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# IMPACT OF TEMPERATURE AND RAINFALL DISTRIBUTION OVER 1989-1996 ON THE BIOMETRIC AND STRUCTURAL CHARACTERISTICS AS WELL AS ON THE 'JUNO' YELLOW LUPIN YIELDING

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ABSTRACT
INTRODUCTION
MATERIAL AND METHODS
RESULTS
DISCUSSION
CONCLUSIONS
REFERENCES

## ABSTRACT

The results of 8-year field experiment helped to analyse the impact of weather conditions on biometric and structural characteristics and on 'Juno' yellow lupin yielding. Over 1989-1996-vegetation period there was recorded a large weather conditions variation; the coefficient of temperature variation amounted to 16% and of rainfall –about 49%. The relationship between temperature and rainfall and biometric and structural characteristics as well as seed yielding was defined with statistical regression method. It was observed that temperature had a greater effect in initial and final growth and development phases, while rainfall – over vegetation.

**Key words:** yellow lupin, temperature, rainfall, biometric and structural characteristics, seed yield

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## INTRODUCTION

Yellow lupin remains extremely sensitive to the conditions of growth and development; especially weather conditions. Numerous research focus on the agricultural practices required for specific species, yet fewer investigate weather conditions which show such a great effect on the yielding variability.

The most crucial yielding-related weather conditions include air temperature and rainfall [2,5,13,16]. The seed yield obtained for all the crops depends on the rainfall and rainfall distribution over the vegetation period [4]. Legumes show greatest water demand for about two weeks prior to flowering until first flat pods are formed. Over that period both rainfall shortage and rainfall surplus can be unfavourable for yielding [15,18]. Rainfall has a direct effect on the soil water content, which affects temperature and aeration in soil. The impact of those climatic factors can differ considerably within a single soil type.

The variation in biometric characteristics in legumes has been investigated by numerous authors. Many of them claim that legume yields vary considerably, which is related to their high sensitivity to climatic conditions [15,19,20], susceptibility to diseases, pests [7,20,21] and other habitat conditions [3,11,12,17,18,21]. Bearing all that in mind, it is believed that the evaluation of cultivars should, first of all, include the analysis of their reaction to changing environmental conditions [10], which leads to a better geographical location of respective species and legume cultivars. Geographical location remains also a cost- and time- effective measure to increase production [11].

To recapitulate, identifying the quantitative impact of weather conditions on the yellow lupin yielding and defining the probability of extreme values for factors limiting yielding can enhance the geographical location of the crop and, consequently, increase its productivity [14].

## MATERIAL AND METHODS

The analysis of the relationship between the structural and biometric characteristics and yellow lupin yielding was based on the material obtained from a 1989 – 1996 strict field experiment located at the Tomaszkowo Experiment Station of the Warmia and Masuria University, on IV quality class soils. The field experiment covered a few cultivars of the species; ‘Juno’ represented the longest non-stop observation period. Plant cultivation followed general guidelines, most importantly the cultivation of lupin in crop rotation after cereals, at mineral fertilisation of 20 kg of N, 50 kg of P and 80 kg of K per ha. The seeds were collected over harvest maturity phase. Over vegetation the dates of respective full development phases were recorded. Shortly prior to harvest the following values were recorded: stem length, first-pod setting height, number of pods per plant, number of seeds per pod and per plant and the weight of 1000 seeds. Field germination percentage was defined after emergence and plant density prior to harvest. Weather conditions details were provided by the Tomaszkowo Station.

For each period between the dates when respective development stages had been reached, there were defined two parameters, namely sum of effective temperatures and rainfall.

