WEATHER INFLUENCE ON THE YIELD INSTABILITY OF PEAS (*PISUM SATIVUM* L.)*

J. Fachadas Hrachovinová[1], V. Hosnedl[2], T. Mezlík[3]

[1]Camposol II., Lda, Vila Nova de Milfontes, Portugal
[2]Czech University of Life Sciences, Faculty of Agrobiology, Food and Natural Resources, Prague, Czech Republic
[3]Central Institute for Supervising and Testing in Agriculture, National Varieties Office, Brno, Czech Republic

The aim of this work was to research the relationship between variable meteorological conditions and the instability of the length of growth stages and yield of peas. The criterion was year, and site variability of temperature and precipitation conditions, the variability of length of growth stages and yield of pea. The results of phenological growth and yield was obtained from varietals experiments during 1993–2003 (cultivar Komet) and 1980–1994 (cultivar Bohatýr) from the database of the Central Institute for Supervising and Testing in Agriculture (CISTA) and primary meteorological values from the database of Czech Hydro meteorological Institute. The relationships between appointed criterions were evaluated on the base of correlation coefficients. The yield capability of the tested cultivars is high, but with very high year on year yield fluctuation (from 2.87 to 7.53 $t.ha^{-1}$), even in the precise field experiments of CISTA. The yield variability, and its dependence on site conditions, is proved by coefficients of variance from 10.0% (the locality with low yield variability) to 26.8% (the locality with high yield variability). The results confirmed the general conclusions, obtained before, that the susceptibility to variable environmental conditions, primarily weather, continues to be the main reason for the yield instability. They influence the onset and length of growth stages of peas. The length of the generative stage has a positive effect on the yield of peas and, is prolonged by increasing the number of days with lower temperatures (under 15 °C) with correlation coefficients r = 0.65–0.97 and/or by precipitation conditions, ordinarily the number of days with measurable precipitations with r = 0.78–0.83.

pea; growth period; yield; yield variability; weather conditions; correlation.

INTRODUCTION

The climate of Central Europe shows significant instability in weather conditions. That, together with soil conditions, influences the plant growth and yield formation during all the vegetative period. They influence time of spring crop sowing, growth and development of plants, evaluated according to phenological phases and participate in formation, and also reduction, of individual yield components. The level of reduction of crop yield is depending on the intensity of stress conditions and on the time of their incidence. Other causes of imperfect varietals yield potential utilization are the productivity and adaptability of cultivars and, the growing technology (Mathe-Gaspar et al., 2005) and, biotic factors, i.e. pathogens and pests, or weed.

Peas belong to crops with higher sensitivity to environmental conditions, especially shortly after fertilization, when forming pods and seeds. Increased reduction of number of pods and seeds is caused by high temperatures and by insufficiency of soil moisture. Seed growth rate is limited and also total storage capacity is reduced (Munier-Jolain et al., 1998). The critical period is 10–12 days from the beginning of pod formation. Duthion and Pigeaire (1991) defined this period by cumulative degree days with value of 300 CDD, after that the number of pods and seeds does not change in healthy plants anymore.

Water and temperature stress, during seeds formation, accelerates ageing of assimilatory tissue, decreasing assimilates formation and their conversion to seeds (Copeland, McDonald, 1995). The vegetative period shortens and seeds production is negatively affected. In soybean it was found that the shortening of the generative period by 18–29% caused a decrease in yield by 26–44%. Peas and other legumes have difficulty to used assimilates formed before flowering in the period of seeds formation (Bewley, Black, 1994). This resulted in an increment of requirements on assimilate production for a very short period.

An extensive research of yield formation of peas and limiting factors was carried out by Petr and Hosnedl (1988). High emphasis was put on the cultivar differences, according to their response to the variable weather conditions.

MATERIAL AND METHODS

The relationship of environmental conditions, to instable utilization of pea yield potential, was evaluated by processing the data from the database of the Central Insti-

* The research and its results presented in this paper were processed in the research plan MSM 6046070901, and were realized with its support.

tute for Supervising and Testing in Agriculture (CISTA) and primary meteorological values. CISTA provided necessary data about phenological growth evaluation and yield results. The weather conditions (temperature and precipitation), corresponding with appropriate phenological growth phases, were obtained from the database of Czech Institute for Hydrometeorology. Results concerning variability and the correlation between the environment, growth and pea yield, were processed in cultivar Komet, during years 1993–2003 at 6 experimental stations of CISTA, in different areas of the CR. To verify cultivar sensitivity, evaluation of percentage ratio, in potential utilization was completed with cultivar Bohatýr, used in experiments during years 1980–1994 at 8 experimental stations of CISTA. Selection of model cultivars is limited and is dependent on at least a ten year period of cultivar testing. Cultivars Komet and Bohatýr suited this requirement.

Environmental conditions, characterized by soil conditions and by long-term average of climatic conditions (Table 1), are also characterized according to value of soil fertility (the highest quality of soils is evaluated by coefficient 90–100) (Tomiška et al., 2003). Generally high soil fertility, in experimental stations, contributed to the certain elimination of influence of soil condition on yield formation. Year on year variability of weather, for each area, is calculated in selected meteorological criteria. Evaluation uses dynamic approach, where meteorological values are always put into direct relation with the growth phase of the crop, and year on year variability of length of each phase or growth period is respected. Meteorology data was processed in Excel and evaluated separately according to growing areas.

Evaluated criteria:

- average daily temperature of air in specified growth stage (methodology of Klabzuba and Kožnarová, 1993),
- sum of average daily temperatures in specified growth stage,
- number of tropic days ($t_{max} \geq 30$ °C) in specified growth stage,
- number of days with average temperature < 15 °C in specified growth stages,
- sum of precipitations in specified growth stages,
- number of precipitations days with precipitations total ≥ 1.0 mm in specified growth stages.

