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PRODUCTIVITY AND YIELD STABILITY OF SIX GRAIN LEGUMES IN THE MODERATE CLIMATIC CONDITIONS OF BULGARIA

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Abstract

Increasing the production of plant protein for feed and food purposes is one of the most important tasks of agricultural production. The aim of study was to establish the productive capacity and yield stability of six annual grain legumes: 2 conventional species - spring pea (Pisum sativum L.) and wintering pea (Pisum arvense L.) and 4 new species: spring vetch (Vicia sativa L.), bitter vetch (Vicia ervilia L.), grass pea (Lathyrus sativus L.) and chickpea (Cicer arietinum L.) in the environmental conditions of Bulgaria during 2010 - 2013, at the experimental base of the "Plant Growing" Department, Trakia University - Stara Zagora. The trial was designed by the block method in 4 repetitions. The plants were cultivated by the conventional technology. Results obtained for the grain yield were statistically processed by ANOVA and regression equations among the yield and rainfalls were developed. It was established that in the non-irrigation conditions of Bulgaria, P. sativum and C. arietinum were the most productive. The most valuable was L. sativus due to combines high grain yield and high stability. Climatic conditions over the years had the least impact on the productivity of C. arietinum and L. sativus. The type of crop as factor had the strongest influence on grain yield and plant height than the year. The stem height in the examined legumes correlated well with the rainfall in May. The grain yield of P. arvense and V. ervilia was in a good correlation with the amount of rainfall during the period from March to June, and of V. sativa – with the amount of the rainfall in May. Regression equations were developed on this base, which allows preliminary assessment of legumes grain productivity with approximate accuracy for practical purposes.

***Key words**: regression equations, legumes, rainfall, stem height, yield.*

INTRODUCTION

Legumes play an important role in natural ecosystems, agriculture and agroforestry, where their atmospheric nitrogen fixation ability makes them excellent predecessors for most crops, and also for successful human and animal nutrition. One of the most important factors determining their great economic importance is the high protein content with a high nutrition effect in their seeds (Duranti, 2006). The areas of leguminous crops have declined repeatedly despite their high nutritive value. A recent investigations published by the European Commission, revealed a significant decrease in the production of protein crops in the European Union, especially over the last ten years. Main leguminous plants decreased by 30% and soybean production by 12%.

Pea is one of the most widespread grain legumes due to its easy cultivation as a wintering and spring crop, being an excellent predecessor for cereals and its indisputable contribution to resolving the protein problem (Georgieva et al., 2013; Miller et al, 2003; Tekeli and Ates, 2003; Zhelyazkova and Pavlov, 2007; Zhelyazkova et al., 2007a). Productivity of this culture in Bulgaria has been influenced mostly by the weather conditions (Zhelyazkova et al., 2007a; 2012). The unstable yields of peas have been a serious reason to look for the cultivation of alternative crops.

Spring vetch (*Vicia sativa* L.) with its good economic performance and lower demands to soil and climate conditions is an alternative source of plant protein (Mihov et al., 2005; Nenova and Venkova, 2005; Delchev et al., 2013; Zhelyazkova et al., 2007b). After its growing, the available nitrogen in the soil increases, which makes it an excellent predecessor for winter cereals.

Chickpea (*Cicer arietinum* L.) is the third largest grain bean culture in the world beans production. It can be grown in different ecological conditions, saline, arid and semi-arid areas (Krouma, 2009). Traditionally it is grown in Asia, Europe, Africa and Australia (Berger and Turner, 2007), as a source of cheap protein for human nutrition (Zia Ul-Haq et al., 2007). The seeds of C. arietinum contain protein like kidney beans, but have higher amino acids value, fats, vitamins A and B1 and minerals. It possesses a number of valuable features such as hard stem, resistant to insects, adapted for mechanized harvesting (Atanasova and Mihov, 2005). It has also high productive capacity and obtaining yields above 2000-2500 kg.ha^{-1} is possible for most soil and climate conditions (Toker and Canci, 2003).