Statistical analysis focused on defining relationships between the estimated parameters of weather, vegetation and plant efficiency. The analysis covered those data which had been

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estimated to remain in logical relations with the linear multiple regression. The choice of independent variables was made with the stepwise regression. The method involved successive increases in the set of independent variables till the successive variable exceeded the agreed level of variable tolerance. Finally there were calculated multiple correlation coefficients as well as regression equations. Conclusions were drawn from the results of the regression equation with independent variables, significant at p=95%. Each of the defined structural and biometric characteristics and plant yield was analysed considering weather conditions for development phases and, additionally, separately for the total plant vegetation period. The significance of the equations was verified with the test [F]. Calculations were made using a statistical software package, STATISTICA.

## RESULTS

The vegetation period of 'Juno', a lupin cultivar, under the conditions of the present field experiment, covered an average of 114 days (Table 1). There were observed no considerable differences in its duration over respective years, which is seen from the variation coefficient, calculated for the 8-year values, which amounted to 16% only. However taking into consideration respective development phases, more considerable fluctuations from the mean values were noted. The most variable duration time was recorded for the period from sowing to emergence, and then from flowering to harvest maturity, which is confirmed by development rhythms of numerous species, including those of opposite soil and climatic requirements. Mean daily temperatures for respective development phases increased gradually. Generally lupin was sown under favourable temperature conditions, hence the mean temperature for the phase from sowing to emergence turned out considerably high. One has to bear in mind, however, that temperatures of that period differed considerably over years; the variation coefficient turned out highest here and amounted to 38.2%. Over the other phases the temperatures were more uniform and means for the total vegetation period in respective years were defined with the variation coefficient which amounted to 11.6%, only. The sum of effective temperatures, calculated as a product of mean daily temperatures and phase duration time, showed some variability reflecting the values of the factors the sum was determined by. Here the greatest differences were observed for the periods from flowering to pod setting [variation coefficient of 33.4%]. Rainfall remains the most varied weather parameter. The present experiment breaks down rainfall reported for different period lengths. As a result an average rainfall for the lupin vegetation period amounted to slightly over 200 mm which is enough to meet the demand of this species. The highest mean rainfall over vegetation coincided with the phases between plant emergence and flowering as well as between pod setting and harvest maturity.

**Table 1. Statistical values of parameters of yellow lupin vegetation period and its weather conditions over 1989-1996**

| Parameters of vegetation | Development phases | | | | |
|---|---|---|---|---|---|
| | Sowing - emergence | Emergence-flowering | Flowering-developing of pods | Developing of pods-harvest maturity | Emergence-harvest maturity |
| Length | | | | | |
| X, days | 17.5 | 54.4 | 7.0 | 53.0 | 114 |
| Cv, % | 42.2 | 14.6 | 35.8 | 38.9 | 15.9 |

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| | | | | | |
|---|---|---|---|---|---|
| Mean daily temperature | | | | | |
| X, °C | 10.9 | 14.9 | 17.0 | 18.8 | 16.5 |
| Cv, % | 38.2 | 11.1 | 14.2 | 16.6 | 11.6 |
| Sum of temperatures | | | | | |
| X, °C | 170 | 807 | 116 | 960 | 1876 |
| Cv, % | 18.7 | 13.8 | 33.4 | 29.4 | 16.7 |
| Rainfall | | | | | |
| X, mm | 10.8 | 90.0 | 7.4 | 102 | 206 |
| Cv, % | 103 | 43.9 | 134 | 106 | 49.0 |
| Number of raining days | | | | | |
| X, days | 5.0 | 19.7 | 2.3 | 18.8 | 42.5 |
| Cv, % | 81.4 | 52.6 | 94.3 | 66.8 | 33.7 |
| Raining days | | | | | |
| X, % | 28.3 | 31.2 | 29.6 | 33.2 | 36.7 |
| Cv, % | 80.6 | 59.3 | 97.7 | 33.6 | 24.7 |

