type

1. Introduction

The limitation on the cultivation of common beans in Kosovo has been conditioned, among others, by the low availability of cultivars with high production capacity. The yield of this plant in recent years, compared to others, does not show any significant increase, where the main factor of production restriction may be a dis-balance between photosynthetic activity and the use of assimilates among different plant components (Scarascia et al. 1979).

Improving the production of common beans by analyzing the components of production has continued for a long time, and not underestimating the positive results, it has often been observed that the increase in the value of a component is counter-balanced by decreasing values of others. This shows that a particular individual, like an entire population, is a well-integrated system (Olivieri et al 1979).

Plant morphology, as well as the particular components of production, being a manifestation of the genotype may vary depending on the environment and the cultivation technique. Achieving a high biological yielding per unit area is only one component in the equation for yield increase (Donald and Hamblin 1976). It is equally important as well the ratio of distribution of biological to economic production. In the basement of these processes, lies photosynthesis and transpiration, which in turn depend on the leaf area, dry matter accumulation rate, plant genotype architecture, as well as the environmental factors and cultivation technology.

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In this regard, this study may serve for a better understanding of the physiological basis of beans production, with a special view of the dry matter accumulation model, leaf area and eventual relationship between them and grain production.

2. Material and Methods

In this study four cultivars and lines of common beans were planted, where the cultivars "Kallmet" and "Lapardha" represented the determinant type of growth habit, while lines L-232 and L13-2 represent the semideterminant type. The experiment was developed according to the randomized block scheme with three replications. Each cultivar was planted in 5 rows of 3m length and 60cm space between them. The standard practices of cultivation were applied in the experiment. The measurement of the studied parameters was done in 5 growth periods (P), starting from flowering to full maturation. The distance between each measurement period was 10-12 days. For each cultivar 5 plants per replication were harvested. Each plant was divided according to their different organs (fully open leaves, new leaves, stems and pods). The leaves and other parts of the plant were dried in the thermostat for 24 hours at 105^{0}C. After drying, the plant parts are weighed separately and thus the amount of dry matter accumulated for the plant is calculated (Scarascia et al, 1979, Hunt 1982).

2.1. Measurment methods

The leaf area is measured by using a digital area-meter (AM300 portable leaf area meter). Based on the leaf area and the dry matter, growth traits such as leaf area index (LAI), crop growth rate (CGR) and leaf area duration (LAD) were analyzed according to the methods of Watson (1947), Wallace and Munger (1965), Scarascia et al. (1979), Hunt (1982), Steinmaus and Norris (2002) and Rajput et al. (2017).

At full maturation stage, 10 plants per replication of each variant were analyzed to determine the yield components.

The research data were calculated using Microsoft Excel, while data analysis and comparison were subject of variance analysis (ANOVA) in statistical software Minitab16® and Jump13®.

3. Results

3.1. Climatic conditions

Based on the average temperature analysis, it can be noticed that for the two years of study (2016-2017) their values were optimal for the growth and development of beans (Table 1). However, considering the minimum and maximum temperatures there could be drawn the conclusion that during the year 2017 the average minimum temperatures, mainly in the first half of May, were below the baseline temperatures for this plant and on specific days were lower than 5°C. Also, comparing the maximum temperatures during the reproduction period of the beans (July-August) it has been noticed that their values, above 29-30°C, were stresses for the bean plant. At certain days the temperatures could reach values above 37°C, with consequences on the physiological activity of the leaf area and other physiological indicators.

3.2. Leaf growth analysis

The most complex indicator of plant growth traits is the leafe area index (LAI), which directly affects the dry matter accumulation rate in the agricultural plants (Watson 1952, Brougham 1956, Davidson and Donald 1958, Kashta et al. 2012). However, among crops with the same leaf area, differences in dry matter accumulation have been found, which are related to changes in other plant growth parameters.

The direct and diffuse solar radiation reaching the leaves located in the upper part of the plant canopy can be absorbed, transmitted or reflected by leaf pigments. It means that only part of radiation can penetrate into the lower layers of the plant cover or on the leaves set below. The deeper the radiation penetrated inside the plant, the more decreases its energy. Reducing of the solar energy is the function of leaves layers where solar radiation penetrate, which in turn is the function of LAI and the angle of leaf setted in plant (Hay and Porter, 2006).

Our research results, shows that between the two biological types there are statistically significant differences in the LAI, almost throughout the full plant cycle of the common bean. The highest values of this indicator are reached 52-63 days after emergence for the determinant type and 62-75 days after emergence for the semideterminant type. These periods coincide with the flowering time respectively, pod's setting and grain filling of the common bean. In the last analysis related to the period of physiological maturation, LAI values were reduced significantly in the determinant type but had still high values in the semideterminant type (Table 2).