Grass pea (*Lathyrus sativus* L.) is characterized by high resistance to biotic and abiotic stress, which means less attack from diseases and pests (VazPatto et al., 2006). *L. sativus* seeds contain high levels of proteins (25.6 ± 0.20 g. 100 g^{-1}), essential amino acids (7.92 g. 100 g^{-1}), lysine, polyunsaturated fatty acids (αlinolenic, linoleic and γ-linolenic) and are valuable source for healthy foods (Chinnasamy et al., 2005; Tamburino, et al., 2012). The good taste and high nutritional value of seeds evoke the growing interest to this culture. Under favourable climatic conditions from *L. sativus* more than 3 t. ha^{-1} seeds can be obtained (Montenegro and Mera, 2009).

Bitter vetch (*Vicia ervilia* L.) is propagated in the Mediterranean region characterized by many favorable characteristics: resistance to drought, diseases and pests, short vegetation period, easy, cultivation and harvesting (Sadeghi et al., 2009). Its seeds are valuable source of energy and protein to animals (Reisi et al., 2011; Sadeghi et al., 2009a). With its high drought resistance this legume would be suitable for growing in South-Eastern Bulgaria, where there are many of its wild forms (Vateva and Krumov, 2011). Its biological potential is good as a forage crop. The straw contains more protein than that of *V. sativa* and grain yields are often higher. Increasing the production of plant protein for fodder and food purposes is one of the important tasks of agriculture production. To produce the highest amount of protein in a specific area, at the lowest cost, the legumes most appropriate for the specific circumstances must be explored and recommended.

The aim of the present study was to establish the productive capabilities and yield stability of six annual grain legumes: 2 conventional species - spring pea (*Pisum sativum* L) and wintering pea (*Pisum arvense* L) and 4 new species: spring vetch (*Vicia sativa* L), bitter vetch (*Vicia ervilia* L), grass pea (*Lathyrus sativus* L) and chickpea (*Cicer arietinum* L) in the agro-environmental conditions of South-Central Bulgaria.

MATERIALS AND METHODS

The survey was conducted during the period October 2009 – July 2013 on the experimental base of the "Plant Growing" Department at Trakia University, Stara Zagora. A field experiment was conducted to establish the growth and productivity of six annual grain legumes - 2 conventional species: -spring pea (*Pisum sativum* L.) cultivar Bogatir, wintering pea (*Pisum arvense* L.) cultivar Mir and 4 new species: spring vetch (*Vicia sativa* L.) cultivar Dobrudja, bitter vetch (*Vicia ervilia* L.) cultivar Borina, grass pea (*Lathyrus sativus* L) cultivar Strandja and chickpea (*Cicer arietinum* L.) selection line FLIP 06-136. The species of spring pea, wintering pea, spring vetch, grass pea and bitter vetch originated from Bulgaria. The test line chickpea FLIP 06-136 was received through exchange of breeding materials for improved dry and cold resistance from the International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. The experiment was conducted by the block method in 4 repetitions, after a wheat predecessor.

The legumes were grown according to the conventional technology adopted in the country and the region, without irrigation.

To prepare the soil, tillage at 22 cm was used after harvesting the predecessor and as pre-sowing cultivation with harrowing. Before the tillage, fertilizer of 60 kg.ha^{-1} phosphorus was applied, whereas with the pre-sowing cultivation nitrogen in a dose 40 kg. ha^{-1}was applied. For weed control after sowing before emergence herbicide Afalon 45 SC (Linuron) at a dose rate of 3 l. ha^{-1}was applied. For pest control against the grain weevils, two treatments – at the beginning of flowering and 8 – 10 days later were conducted every year. The insecticide Nurele D (Chlorpiriphosetyl + Cypermethrin) was used at a dose rate of 500 ml.ha^{-1}.

During the experiment the height of plants at harvest and yield of grain in standard humidity (13%) were established. The data obtained was

processed statistically and used to establish the correlation and regression equation by means of StatSoft STATISTICA for Windows (2000).
Yield stability and technological value of cultivated annual grain were established on the base of the factor analyses, interaction of plant yield and year by the methods of: stability variances σi2 and Si2 of Shukla (1972), the ecovalence Wi of Wricke (1962) and the technological value stability criterion YSi of Kang (1993).
The soil in the area was typical *Gleic Chromic Luvisols*, moderately supplied with hummus, with a slight acidic reaction, poorly supplied with nitrogen and phosphorus and very well supplied with potassium (Table 1). These soil conditions are favorable for the development and growth of the grain legumes.