**X - mean value**
**Cv - coefficient of variation**

Even though the periods were the longest, each day of these phases showed an almost two-fold higher rainfall than in the remaining phases. The greatest rainfall variability was recorded over the shortest phase from flowering to pod setting and amounted to over 133%. Considering the rainfall day distribution against the total number of days over a given phase, slight differences were observed. Both the total vegetation period and respective phases showed a share of such days of about 30%. A variability in the share of those days in the total vegetation period was relatively low (24.7%), however since the sowing date till emergence and from flowering to pod setting the variation coefficient values were 80.6% and 97.7%, respectively. Such weather conditions were well reflected in the variation in the structural and biometric characteristics as well as in the lupin yielding (Table 2). The characteristics which remained least dependent on numerous weather conditions included: plant height, first-pod setting height and the weight of 1000 seeds and over the 8-year research their variation coefficient amounted to about 11%, while those most dependent - a number of pods per plant. The variation coefficient value exceeded 120%, which is typical for a majority of legumes. A varied, from year to year, number of pods per plant results mainly from weather conditions over flowering. The 1989-1996 ‘Juno’ yellow lupin seed yield ranged from 0.79 to 1.69 $t \cdot ha^{-1}$ and the variation coefficient amounted to about 21%.

**Table 2. Statistics of yellow lupin yield and its structure over 1989-1996**

| Specification | Minimum value | Maximum value | Mean | Standard deviation | Coefficient of variation, % |
|---|---|---|---|---|---|
| Height of plants, cm | 67.7 | 98.4 | 80.8 | 9.13 | 11.30 |
| Height of first pod setting, cm | 53.9 | 84.8 | 84.8 | 9.69 | 11.43 |

| | | | | | |
|---|---|---|---|---|---|
| Number of pods per main stem | 6.20 | 11.4 | 8.00 | 1.81 | 22.6 |
| Number of pods per lateral branches | 0.00 | 4.90 | 1.40 | 1.69 | 120 |
| Number of seeds per pod | 6.70 | 14.3 | 9.40 | 2.59 | 27.5 |
| Number of seeds per plant | 13.1 | 52.9 | 32.1 | 12.5 | 39.0 |
| Weight of 1000 seeds, g | 123 | 173 | 144 | 14.8 | 10.3 |
| Germination, % | 63.0 | 100 | 86.3 | 15.2 | 17.6 |
| Number of plants per 1 $m^2$ prior to harvest | 58.0 | 94.0 | 78.1 | 12.1 | 15.5 |
| Seed yield, $t \cdot ha^{-1}$ | 0.79 | 1.69 | 1.46 | 0.30 | 20.5 |

The multiple regression defined the impact of a number of selected weather conditions on the biometric and structural characteristics as well as on the lupine yield. Table 3 offers a breakdown of results, with B coefficients, in particular, which stress the extent of the dependent variable per unit of independent variable. Intercept of regression equation and the values of the coefficient of determination, $R^2$ (%) were calculated. Drawing on the regression coefficient values and mean values of the variables, there were defined simulated values of biometric and structural characteristics as well as of the lupin seed yield.

**Table 3. Impact of weather conditions over development phases on the yellow lupin morphological structure and yield (according to the analysis of regression)**

| Weather factors | Independent variables | Development variables | | | | | |
|---|---|---|---|---|---|---|---|
| | | Height of plants | Number of pods per main stem | Number of seeds per plant | Weight of 1000 seeds | Plant density prior to harvest | Seed yield |
| Weather conditions over development phases | | | | | | | |
| Sum of air temperature | Sowing - emergence | - 0.31 | - | - | 0.31 | 0.22 | 0.007 |
| | Emergence – flowering | - 0.03 | - 0.02 | - | 0.11 | 0.14 | |
| | Flowering – pod setting | - | - | 0.10 | - | - | - |
| | Pod setting – harvest maturity | - | - | 0.11 | - 0.02 | - | 0.002 |
| Rainfall | Sowing - emergence | 0.06 | - | - | - 1.40 | - 0.92 | |
| | Emergence – flowering | 0.43 | - | - | - | - 0.08 | 0.003 |
| | Flowering – pod setting | 0.35 | - | - | - | 0.68 | - 0.012 |
| | Pod setting – harvest maturity | | - | - | - | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Intercept | | 140.4 | 27.0 | 84.7 | 7.91 | - 60.5 | 0.13 |
| $R^2$ of multiple regression equation, % | | 88.2 | 59.0 | 86.0 | 92.4 | 88.0 | 98.0 |
| Weather conditions over vegetation period | | | | | | | |
| Sum of air temperature | Emergence – harvest maturity | - | | - 0.05 | - | - | - |
| Rainfall | Emergence – harvest maturity | - | | 0.15 | - | - | - |
| Intercept | | 70.7 | | 88.1 | 159 | - | - |
| $R^2$ of multiple regression equation, % | | 16.0 | | 80.2 | 9.0 | - | - |
| Simulated value | | 105.4 | 10.9 | 202 | 123 | 77.9 | 3.1 |