Comparing the LAI between the two years of study, 63 days after emergence, or during the pod's initiation and grain filling, it could be seen that its values are lower in 2017 for all cultivars and lines in the study. This fact is argued not only with stress temperatures during this period of 2017, but also with the lowest amount of rainfall (Table 1).

Table 1. Temperatures and rainfall during the plant cycle of common bean (2016 and 2017) (HMIK*).

Years	**2016**						**2017**					
	Months											
	IV	**V**	**VI**	**VII**	**VIII**	**IX**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**
Max. temp. (^{0}C)	20.5	19.1	26.8	28.4	26.8	22.8	16.3	21.3	26.3	29.1	30.1	23.0
Min. temp. (^{0}C)	6.1	7.7	12.6	14.4	13	9.8	3.3	8.1	13.1	14.2	12.6	9.6
Avg. temp. (^{0}C)	13.1	13.5	19.9	21.7	20	16.1	9.6	14.8	20.9	22.2	21.9	16.2
Rainfalls (mm)	39.5	106.2	53.7	94.9	51,1	65.7	57.3	84.8	72.2	34.2	45.0	35.9

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Changes in the leaf area index are mainly due to the number of leaves per plant. Thus semideterminant cultivars (L232 and L13-2) had higher LAI values, because they had higher number of leaves than determinant cultivars ("Kallmet" and "Lapardha") (Table 3).

In the period of pods growing and grain filling, the lower leaves senescence begins. However, in the semideterminant type, the emergence of new leaves continues the photosynthetic activity of the plant during this important period of production.

Table 2. Variation in leaf area index (LAI) of studied cultivars and lines for two years of research (2016-2017)

Cultivar	**LAI ($m^2 \cdot m^{-2}$)**									
	Days after emergence (DAE)									
	26-38		**39-51**		**52-62**		**63-75**		**80-95**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Kallmet	1.67	1.44	2.33	2.00	4.22	4.00	2.78	2.20	0.89	0.44
Lapardha	1.22	1.22	2.11	1.89	3.89	4.22	3.78	2.91	1.11	0.67
L 232	2.33	2.33	4.22	4.78	6.22	6.67	6.33	5.68	1.56	1.22
L 13-2	2.78	2.22	4.67	5.00	6.22	6.89	6.44	5.45	2.00	1.46
LSD 0.05	*0.70*	*0.38*	*2.78*	*0.76*	*1.34*	*1.90*	*2.20*	*2.57*	*0.45*	*0.40*
LSD 0.01	*1.05*	*0.57*	*4.71*	*1.15*	*2.04*	*2.88*	*3.33*	*3.90*	*0.68*	*0.61*

Table 3. Number of leaves per plant.

Cultivar	**Days after emergence**									
	26-38		**39-51**		**52-62**		**63-75**		**80-95**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Kallmet	13.8	14.3	20.4	23	30	28.3	16.6	11.7	3.1	2.2
Lapardha	12.1	10.7	18.1	17.3	29.7	30	23.1	12.4	4.2	3.2
L232	26.8	23.7	32.2	54.5	56.8	64.3	65.8	42.3	10.7	7.4
L13-2	24.3	24	34.3	49.5	64.8	62.7	59.6	43.1	9.6	9.8
LSD 0.05	*10.88*	*7.26*	*12.77*	*9.7*	*15.53*	*24.8*	*14.9*	*19.5*	*4.74*	*6.52*
LSD 0.01	*14.49*	*11*	*15.35*	*14.69*	*23.53*	*37.58*	*22.08*	*29.56*	*7.19*	*9.87*

In determinant cultivars, the senescence rate and fall of the lower leaves of the plant is very low, but there is no emergence of new leaves.

This fact is explained from the better lightening of the lower leaves of the plant, which continue the photosynthetic activity, as well as the termination of vegetative growth and beginning of the pods development.

3.3. Plant and crop growth analysis

Growth analysis shows the difference between two biological types for the most part of the biological cycle. The increase of plant dry matter continues at the same rates within the same biological type, but at different rates between the two biological types (Table 4). Dry matter accumulation rates goes down 63 days after emergence in determinant-type cultivars, “Kallmet” and “Lapardha” and 75 days after emergence in semi-determinant type lines. It is to be noted that the different growth periods of both biological types resulting shifted for 4-7 days, 28 days after emergence that coincides with the flowering initiation for the determinant type and 32-35 days after emergence for the semideterminant types. From the obtained data it can be noted that in the period (stage) of physiological maturation although the two semideterminant lines have the same leaf area, they accumulated different amounts of dry matter as consequence of other growth parameters, and almost twice as much as the cultivar “Kallmet” and “Lapardha”. This fact gives these lines the premise of a high potential of final yield.

