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REGULAR ARTICLE

Influence of irrigation regime on the leaf area and leaf area index of French bean (*Phaseolus vulgaris* L.)

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Abstract

In field experiments the influence of irrigation regime on leaf area and leaf area index in bean plants are investigated. Cultivar “Strike" was used, which is a highly yield, with cylindrical pods and is intended mainly for the canning industry. Experiments were conducted according to the block method, in four replications and size of experimental plots 17.5 m^2, and crop plots - 10 m^2 and planting pattern of 50 x 5 cm. The variants are the following: 1. Without irrigation; 2. Optimum irrigation by the maintenance of “pre-irrigation soil moisture” over 80% of the Field Capacity (FC); 3. Irrigation with variant 2, but with 30% reduction of irrigation norm; 4. Irrigation with variant 2, but with 70% reduction of irrigation norm. A close relationship between the irrigation norms and leaf area index (LAI) for the conditions of the experiment is established. This relationship is subject to the equation $Y=1-0.609(1-x)^{1,5}$, where R^2 = 0.981. Relationship has been found between LAI and yield, which is expressed best by the quadratic equation: $Y=547.8\ x-31.9x^2-746.6$, at R^2 = 0.91. The relationship between the mass of leaves (x) and LA is linear, as in terms of dry mass, it is expressed by the equation LA= 81.95x, with R^2 =0.843. In terms of fresh leaf mass equation is: LA=35.073x at R^2=0.912.

Key words: French bean, Irrigation regime, Leaf area, Leaf area index

Introduction

The role of leaves as main assimilating organs is crucial, as more than 90-95% of organic production is created in the process of photosynthesis (Nikolov, 1973). The biological and economic yield depends largely of the amount of leaf area, the speed of its formation and duration of its work. To achieve maximum leaf area of plants, it should be ensured favorable water and air climate, nutrient conditions, as well as proper and timely implementation of other agricultural activities. In terms of actual production, the creation of appropriate conditions for growing crop plants (including French bean) is often impossible due to technical, organizational or economic reasons. Usually there are compromises with irrigation by slowing the submission of watering or watering with smaller sized irrigation norms. As a result, plants experiencing water stress, which react differently depending on plant development.

Allowing water stress in bean plants leads to a shortening of flowering period and development of pods, and dampen of leaf formation (Lopes et al., 1986; Nuñez-Barrios, 1991). Results delivered by Gomes et al. (2000) have shown that these negative effects are available in varieties with different tolerance to soil drought. Acosta Gallegos and Shibata (1989) reported a significant decrease in the values of leaf area index (LAI) and yield in repealing irrigations only to bud stage. Gunton and Evenson (1980) received the same results and concluded that for the conditions of Queensland (Australia) cancellation of irrigation before flowering resulted in a decrease of yield of 31-44%, while repealing irrigations during flowering losses are 31-55%. The authors found a close correlation between yield and leaf area. Experiments of Bascur et al. (1985) conducted in Colombia with 12 varieties of beans with different sensitivity to lack of soil moisture confirmed the criticality of reproductive period and changes in LAI. Nuñez-Barrios et al. (2005) also recorded a significant reduction in yield due to the termination of irrigations during the reproductive period. The authors reported decreases in leaf area of stems

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with 60.1%, and in leaf area of the branches - by 10.4%.

The aim of the study was to establish the influence of irrigation with reduced irrigation rates on the amount of leaf area and Leaf Area Index (LAI) in French bean grown as a spring crop.

Materials and Methods

Field experiments with French bean were conducted during the years of 2010 – 2012, in the region of Research Experimental Field of Agricultural University-Plovdiv, on alluvial-meadow soil. Plants were grown under agro technology for early field production. Cultivar “Strike" was used, which is a highly yield, with cylindrical pods and is intended mainly for the canning industry. Experiments were conducted according to the block method, in four replications and size of experimental plots 17.5 m^2, and crop plots - 10 m^2 and planting pattern of 50 x 5 cm.