The greatest dependence on the weather conditions was observed for lupin yield. The link between the temperature and rainfall parameters calculated for respective phases amounted to 98%, which shows that yellow lupin yielding variability may reflect an impact of significant regression equation elements. The intercept in that equation amounts to 0.13 $t \cdot ha^{-1}$ which represents the yield which could be obtained for zero values of the variables considered. The highest impact on the seed yield defined per unit was observed for a rainfall from flowering to pod setting. A change in the rainfall over that sensitive period by 1 mm significantly decreased the yield by 0.012 $t \cdot ha^{-1}$. Similarly there was recorded a relatively high impact of the sum of temperatures from sowing to emergence; an increase by 1$^{o}$C resulted in a yield increase by o 0.007 $t \cdot ha^{-1}$. The other two significant variables, confirmed by the regression equation obtained included sum of temperatures of the phase pod setting - harvest maturity and rainfall over the plant emergence - flowering. In both cases an increase in the sum of temperatures or rainfall by unit was reflected in an increase in lupin productivity. An increase by 1 Celsius degree of the sum of temperatures and/or by 1 mm of rainfall increased the seed yield by 0.002 and 0.003 t of seeds per ha, respectively. The regression analysis which covered the weather factors studied for the total vegetation period did not show significant correlation. For lupin, similarly to a majority of crops a distribution of over respective development phases remains essential, unlike the total values for the vegetation period. The present analysis shows that the crops could not compensate the losses which resulted from a shortage or surplus of rainfall or too high or inadequate temperature. A degree of variation in weather conditions recorded for the multi-year was high enough to result in irreversible changes (e.g. flower abscissions, absence of pod primordium). The calculations showed that if a given year recorded mean multi-year values of sums of temperatures and rainfall, a simulated yield could amount to 3.15 $t \cdot ha^{-1}$, which exceeds the mean real value by about 1.7 $t \cdot ha^{-1}$. None of the research years recorded such favourable conditions.

The highest number of significant correlation for biometric and structural variables was obtained for the plant height which was most affected by both temperature recorded from sowing to flowering and rainfall from sowing to pod setting. A correlation analysis showed higher phase temperature sums decreased the stem length, while an increase in the rainfall its increase. The result of the regression equation with mean values of the parameters investigated amounted to 105.4 cm, while the real mean to 80.8 cm. The lupin stems over the eight-year research did not exceed the height of 98.4 cm.

Such a very significant parameter as a number of pods per plant depended statistically only on the sum of temperatures over plant emergence – flowering; an increase in its value decreased the number of pods. A simulated number of pods calculated just like before amounted to about 11, while the mean real – to 9.4 (sum of pods per main stem and branches).

A number of seeds per plant depended on the sums of temperatures from flowering to harvest maturity. An increase in the air temperature of that period increased the number of seeds, and the simulated result, calculated from mean values exceeded the real mean value many-fold. The coefficient of determination of that equation, however, turned out quite high and amounted to 86%.