Even the vegetative growth rate results to be the same 39-51 days after the emergence for studied cultivars and lines, respectively for the two biological types of beans (Table 5). The highest CGR values for both biological types are observed 52-62 days after emergence, corresponding to the period of massive flowering and the pods initiation, and grain formation. These crop growth rate values remain the same for 75 days after the emergence for semideterminant lines that coincide with the period of grain filling. On the other hand, CGR values begin to decrease 62 days after emergence for both determinant cultivars “Kallmet” and “Lapardha”. The results of the study show that 52-62 days after emergence and until the end of the plant cycle, the CGR values for the semideterminants are higher and statistically significant compared to the determinant cultivars.

From the data analysis of the yield per plant and elements of production, it could be noticed that cultivars and lines taken in the study have differences between both biological types and between the cultivars themselves. Among the determinant cultivars, the “Lapardha” cultivar had higher values of yield components, but also of the final yield (g·m^{-2}) (Table 6). Even among semi-determinant cultivars the values of the yield components are statistically higher in L13-2 compared to the L232. These two lines, although having the same values of LAI, in all periods of analysis, accumulate different amounts of dry matter, manifested in the final production or yield.

Table 4. The accumulation of dry matter (DMA) in different years and periods of crop growth (2016-2017).

Cultivar	**DMA (g·m^{-2})**									
	Days after emergence									
	26-38		**39-51**		**52-62**		**63-75**		**80-95**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Kallmet	133.6	69.1	213.7	202.1	427.2	240.43	562.6	420.9	631.7	431.8
Lapardha	117.3	70.4	250.9	156.3	448.4	364.69	622.1	494	692.8	519.7
L 232	159.9	105.3	236.1	288.8	471.6	520.51	798.1	753.2	999	812.9
L13-2	174.4	96	257.3	436.6	508.5	434.19	925.2	906.37	1213.9	1011.3
LSD0.05	*134.1*	*32.3*	*88.5*	*181.1*	*122.2*	*197.8*	*158.2*	*215.9*	*108.7*	*180.2*
LSD0.01	*203.2*	*48.9*	*134.1*	*274.3*	*185.1*	*299.5*	*239.7*	*327.1*	*164.6*	*272.3*

Table 5. Crop growth rate (CGR) (g· m^{2}· day^{-1}) at different growth periods during 2016 and 2017.

Cultivar	**Days after emergence**									
	26-38		**39-51**		**52-62**		**63-75**		**80-95**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Kallmet	3.17	2.23	5.67	4.09	15.32	5.96	8.92	3.37	2.73	2.20
Lapardha	3.56	2.27	11.46	4.16	13.79	6.70	9.14	5.11	3.88	3.03
L232	4.32	2.70	8.35	6.29	20.29	9.97	15.94	11.89	9.16	6.90
L13-2	4.32	2.46	8.58	6.72	20.68	9.92	11.84	10.35	6.1	6.41

LSD 0.05	*2.93*	*0.99*	*3.03*	*4.52*	*8.21*	*3.29*	*5.49*	*3.54*	*2.88*	*3.33*
LSD0.01	*4.15*	*1.50*	*4.29*	*6.84*	*12.43*	*4.99*	*8.31*	*5.37*	*4.36*	*5.04*

Table 6. Production elements per plant and per unit area of cultivars and lines.

Cultivar	**Plant yield components**							
	PNP		**GNP**		**GWP**		**GW·m^{-2}**	
	2016	2017	2016	2017	2016	2017	2016	2017
Kallmet	25.33	21.00	81.29	71.17	32.93	28.35	395.16	340.20
Lapardha	28.00	22.50	89.71	74.67	36.96	30.50	442.52	366.00
L 232	42.00	37.00	158.41	142.50	50.59	42.54	605.48	510.48
L 13-2	43.67	38.43	172.16	160.50	55.83	51.50	669.96	618.00
LSD0.05	*13.63*	***10.86***	*61.80*	***66.30***	*14.80*	***24.15***	*118.39*	***144.93***
LSD0.01	*20.65*	***16.46***	*93.62*	***100.45***	*22.42*	***36.58***	*179.36*	***219.55***

PNP- pods number per plant, GNP- grain per plant, GWP- grain weight per plant, GW^{-2}- grain weight

Through the comparison of a synthesis of the results above, it could be seen a clear grouping of both biological types for LAI value and other studied traits. Among determinant type cultivars, there are no significant differences to the analyzed traits, although "Lapardha" cultivar had a higher values of LAI and other traits than "Kallmet".