The variants were the following:

1. Without irrigation
2. Optimum irrigation by the maintenance of “pre-irrigation soil moisture” over 80% of the Field Capacity (FC) (100% m)
3. Irrigation with variant 2, but with 30% reduction of irrigation norm (70% m)
4. Irrigation with variant 2, but with 70% reduction of irrigation norm (30% m)

Set in variant 2 “pre-irrigation soil moisture” refers to the soil layer 0-40 cm, and irrigation rates are calculated for active soil layer 0-60 cm so as to restore the water supply to the FC.

Irrigation of experimental plots is done by gravity on short closed furrows for accurate dosing of irrigation water.

The dynamics of growth of leaf area was determined at intervals of 10 days, using 10 plants from each variant. Leaves were removed from the test plants and then were scanned and processed using specialized computer program that calculates the exact size of the resulting images. The maximal leaf area formed per unit ground area is represented by the Leaf Area Index (LAI), which is the ratio of leaf area to soil surface (Georgiev and Matev, 1998).

Results

The influence of the irrigation regime on growth and development of French bean is related to weather conditions during the growing period. In this connection, statistical evaluation of the experimental years, in terms of rainfall and temperature sum for May to July period, using data over 101 years, was carried out (Table 1).

Table 1. Meteorological data from May to July in the Plovdiv region.

Parameter		Mean	2010	2011	2012
∑N	mm	170.2 mm (for 101 years)	197.8	96.9	205.6
	P %		24.8	89.2	23.5
∑T°	°C	1910°C (for 101 years)	1960	1993	2089
	P %		30.4	21.6	4.9

* Σ N – amount of rainfall; Σ T° – sum of temperature; P % – probability of meteorological factor

The first experimental year had an average rainfall with a probability of 24.8% and a precipitation of 197.8 mm. These factors allowed the plants to reach the phase "bud formation". During flowering and initial formation of buds, rainfall is slight and rainfall reach over 100 mm at the end of harvesting period, which has not agronomic importance. The distribution of rainfall during the vegetation period of 2011 remained similar and over 50% of the rain fall occurred at the beginning of the reproductive period. During flowering there was a drought, and rainfalls at the end of the vegetation period reached about 40 mm, which were also ineffective. 2011 is characterized as dry, with 89.2% probability. The third experimental year (2012) had a medium moist with a probability of 23.5%, but 98% of the rainfalls, occurred in the initial stage of development of plants and those maintaining soil moisture at an optimum level to "bud formation" stage.

The sum of the daily average air temperature, from May to July, in the first experimental year (2010) was 1960°C, in the second - 1993°C, and during the third–2089°C. Probability was respectively 30.4%, 21.6% and 4.9%. In fact, the first two years are on average warmer and the third one is warm.

Differences between experimental years, in terms of weather conditions, lead to differences concerning the parameters of the irrigation regime. In the first experimental year three irrigations were realized, one in phase "bud formation", while others were in "flowering stage" and "fructification stage", with the optimal norm (variant 2) of irrigation of 148.4 mm. When reducing the irrigation rate from 30% to 70%, it is respectively 104.1 and 44.6 mm. In the second experimental year, six irrigations were done, the first one in the vegetative period, and the others five are distributed one per stage as follow: "bud formation", "flowering", "emergence of first beans", "fructification" and the latest one after the first harvest. The size of the irrigation depth is optimal at 303.3 mm, and variants with reduced rates are respectively 212.3 and 91.0 mm. In 2012 irrigation period begins in stage "flowering". During this stage, and the formation of the first fruits, one of the irrigations has carried out and in the stage of “fructification” two irrigations were done. After the first harvest, to ensure the growth of the rest of the pods, additional irrigation was carried out. The irrigation depths were 254.0, 177.8 and 76.2 mm, respectively, for the three irrigated variants.