Table 1. Soil characteristics

pH (KCl)	Humus, %	Mineral N, mg.1000 g^{-1}	N –NH_4, mg.1000 g^{-1}	N-NO_3, mg.1000 g^{-1}	Available P_2O_5, mg.100 g^{-1}	Available K_2O, mg.100 g^{-1}
5.44	3.93	33.2	13.6	19.6	3.9	44

RESULTS AND DISCUSSIONS

The climate conditions during the period of study differed significantly. 2010 was the most humid when the rainfall was 31.3% above the average for the period 1936-2009 (Table 2). 2012 was also humid, and then the rainfall was 11.7 % above the average for the multi-annual former period. 2011 was characterized as dry, during which the amount of rainfall was 32.3% below the long-term period. Closest to the average multi-annual former period was the annual rainfall in 2013.
The distribution of rainfall in the four years of the study was uneven by months, with periods of intense drought and moisture. In terms of temperature 2012 and 2013 were warm years and the average annual air temperatures were 1.2-1.3°C above to the multi-annual period values. 2011 was cool and then the average annual air temperature was 0.2°C below the multi-annual period.
The amount of rainfall during the growing season (March – June) of the spring crops (*P. sativum, V. sativa*, *L. sativus*, *V. ervilia* and *C. arietinum*) average for 73 years (1936-2009) was a little higher than precipitation during growing season for the years of study.
The greatest amount of rainfall during vegetation period was registered in 2010 and

Table 2. Climate conditions of South-Central Bulgaria

Years	Janu-ary	Febru ary	March	April	May	June	July	August	September	Okto ber	Novem ber	December	I-XII
Total rainfall, mm - Stara Zagora													
2009	68.8	60.4	39.1	10.3	22.3	73.6	75.1	43.5	29.8	63.1	26.6	75.6	588.2
2010	46.9	105.3	48.1	65.7	28.3	76.0	145.0	19.8	44.0	101.9	11.2	33.2	725.4
2011	35.6	27.2	12.4	15.8	34.4	26.7	40.9	51.7	13.3	70.6	1.3	44.3	374.2
2012	107.9	84.3	8.3	23.4	110.4	32.4	5.0	43.9	35.3	59.3	14.9	91.9	617.0
2013	90.0	74.8	49.0	53.5	11.9	70.7	29.1	5.3	16.6	75.3	49.3	8.6	534.1
1936-2009	40.1	33.8	37.6	45.4	63.7	62.3	51.0	44.3	35.1	40.8	50.5	48.0	552.5
Average temperature, ^{0}C – Stara Zagora													
2009	0.1	3.3	6.3	11.7	18.4	22.3	24.6	24.2	19.2	13.9	7.8	4.4	13.0
2010	0.7	3.6	6.1	12.4	17.8	21.4	23.5	26.9	20.4	11.4	11.4	3.1	13.2
2011	1.3	1.6	6.6	10.9	17.2	21.6	23.5	24.1	21.8	11.4	3.9	2.8	12.2
2012	-0.3	-0.7	7.2	14.0	17.3	23.9	27.9	25.7	21.0	16.2	9.1	1.3	13.6
2013	1.4	5.0	7.6	14.2	20.4	22.1	24.8	26.2	19.8	11.6	9.4	1.3	13.7
1936-2009	1.0	2.8	6.6	12.0	17.1	21.1	23.6	23.1	18.9	13.0	7.4	2.7	12.4

the smallest in 2011. The largest monthly amount of rainfall during the growing period 2010 – 2013 was supplied in May 2012), while the smallest was in March 2012. During the vegetation period, multi-annual average rainfall was distributed unevenly, with highest values in May and June. During the years of study, this unevenness was also well expressed in

2011 and 2013, as these years were characterized by severe spring drought, especially dramatically in March and April 2011 and in May 2013.

In 2010 and 2011 the average air temperatures during the growing season of spring crops did not differ substantially compared to the average multi-annual previous period. In 2012 and 2013, the average monthly air temperatures in the initial phases of development of the plants (March and April) were above normal with 1.0 to 2.2°C. In May 2013 during the flowering and ripening phases, the average monthly air temperatures were significantly higher –3.3°C above the average multiannual for the same period. This, combined with the drought, extended the periods of the reproductive phases. The rainfall in May - 11.9 mm, had negative effect on the plants development and their productivity.