The weight of 1000 yellow lupin seeds depended mostly on the temperature. There was observed a favourable effect of the sums of temperature over emergence to flowering, and unfavourable - from pod setting to harvest maturity. Similarly there was noted an unfavourable effect of rainfall over sowing to emergence on the weight of 1000 seeds. Statistics indicated that there was observed a linear, proportional relationship neither between the number of seeds nor between the weight of 1000 seeds (parameters clearly defining plant productivity) and the weather conditions. All that does not signify that such relationship does not exist at all, but, most probably, that it takes a form of a more complex function.

Very often the final plant productivity is defined by the plant number per area unit. As it was observed in the present experiment the plant density showed many significant relationships between weather independent variables. There was observed a favourable effect of increasing sums of temperatures till emergence, and then till flowering, on the plant performance. However higher sums of temperatures over those phases decreased the lupin plant density. Only over the period following flowering did the rainfall show a positive effect, here limiting the plant loss. A simulated plant density calculated with significant mean values of the weather variables amounted to about 78 plants per $1m^2$ and did not differ much from the real value.

## DISCUSSION

The vegetation conditions of temperate latitudes is characterised by a lower risk catastrophic extremes – very severe droughts or specially heavy and long-time rainfall with a high variation in weather components with years [6]. A detailed recognition of relationships between weather conditions and plant vegetation and yielding remains of key importance for the cultivation technology applied. Over the multi-year period analysed the rainfall ranged from 44 to 134%, depending on the plant development period, while the temperature only to about 33%; the index of yielding variability reached about 21% challenges the common view of quite a high yellow lupin sensitivity to weather changes. Yellow lupin is a plant highly sensitive to rainfall and temperature, which had been confirmed by numerous research [9,11], and its reaction to those key vegetation conditions remains complex and difficult to define.

The simplest, although not free from errors, method to estimate the impact of weather conditions on the plant development and yielding is regression analysis, while the most frequent independent variables for each species – temperature and rainfall. As for temperature, the sum or means for a given phase are calculated [6,8,9]. The research conducted so far do not show clearly which method is better as it depends also on the species and habitat conditions. The plants for which temperature remains a key factor - the means shows more applicable [8]; hence for lupin- a choice of effective sum over the threshold value

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of 5°C, which is commonly applied in the States as the so called 'heat units' [1]. Sums of effective temperatures, together with the water conditions, showed helpful in predicting both the yield and structural characteristics and biometrics, which was seen especially over the first plant development phases. In the present research one shall highlight the combined effect of water and temperature conditions, as many reports stress, first of all, the sensitivity of lupin to water shortages over seed germination and plant emergence [9]. A significant impact of the temperature factor was observed throughout the vegetation period, including seed yield-determining factors and the yield itself, over the last development phase: pod setting – harvest maturity. Rainfall, however, of that period appeared of lesser importance, dominated by air temperature.

## CONCLUSIONS

1. The length of the 'Juno' lupin vegetation period recorded over years helped to define the variation of that parameter, which amounted to about 16%. The greatest differences in the development phase lengths were noted for the period from sowing to emergence - 42.2%. The most crucial weather condition factors over the vegetation period varied over the eight-year research and amounted to about 17% (sums of temperature) and about 49% (rainfall). The values of the weather condition parameters ranged most over the shortest phase (from plant flowering to pod setting).
2. Out of numerous biometric and structural characteristics, the greatest stability, hence a considerable independence of the weather conditions included the weight of 1000 seeds and the plant height. The most sensitive to external disturbances turned the number of pods per plant; the variation coefficient for eight-year research amounted to about 121%.
3. The highest value of the coefficient of determination ($R^2$ = 98%) of the multiple regression equation was observed for the relationship between the phenophase weather conditions – seed yield. The equation significant variables included the temperatures of the beginning and the end of the vegetation period, however rainfall from the mid growth and development period. Similarly those factors showed a significant linear impact on some biometric and structural characteristics. The weather conditions for the total vegetation period turned insignificant for lupin yielding and most of its characteristics.

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