Influence of irrigation regime on leaf area

At optimal irrigated beans (variant 2) there is a real prerequisite for maximum development of leaf apparatus, i.e. to reach a maximal leaf area for the respective phenophases. Allowing water deficit, negatively affect the process of leaf formation, and this negative effect was very pronounced in the drier 2011 and 2012 years. In figures 1, 2 and 3 it is shown the dynamics of the accumulation of leaf area per year for the different variants.

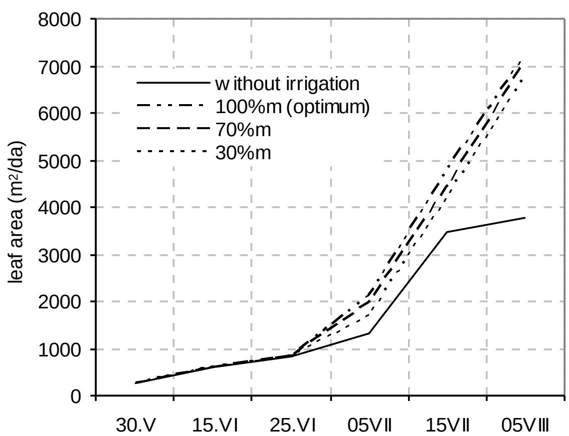

Figure 1. Dynamics of leaf area increasing under irrigation with reduced rates in 2010.

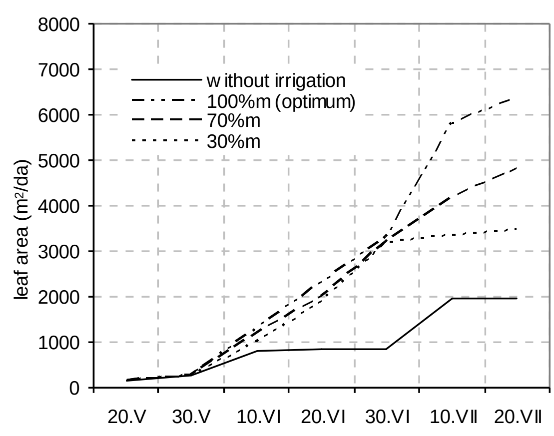

Figure 2. Dynamics of leaf area increasing under irrigation with reduced rates in 2011.

Over the first experimental year (2010), when during the vegetative period of culture rainfalls are sufficient to meet the water needs of plants; the negative impact of smaller irrigation rates was mitigated. Submitted norms, albeit reduced, were enough and accumulated sufficient leaf area, which was comparable to that at optimal irrigated variant.

Over the second and the third experimental years, the lack of rainfall in most of the vegetative season inhibited leaf formation, and the differences compared to irrigated variants after flowering significantly increased and during the period of harvest are about 2 times at a rate of 30% to more than 3 times under optimal variant. This indicator displayed a very close proximity between the data obtained at rates 30% and 70%, while values at optimum irrigation were significantly higher. Taking into account the results received during the three experimental years, it can be concluded that for the dynamics of leaf area of French bean regular irrigations are more important than the amount of irrigation norm, especially in years with long spring and summer droughts.

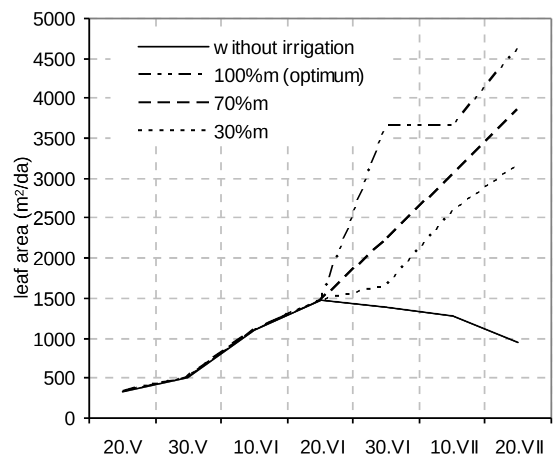

Figure 3. Dynamics of leaf area increasing under irrigation with reduced rates in 2012.