Regarding wintering pea, the amount of rainfall during the growing season (October – June) in 2009-2010, 2011-2012 and 2012-2013 was 13.2%, 14.4% and 10.9% above the average for the multiannual previous period, respectively. The vegetation amount of rainfall during the period of 2010-2011 was 37% below the average for the long-term period, which characterized 2011 as a dry year. The winter conditions were normal and no damage by low temperatures was reported on crops of *P. arvense*, with the exception of the months of January and February in 2012, when were reported record low temperatures, 1.3 and 3.5°C below normal, respectively. The thin snow cover and high winter resistance of *P. arvense* variety "Mir" resulted in minimal frost damage (14.2%) on plants and crop formation of optimum density.

The yield of grain as a resulting parameter showed the best of all productive potential of the crops. It varied by years depending on the agro climatic conditions (Table 3). 2010 was characterized with more favorable weather conditions, which created the precondition for an optimal growth and formation of high yields in all tested legumes. A significantly drier spring of 2011, adversely affected the growing crops and the yields that year were lower - 19.4% less compared to 2010.

Table 3. Yield potential by years, average for the period 2010 – 2013

Plant	Yield of grain, $kg.ha^{-1}$, n=96					
	Years				Average	
	2010	2011	2012	2013	$kg.ha^{-1}$	%
Pisum sativum L.	2800.0	2030.0	1910.0	1685.0	2106.3a	100.00
Pisum arvense L.	2425.0	1625.0	1850.0	1660.0	1890*** b	89.73
Vicia sativa L.	1526.7	1525.0	1575.0	1480.0	1526.7***	72.48
Vicia ervilia L.	1650.0	1250.0	1300.0	1175.0	1343.8***	63.80
Lathyrus sativus L.	2375.0	1850.0	1775.0	1575.0	1893.8*** b	89.91
Cicer arietinum L.	2150.0	2150.0	1975.0	1625.0	1975.0** ab	93.77
Average	2154.4	1738.3	1730.8	1533.3	1789.2	
LSD, P < 0.05	140.6	176.8	142.7	104.4	141.1	7.89
LSD, P < 0.01	194.7	244.9	197.7	144.6	195.4	10.92
LSD, P < 0.001	268.6	337.8	272.7	199.4	269.6	15.07
SD					391	
CV					152969	
SEE					40	
Min					1100	
Max					2900	

* Different letters indicate statistically significant differences among variants at P < 0.05

*, **, *** - Statistically significant differences of the variants and control at P< 0.05; 0.01 and 0.001, respectively.

In terms of productivity, in 2011, the response of the species to naturally generated abiotic stress was of importance. The analysis of the data showed that in 2011 significantly higher yields were preserved in *L. sativus* and *C. arietinum*. Preserving the level of yields in these two plants in 2011 at the level of the yields in 2010, was probably due to their high drought tolerance. The yields were the lowest in 2013, when the monthly average temperatures during flowering period and the grain forming period were unusually above normal but the rainfall was below normal.

Average for the period of investigation the highest grain yield was obtained from *P. sativum*. The second highest productivity was obtained from *C. arietinum*. The difference between the productivity of these two cultivars was not statistically significant. Maintaining a higher level of yield in the *C. arietinum* in comparison with the other tested legumes was probably due to its great drought resistance.

On the third place was the productivity of *P. arvense* and *L. sativus*. The differences between the productivity of these two cultures and *C. arietinum* were not statistically proven. The specific climatic conditions over the years had the least impact on productivity of *C. arietinum* and *L. sativus*.

On average for the period of study from the *V. sativa* was received yield with 27.52% lower compared to the average productivity of *P. sativum*. According to Nenova and Venkova (2005) the productivity of this culture in Bulgaria is influenced strongly by the water supply during the reproductive phase, and the productive possibilities are function of the interaction between rainfall and temperatures during the months of April, May and June.

V. ervilia was with the lowest productivity, both in years and on average for the research period. This lower productivity of *V. ervilia* was statistically significant at $p<0.001$compared to all other varieties. Height of the stem is an important indicator on which depends the resistance to fall of the crop, suitability for mechanized harvesting, the quantity and quality of the seeds. The stem height in the leguminous crops is a trait that depends mainly on the specific climatic conditions (Table 4).

It is known that a major influence on the height of the stem in the legumes is mostly affected by rainfall. Relatively greater rainfall in 2010 and 2012 and especially the great amount of rainfall during the months of April and May led to formation of plants with greater height of the stem in all studied crops. During these years stem fall of plants for peas and vetches was found. In 2013, the climatic conditions during the vegetation period created a prerequisite for forming stems with 3.3% (*C. arietinum*) to 52.2% (*V. sativa*) lower height at harvest, compared to 2012.