4. Discussion

Through the comparison of the semideterminant lines it is noted that L232 despite the equal values of LAI with L13-2, its leaf area duration was shorter, which is explained by the structural construction of its own plant. The more planofile of leaves setting on this line causes shading of the bottom leaves. As a C_3 type plants, the beans have a low point of photosynthesis compensation. For this reason, the upper leaves, which remain in full light, are quickly saturated and therefore a good part of this radiation cannot be used by plant for photosynthesis. The leaves of the lower layers, being less illuminated, have a little contribute to photosynthesis. If the illumination levels are low, the illumination of the lower leaves is not sufficient to reach the light compensation point and in these conditions the respiration is superior to photosynthesis, the balance becomes negative, the leaves become yellow and senescence.

Line L13-2, in the period of maturation, had higher LAI values. This gives it the opportunity for a higher production potential. Such a plant canopy, with erektofil architectural construction, allows a greater penetration of solar light into the lower leaves layers and higher photosynthetic activity, in a time when the upper leaves do not reach the light saturation point. In the complex the photosynthetic efficiency of the plant will be greater. In general it can be said that ideal leaf architecture is one in which the upper leaves are more inclined than the lower layers of the plant leaves.

As in other plants, in beans during the vegetative and reproductive period, there are changes in the distribution of produced assimilates. Its amount depends on the growth model, which is conditioned by the genotype and the environmental conditions. At the stage of grain filling, the quantity of assimilates produced is not enough to meet the requirements of the pods and grains. According to Kipps and Boulter (1974), green pods also perform photosynthesis. The photosynthesis of pods even in lower rate than the leaves photosynthesis, is important for grain assimilates, especially when photosynthetic activity of leaves is small. But since the pods are placed inside the plant cover, deprived of solar lighting, the photosynthetic activity is very limited. An erectile structure of the plant cover would allow a better penetration of the solar lighting, which would increase the photosynthetic activity of the pods for the account of the grain development.

The number and weight of grains that reach the maturation determine the production. In assimilates distribution, the genotype and grain capacity to endure competition within the plant is very important.

When the amount of assimilates translocated from the leaves to the pods grains decreases, the competition between them increases, and the number of grains that reach the full maturation decreases. The grains of a pod interact with each other as plants of a population. When the grains growth rate is greater than the translocation of assimilates, the largest grains take place in the center, with higher growth rates, and thus will grow at the expense of other grains.

From this discussion it could be drawn that the number and weight of grains in the pod and in the plants is a consequence of the photosynthetic activity of the cultivar, which is conditioned by the plant canopy architecture, environmental conditions and cultivation technology.

To summarize the above results, by comparing lines of the same biological type, it is noted that the semideterminant lines, although having the same LAI, have different photosynthetic activity and different distribution of assimilates to the benefit of real production.

5. Conclusions

From the analysis and discussion of the above data we can conclude that:

- The biological types of bean cultivars differ among them for some indicators of growth traits throughout its plant cycle.
- Climatic conditions, mainly extreme maximum temperatures, have influenced the leaf area index and other growth parameters during 2017.
- Semideterminant cultivars L-232 and L-13-2 had higher LAI values throughout the plant cycle than determinant types – "Lapardha" and "Kallmet". In the semideterminant biological type, at the end of the plant vegetation period, cultivar L13-2 had higher values than L232 as a result of new leaf emergence and erectofil structure of the plant. In the determinant biological types there are no significant changes to the value of the leaf area index, but only a higher value to the "Lapardha" cultivar.
- The crop growth rate was higher during the reproductive period. Among the two biological types, the growth rate was highest in the semideterminant biological type at the end of the reproductive period.
- The dry matter accumulation is the function of the leaf area and the main climatic elements, such as temperature and water balance, mainly during the reproduction period. Cultivars of the determinant type has accumulated almost 50% of dry matter compared to semideterminant cultivars. Line L13-2 though having the same leaf area as line L232, has accumulated a larger amount of dry matter due to the different construction of plant architecture and other growth parameters.
- Cultivars and lines in the study are distinguished for different indicators of growth traits, consequently the discussion of genetic material should be based on complex indicators of growth traits and not on particular indicators.

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