Effect of irrigation regime on leaf area index (LAI)

Because harvesting of French bean occurs during a period when leaf area (LA) has reached maximum size, leaf area index is calculated based on the values obtained in this stage of vegetation. With the exception of the variant 1ine 2012, where maximal LA was formed 20 days before other variants, leaves started dying and defoliating when other variants have a maximum LA. Indeed, LA of variant 1 decreased by over 30%. This is due to the extreme weather conditions experienced at this year. Figure 4 presents a visual indicator values for variants during experimental years.

Data in Figure 4 clearly show the influence of weather conditions, in a particular year, on the values of LAI, within a given variant. However, the irrigation regime is decisive in the three experimental years.

Reducing the irrigation rates display a negative impact on the values of LAI, but because the number of irrigations coincides with the irrigations at variant 1, it is likely rainfalls between irrigations to supplement partially or fully water deficit caused by the decrease of irrigation norm. In such cases the results are close to those observed in irrigation with maximum irrigation rate. Such a typical example of the experimental conditions is LAI in 2010. When irrigation is with 70% reduced irrigation rate, it reaches 94% of that at the optimum irrigation, and with 30% reduction - 98%. In the remaining two experimental years, the negative effect of the reduction of the irrigation rate is pronounced, but a significant role may play also adverse weather conditions during the growing season (mostly small quantity and unevenly distributed rainfall).

A correlation between the relative amount of the irrigation rates and the relative values of LAI was determined. The same can be represented much more accurately by the speed function using the formula of Davidov (1994, 2004): $Y=1-(1-Y_c)(1-x)^n$, where: Y is sought LAI; Y_c - LAI in non-irrigated beans; x - the relative irrigation depth and n - exponent. The results are shown graphically in Figure 5.

Besides the high correlation coefficient (R>0,98) all four curves in the graph describe in the best way, the changing in LAI, depending on the size of the irrigation norm. In the first experimental year, due to high levels of LAI, still at a rate 30%, the equation has a high exponent (n = 4.7), being the result that the curve a strong convex parabola. In a worst case, 2011 and 2012, the increase of the normal LAI was gradually, so that the curves approximating the experimental points are less prominent, and the exponent - lower (respectively n = 1.1 and n = 1.6). For the three experimental years, the relationship between the amount of irrigation and LAI can be represented by the equation $Y=1-0,609(1-x)^{1,5}$, where R=0,981. In Figure 6 the relationship between the experimental and the calculated values of LAI, common to all variants and years, is presented, with correlation coefficient R=0.99.