Table 4. Stem height at harvest by years and average for the period 2010 – 2013

Plant	Stem height, cm, n=96					
	Years				Average	
	2010	2011	2012	2013	cm	%
Pisum sativum L.	85.80	52.40	89.20	44.43	67.96 a	100.00
Pisum arvense L.	149.88	123.25	151.10	113.70	134.48***	197.89
Vicia sativa L.	65.86	52.23	98.35	47.00	65.86 a	96.91
Vicia ervilia L.	37.90	29.05	49.28	28.70	36.23***	53.32
Lathyrus sativus L.	65.97	53.98	87.30	43.35	62.65 a	92.19
Cicer arietinum L.	52.38	36.90	39.00	37.73	41.50***	61.07
Average	76.30	57.97	85.70	52.48	68.11	
LSD, P < 0.05	4.05	6.60	9.80	3.83	6.07	8.93
LSD, P < 0.01	5.61	9.15	13.57	5.31	8.41	12.37
LSD, P < 0.001	7.73	12.62	18.72	7.33	11.60	17.07
SD					35.99	
CV					1295.40	
SEE					3.67	
Min					28.00	
Max					156.00	

* Different letters indicate statistically significant differences among variants at P < 0.05

*, **, *** - Statistically significant differences of the variants and control at P< 0.05; 0.01 and 0.001, respectively.

V. ervilia and *C. arietinum* had the lowest stem without fall from investigated types. The stem of *P. arvense* was the highest and with a natural aptitude for fall. In *L. sativus* and *V. sativa*, the height of stem was near to the values of *P. sativum*, such as differences in this indicator between the three cultures were not proven. The specific climatic conditions significantly affected the height of the stem in grain legumes, and were most poorly expressed in *L. sativus* and *C. arietinum*.

The study on establishing the influence of the investigated factors (type of variety and year) showed that the strongest, very well proven (P< 0.001) influence on the yield of grain and the height of the stem was manifested by the type of legume culture - 46.63% and 80.15% of the total variation in the data, respectively (Table 5).

The power of influence of climate conditions over the years on the indicators of plant height and yield of grain was also very well proven (p < 0.001), but lower. The reason was probably the large variations in meteorological conditions of the years.

The specific climatic conditions over the years as a factor exerted a greater influence on the generative (grain) potential and productivity (33.83% of the total variation) than on the vegetative (stem height) parameters (14.11% of the total variation).

Table 5. Influence of factors on the grain yield and height of plants

Source of variation	Sum of squares	Degree of freedom	Mean squares	F*	P<	%
Factor analysis for yield of grain, kg.ha^{-1}						
Plants	6775730	5	1355146***	157.76	0.001	46.63
Year	4916768	3	1638923***	190.8	0.001	33.83
Plants*Year	2221124	15	148075**	17.24	0.01	15.28
Error	618456	72	8590			4.26
Factor analysis for stem height, cm						
Plants	98630.7	5	19726.1***	967.96	0.001	80.15
Year	17367.4	3	5789.1**	284.07	0.01	14.11
Plants*Year	5597.7	15	373.2*	18.31	0.05	4.55
Error	1467.3	72	20.4			1.19

*F- ratio among the variables; P- Statistical significance, *p≤0.05; **p≤0.01%; ***p≤0.001%.

It is very complicated to explain the exact influence of the climate conditions concerning the generative or vegetative development of legumes. From a practical point of view, especially for the legumes which have a stem likely to fall, the tendency that the drought influenced to a bigger extent the stem height than the grain formation, on one hand, had a positive effect to keep the grain yield and, on the other hand, to preserve fall of stem.

Interaction among the factors, type of legume plant and climate conditions during the years had a lower but statistically significant at P<0.05 to 0.01 effect on the yield and stem height.

Based on proven crop by year interaction, it was evaluated stability parameters for each variant for grain yield of legumes with relation to years (Table 6). It was calculated the stability variances σi2 and Si2 of Shukla, the equivalence Wi of Wricke and the stability criterion YSi of Kang.

Stability variances (σi2 и Si2) of Shukla, which recorded respectively linear and nonlinear interactions, unidirectional evaluate the stability of the variants. These variants which showed lower values are considered to be more stable because they interact less with the environmental conditions.