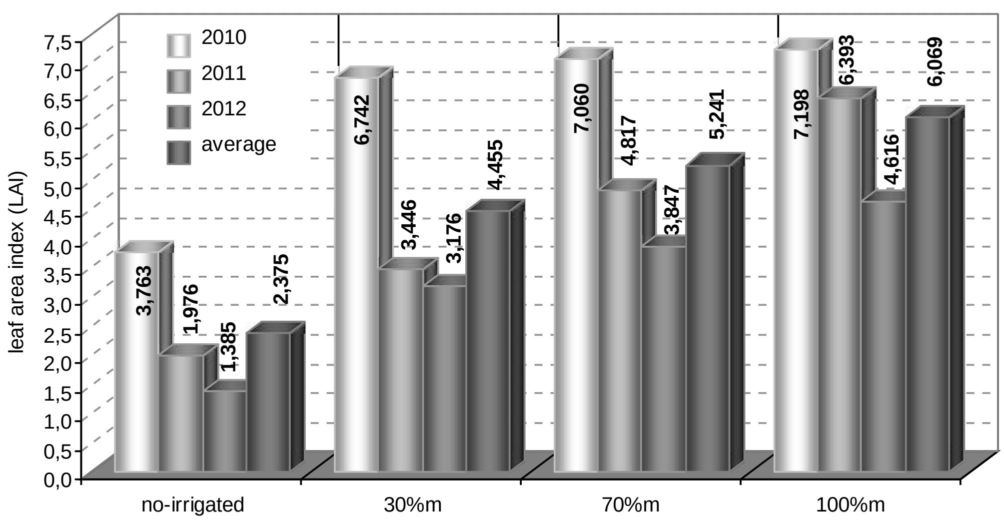

Figure 4. Effect of irrigation rates on Leaf Area Index (LAI).

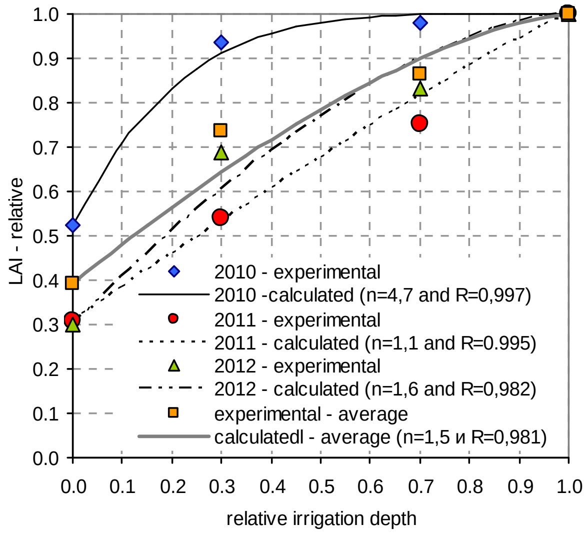

Figure 5. “LAI-irrigation rate” dependence.

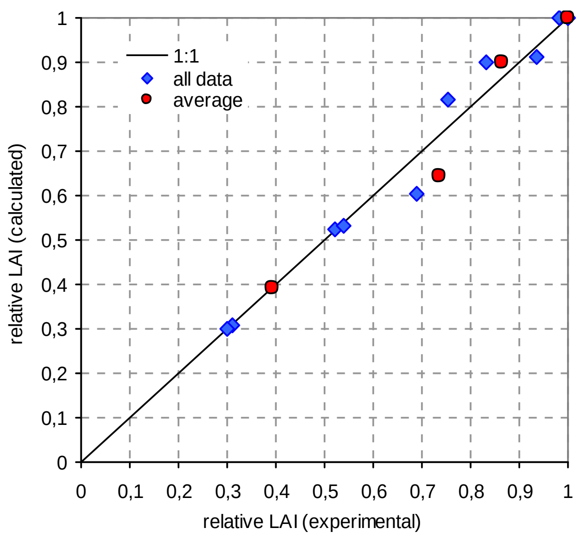

Figure 6. Relationship between experimental and calculated values of LAI.

Using experimental data for the leaf area and the mass of the leaves several established relationships are calculated. These relationships can be used for prognostic purposes and for the indirect determination of certain parameters in the French bean.

In Figure 7 the relationship between LAI and yield is presented. This relationship is expressed best by the quadratic equation, $Y=547.8x-31.9\ x^2-746.6$, which oversees a convex parabola approximating the empirical points at a very high coefficient of determination (R^2=0,91). According to the graph, when LAI is in the range from 0 to 1.5, the yield is zero, and at values of about 2, can be expected to a yield of more than 200 kg/da. The yield increases quickly in the range of 2-3, reaching 610 kg/da (increments 390 kg/da). With increasing LAI, step to the change in yield gradually decreases, and in the range of LAI 7-8, it is 70 kg/da. Maximum yield is obtained by LAI = 9 (1603 kg/da), then in theory the yield began to decline, but in practice that variety of French bean does not reach that size of leaf area. In much of the crops removal of such dependence can be used for purposes of obtaining information about the expected yield much before the end of vegetation (when leaf area of the plant has reached its maximum size). This can be attributed almost all field crops (corn, soybean, sunflower, beet, cereals, etc.). For the current work, and in general for French bean, this information can be obtained immediately before harvest, as LAI values are reported on the basis of leaf area in this part of the vegetation.