Table 6. Stability parameters for the legume grain yield with relation to years

Plant	$\bar{x}$	σ_i^2	S_i^2	W_i	YS_i
Pisum sativum L.	2106.3	277696,1**	18063,4	630694,9	2+
Pisum arvense L.	1890.0	116529,6**	150195,9**	308415,9	-1
Vicia sativa L.	1526.7	338197,8**	-4070,3	751752,4	-9
Vicia ervilia L.	1343.8	-12390,2	-3116,6	50576,5	-3
Lathyrus sativus L.	1893.8	6497,9	8430,8	88352,5	7+
Cicer arietinum L.	1975.0	177777,3**	240006,0**	430911,3	1+

Negative values of the indicators σi2 and Si2 are considered 0. At high values of either of the two parameters - σi2 and Si2, the variant are regarded as unstable. At the ecovalence Wi of

Wricke, the higher are the values of the index, the more unstable is the variant.

On this basis, using the first three parameters of stability, it is found that *C. arietinum* and *P. arvense* are most unstable. In these variants values of stability variance σi2 and Si2 of Shukla and equivalence Wi of Wricke are the highest and mathematically proven. At these two legumes instability is a linear and nonlinear type - proven values of σi2 and of Si2. At *V. sativa* and *P. sativum* instability is a linear type - values σi2, the values of Si2 are not proven.

The reason for this high instability is greater variation in grain yields during years of experiment as weather conditions affect those most. *L. sativus* and *V. ervilia* demonstrate high stability because they interact poorly with the conditions of years. To evaluate the complete efficacy of each legume should be considered as its effect on quantity of grain yield and its stability - the reaction of legumes during the years.

Important information about the technological value of the variant gives the stability criterion YS_i of Kang for simultaneous assessment of yield and stability, based on the reliability of the differences in yield and variance of interaction with the environment. The value of this criterion is that using nonparametric methods and warranted statistical differences we get a summary assessment aligning variants in descending order according to their economic value.

Generalized stability criterion YS_i of Kang, taking into accounts both the stability and value of yields gives a negative assessment of *V. sativa*, *V. ervilia* and *P. arvense*. *V. sativa* and *P. arvense* have these assessments due to their high instability. *V. ervilia* has this assessment due to its low yield. According to this criterion, the most valuable technology appears to be *L. sativus*. It combines high levels of grain yield and high stability of this index during the years. From the technologies point of view for legumes growing, high rating also have *P. sativum* and *C. arietinum*. They combine relatively good grain yields with low stability during the years of the investigation.

Principal component analysis for influence of rainfall on the grain yield of all six annual legumes demonstrated that during the different periods rainfall had a specific effect on the yield and stem height of annual grain legumes.

The amount of rainfall during the months March, April and June had a positive influence as factor 1 and factor 2 on the yield and stem height of investigated annual legumes (Figure 1). The two of the eigenvalues are higher than 1.

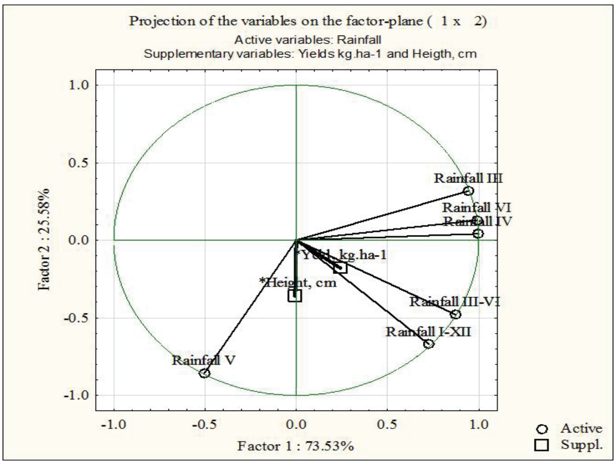

Figure 1. PC Analyse influence of rainfall on the yield and stem height of six annual grain legumes.

Factor loading correlations among rainfall, yield and stem height for these months is very high (0.990-0.997, Table 7). Total sum of rainfall during the year (January-December and the rainfall during vegetation period (March – June) had a positive influence on the same direction with yield as factor 1 describing more than 70 % of the variations. The total rainfall during the year and during the vegetation period is negative as factor 2 describing about 25 %.

Table 7. Factor-variable correlations (factor loadings), based on correlations

	Factor 1	Factor 2	Factor 3
Rainfall I-XII	0.726246	-0.66991	0.154237
Rainfall III-VI	0.871655	-0.47871	-0.10513
Rainfall III	0.945235	0.318289	-0.07227
Rainfall IV	0.997909	0.041708	0.049382
Rainfall V	-0.50449	-0.85834	-0.09354
Rainfall VI	0.990363	0.129537	-0.04901
*Yield, kg/ha	0.241472	-0.17948	0.512696
*Height, cm	-0.0064	-0.36165	0.109521
Eigenvalues	4.411837	1.534509	0.053654
% Total - variance	73.53062	25.57515	0.89423
Cumulative - %	73.5306	99.1058	100.00

Rainfall during May had negative impact on the yield and stem height by the two factors. It can be assumed that rainfall during May is critical period in the development of most of annual grain legumes. Zhelyazkova (2007) has obtained the same results for critical influence of rainfall during May on the yield of peas and vetch.

Water supply during May had an important role for the intensive growth of stem from one side and for normal flowering, pollination and fertilization from other side. This period is very important for both vegetative and generative potential formation of legumes. If rainfall during May are low the stem are also low and the pollination is low. If water supply is too high there is a danger for stem fall and low yield.

Having in mind the specific type of growth, grain yield potential and stem height the different annual grain legumes had a different reaction concerning to water supply by rainfall during different months.

Calculation of the correlation dependencies between productivity, plant height and rainfall (Table 8) shows that the yield of grain in the pea positively correlated with height of the plants, better expressed in *P. arvense*. The correlation analysis of the data indicated that the factor of greatest influence on the height of the tested legumes was rainfall in May.

The yields of grain of *P. arvense* and *V. ervilia* were in a good positive correlation with rainfall during the period March-June. Rainfall in May had higher influence on productivity of *V. sativa*.

Table 8. Correlations (r) among grain yield, height of plants and precipitation

	Yield, $kg.ha^{-2}$	Height, cm	W_{I-XII}, mm	W_{III-VI}, mm	W_{III} mm	W_{IV}, mm	W_{V}, mm	W_{VI}, mm	W_{X-VI}, mm
Pisum sativum L.									
Yield, $kg.ha^{-1}$	1.00	0.53*	0.31	0.39	0.31	0.49	-0.15	0.38	
Height, cm	0.52*	1.00	0.56*	0.47	-0.19	0.09	0.65*	-0.02	
***Pisum arvense* L.**									
Yield, $kg.ha^{-1}$	1.00	0.70*	0.57*	0.69*	0.43	0.65*	-0.02	0.55*	0.01
Height, cm	0.70*	1.00	0.58*	0.44	-0.21	0.089	0.63*	-0.04	-0.11
***Vicia sativa* L.**									
Yield, $kg.ha^{-1}$	1.00	0.47	0.24	-0.03	-0.41	-0.289	0.51	-0.33	
Height, cm	0.47	1.00	0.48	0.25	-0.53*	-0.28	0.94*	-0.36	
***Vicia ervilia* L.**									
Yield, $kg.ha^{-1}$	1.000	0.299	0.462	0.515*	0.322	0.52*	-0.05	0.42	
Height, cm	0.299	1.000	0.568*	0.373	-0.412	-0.144	0.889*	-0.232	
***Lathyrus sativus* L.**									
Yield, $kg.ha^{-1}$	1.000	0.259	0.228	0.365	0.255	0.438	-0.103	0.333	
Height, cm	0.259	1.000	0.441	0.215	-0.540*	-0.273	0.905*	-0.371	
***Cicer arietinum* L.**									
Yield, $kg.ha^{-1}$	1.000	0.360	0.028	-0.248	-0.367	-0.232	0.192	-0.329	
Height, cm	0.360	1.000	0.543*	0.665*	0.520*	0.707*	-0.173	0.616*	

W_{I-XII}– total rainfall for the period January – December; W_{III-VI} - total rainfall for the period March – June; W_{III} - rainfall in March; W_{IV} - rainfall in April; W_{V} - rainfall in May; W_{VI} - rainfall in June; W_{X-VI}- total rainfall for the period October – June, mm; * Statistical significance at P < 0.05