Conducting research related to the establishment of size of leaf area and the rate of accumulation of dry biomass, is often associated with activities, time-consuming or those related to energy consumption. In order to facilitate the procedure of this type, using data from this study about the leaf mass and leaf area, dependencies between these parameters were obtained.

Figure 8 presents the relationship between the absolute dry weight of the leaves per one plant and its leaf area. Dependence is linear and shows high accuracy (R^2>0.8). In the first case, according to the absolutely dry mass of the leaves per one plant of a variant (a number of plants), can be calculated the average leaf area per plant and, depending on the density of the crop, to determine the area of LA per m^2, da, ha etc.

The relationship, shown in fig. 9 is similar to the previous and conceptual overlaps with it, but instead of absolutely dry mass of leaves fresh mass is used. An important condition for its correct practical application is the ability to immediately determine the leaf fresh mass of the specific test, plants because after removing them from the soil, they quickly lose some of tissue water. This would lead to an increasing error in the results. The advantage of this dependence is that LA is calculated at once and, thus, saving time and energy for dry mass determination. Accuracy in this method is also very high, which is clearly visible through the values of the coefficient of determination ($R^2 \geq 0.9$).

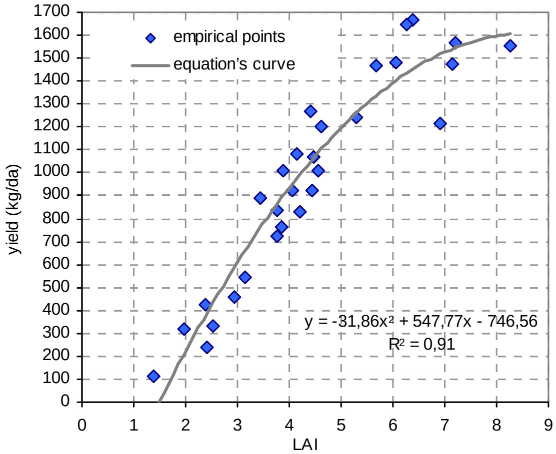

Figure 7. Relationship between LAI and yield.

Results of Figure 10, which presents the numerical and visual relationship between fresh and dry leaf mass, may find practical application in the experiments with French bean. The relationship is again linear at R^2=0.95, and from the equation may be settled that an absolute dry weight of the leaves of French bean was 19%, relatively to the leaves in the fresh state.

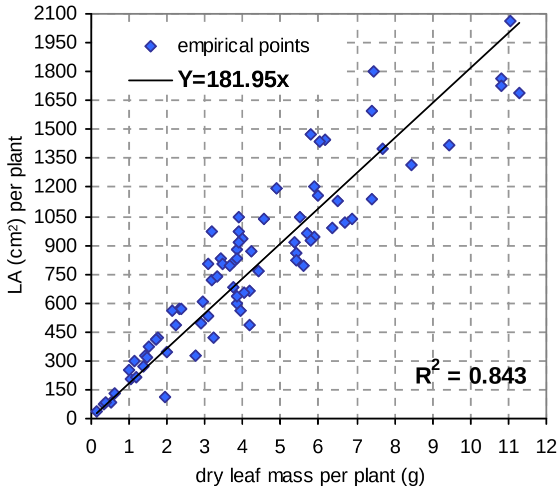

Figure 8. Relationship between dry leaf mass and leaf area per plant.