The good relationships between the height of the plants, the yield of grain and rainfall, allowed developing regression equations (Table 9) for preliminary evaluation of these parameters by climatic factors. For all six legumes the yield of grain can be predicted

Table 9. Regression equations for predicting of yield and stem height based on rainfall

Plant	Equation	*R	SEE	F	P
All six legumes	Yield, kg.ha^{-1} = 4608.311-12.269 W_{I-XII}+0.012W_{I-XII}^2	0.593	5.14	5.7	0.0106
All six legumes	Yield, kg.ha^{-1} =3566.471 - 29.993W $_{III-VI}$+0.107 $_{III-VI}^2$	0.529	12.7	4.08	0.0319
Pisum sativum L.	Height, cm = 36.08+1.182W_V - 0.0064W_V^2	0.681	15.8	5.62	0.0173
Pisum arvense L.	Yield, kg.ha^{-1} = 2456.459 - 55.162W_{IV} + 0.811W_{IV}^2	0.819	0.03	13.3	0.0007
Pisum arvense L.	Yield, kg.ha^{-1} = 3751.352 - 100.725W_{VI} + 1.06W_{VI}^2	0.675	0.12	5.44	0.019
Vicia sativa L.	Height, cm = 43.776 + 0.440W_V + 0.00048W_V^2	0.940	7.18	49.3	0.000001
Vicia ervilia L.	Yield, kg.ha^{-1} = 1873.636 - 43.844W_{IV} + 0.605W_{IV}^2	0.800	0.02	11.5	0.0012
Vicia ervilia L.	Height, cm = 28.35 + 0.126W_V + 0.00056W_V^2	0.889	4.03	24.7	0.00003
Lathyrus sativus L.	Height, cm = 35.65 + 0.858W_V - 0.0035W_V^2	0.918	6.8	34.9	0.000006
Cicer arietinum L.	Height, cm = 53.59 - 1.18W_{IV} + 0.017W_{IV}^2	0.885	5.3	23.6	0.00004
Cicer arietinum L.	Height, cm=77.53 - 0.69W_{III} – VI + 0.0026W_{III-VI}2	0.942	7.46	51.5	0.000001

*R- coefficient of determination; SEE- standard error; F- ratio among the variables; P- Statistical significance; W_{IV} - rainfall in April; W_V - rainfall in May; W_{VI} - rainfall in June;W_{III-VI} - total rainfall for the period March – June, mm

by regression equation based on annual (I-XII) and vegetative (III-VI) rainfall. The grain yields of *P. arvense* and *V. ervilia* could be determined with high accuracy depending on the amount of rainfall in April. The height of plants for V. sativa, *L. sativus* and *V. ervilia* could be determined with high accuracy depending on the amount of rainfall in May. The height of *C. arietinum* plants was determined with high accuracy on the base of the amount of rainfall during the period March-June as an independent variable. The mentioned regression equations had a high degree of statistical significance (P < 0.000) and good reliability. The developed regression equations could be used for approximate preliminary assessment of productivity with accuracy satisfactory for practical purposes.

CONCLUSIONS

Pisum sativum and *Cicer arietinum* cultivated in non-irrigated conditions in the area of South-Central Bulgaria are most highly productive out of the tested grain legumes. The specific climatic conditions over the years had the least impact on productivity of *Cicer arietinum* and *Lathyrus sativus*.

The productive capacity (grain yield) and stem height of the investigated annual legumes during the tested years were influenced mainly by the specific morphological and biological characteristics as factors. The climatic conditions (rainfall and temperature) had lower influence on the yield performance and stem height formation.

Rainfall during March, April and June had a positive influence on the yield and stem height. Water supply during May had critical impact influencing negatively on the vegetative (stem height) and on generative (grain yield) development of annual legumes.

Developed regression equations based on the amount of rainfall during the specific months as independent variables could be used for approximate preliminary assessment of productivity and stem height of annual legumes with accuracy satisfactory for the practice.

Vicia sativa, *Vicia ervilia* and *Pisum arvense* had a negative assessment according to stability criterion YS_i of Kang due to their high instability. From technological point of view the most valuable was *Lathyrus sativus,* because combines the two important characteristics high levels of grain yield and high stability of this index during the years. *Pisum sativum* and *Cicer arietinum* also had high rating due to combine relatively good grain yields with low stability during the years.

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MISCELLANEOUS