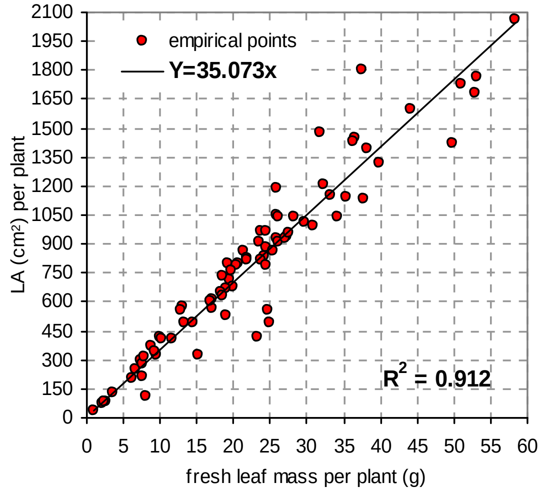

Figure 9. Relationship between fresh leaf mass and leaf area per plant.

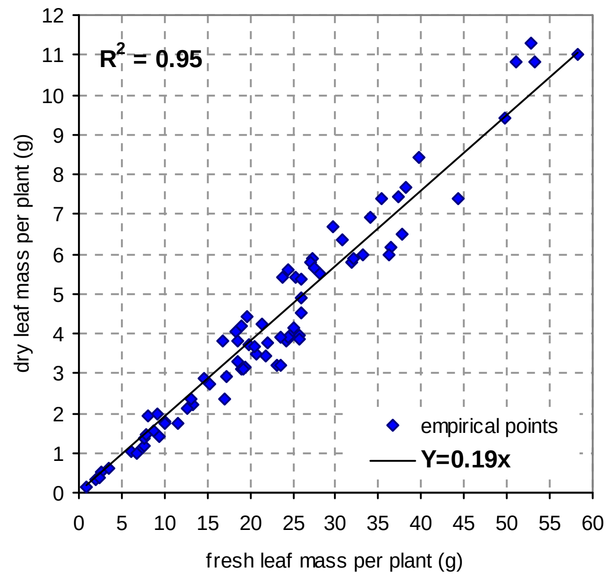

Figure 10. Relationship between fresh leaf mass and dry leaf mass per plant.

Conclusions

Irrigation has a significant impact on the amount of leaf area of French bean. During years with prolonged droughts over the growing period, the difference in values can reach twice when irrigating with small irrigation rates (30% m) and over three times - in optimal irrigation. During such dry years time made irrigations have a significant impact on the dynamics of leaf area growth compared to the size of the irrigation norm. Under irrigation French bean has developed maximum leaf area during the harvest period, and under optimal irrigation LA ranges from 4620 to 7060 m^2/da. The same patterns were observed in terms of LAI. Without irrigation its values range from 1.385 to 3.763 (average 2.375). Through improving the plant water regime and increasing the amount of irrigation norm, LAI increased from 4.616 to 7.198 (average 6.069).

There is a close relationship between the irrigation norms and LAI for the conditions of the experiment. This relationship is subject to the equation $Y=1-0.609(1-x)^{1,5}$, where $R^2 = 0.981$. Relationship has been found between LAI and yield, which is expressed best by the quadratic equation: $Y=547.8\ x-31.9x^2-746.6$, at $R^2 = 0.91$. According to this equation a yield can be obtained at values of LAI>1.5.

The relationship between the mass of leaves (x) and LA is linear, as in terms of dry weight, it is expressed by the equation LA= 81.95x, with R^2 =0.843. In terms of fresh leaf mass equation is: LA=35.073x at R^2=0.912. Practical application in the experiments with French bean is the relationship between fresh and dry leaf mass. The relationship is linear with R^2=0.95 and is represented by the equation: Y=0.19x. This means that the absolute dry mass of the leaves of the French bean is 19% of the fresh leaf mass.

Author contributions

R. K. designed the study, did the analysis, A. M. designed the study, wrote the article and Z. Z. wrote and corrected the article.

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