Coefficients of variance for each trait of environment and growth stage (variability of sowing date and variability of the onset of pea growth stages, emergence, anthesis onset, anthesis termination and achieving full maturity) were determined by statistical methods. The variability of important period lengths (number of days) was also calculated: sowing-emergence, emergence-anthesis onset, anthesis onset-anthesis termination, anthesis onset-maturity, sowing-maturity. Relations between length of growth period and meteorological conditions are expressed by correlation coefficient.

RESULTS AND DISCUSSION

Varietals experiments of the Central Institute for Supervising and Testing in Agriculture represent a source of valuable results, usable for other scientific work. Primary results can be very well used to explain complicated interaction between environmental conditions and yield formation of crops and cultivars. The first work of this nature was published by Petr et al. (1987), where they determined the value limits for weather in important phases of winter wheat growth. The advantage of these approaches is the rationalization of research work, a wide spectrum of factors and results, and precise establishment and performance of field experiments.

We focused our attention on the pea, a crop, in practice, with high yield variability. The yield potential of peas is used insufficiently in practice, normally to 40%. It is probably due to imperfections in farming practices and damaging of vegetation by diseases and pests. Presented results were obtained from precise field experiments and they proved the higher importance of environmental conditions in relation to yield stability of pea. Long-term ex-

Table 1. Meteorological and soil conditions of the experimental stations of ÚKZÚZ (CISTA – characteristic of period 30 years, 1971–2000)

Station Central Institute for Supervising and Testing in Agriculture – CISTA	Altitude (m)	Average temperature (°C)	Year amount precipitation (mm)	Soil type	Soil* texture classes	Productive soil** capability (0–100)
Chrlice	190	9.0	451	fluvisols	loam	90
Včrovany	207	8.7	502	chernozems	loam	100
Čáslav	260	8.9	555	chernozems	loam	96
Žatec	285	9.0	439	chernozems	clay loam	85
Staňkov	370	8.1	537	luvisols	loam	90
Jaroměřice	425	8.0	481	luvisols	clay loam	92
Nechanice	235	8.8	597	luvisols	loam	78
Pusté Jakartice	295	8.3	584	luvisols	loam	92
Libějovice	460	7.9	563	cambisols	sandy loam	88

* surface cultivated horizon

** Note: the most fertile soils 90–100 points

Table 2. The yield variability of pea in the variety trials of ÚKZÚZ for Komet (1993–2003) and Bohatýr (1980–1994)

Station of ÚKZÚZ	Altitude	Variety Komet 1993–2003					Variety Bohatýr 1980–1994				
		crop yield (t.ha^{-1})			max. diference	Cv	crop yield (t.ha^{-1})			max. diference	Cv
	m	average	min.	max.	% average	%	average	min.	max.	% average	%
Chrlice	190	5.35	3.34	7.40	**76**	**26.8**	4.14	2.87	5.76	**70**	**22.2**
Věrovany	207	5.18	3.74	6.89	**61**	**21.1**	x	x	x	x	x
Čáslav	260	6.21	5.28	7.53	36	11.3	4.66	4.10	5.56	31	10.0
Žatec	285	4.59	2.88	6.25	**73**	**24.8**	4.34	3.31	6.83	**81**	**23.9**
Staňkov	370	4.67	3.76	5.92	46	14.8	4.65	3.32	6.03	58	19.6
Jaroměřice	425	4.97	3.23	6.56	**67**	**22.2**	4.94	3.44	6.60	**64**	18.1
Nechanice	235	x	x	x	x	x	4.66	3.43	6.40	**64**	18.1
P. Jakartice	350	x	x	x	x	x	5.13	3.40	6.48	**60**	**20.5**
Libějovice	460	x	x	x	x	x	5.62	3.57	6.77	57	16.2

x – no evaluated (insufficient number of trials on station, less then 9), Cv – coefficient of variability

periments showed year on year yield variability, and also difference between suitable and less suitable areas for pea growing (Table 2). The important factors are the lengths of phenologic phases and their differences between localities.

Joernsgaard and Halmoeb (2003) performed field experiments in similar area, but with more crop types. Also in this case they reached coefficients of yield variability between 5–22%, but it was due to inter-specific differences. The presented variability is logically dependent on the productivity of the crop.

During 11 years, yields of cultivar Komet in state varietals testing, ranged from 2.88 to 7.53 t.ha^{-1}. In cultivar Bohatýr over 15 years, extreme values of yields ranged from 2.87 to 6.77 t.ha^{-1} (Table 2). Year on year pea yields variability, in growing areas, is expressed by coefficients of variance (Table 2) in the interval from 10.0 to 26.8%. This value is lower comparing with the obtained from very short stem cultivars, cultivated 20 years ago (Hosnedl, 1987), where the coefficients of variance reached 13 to 42%.

Weather influences yield formation indirectly, by limiting the beginning of sowing date (Fig. 1), its direct impact lies in influencing plant growth and development. Meteorological factors determine the beginning of each phenologic phase and its duration (number of days). Presented results express instability of evaluated factors, and they were supported by high correlation coefficients, between the length of growth stages and weather (Table 3). Direct interaction between weather, length of growth stages and yield was only found in the case of length of the generative period to yield, correlation coefficient r = 0.44. Very close correlations are in relation to temperature and precipitation conditions, to length of anthesis period or to length of the whole generative period (Table 3). Negative influence on anthesis length, on the whole

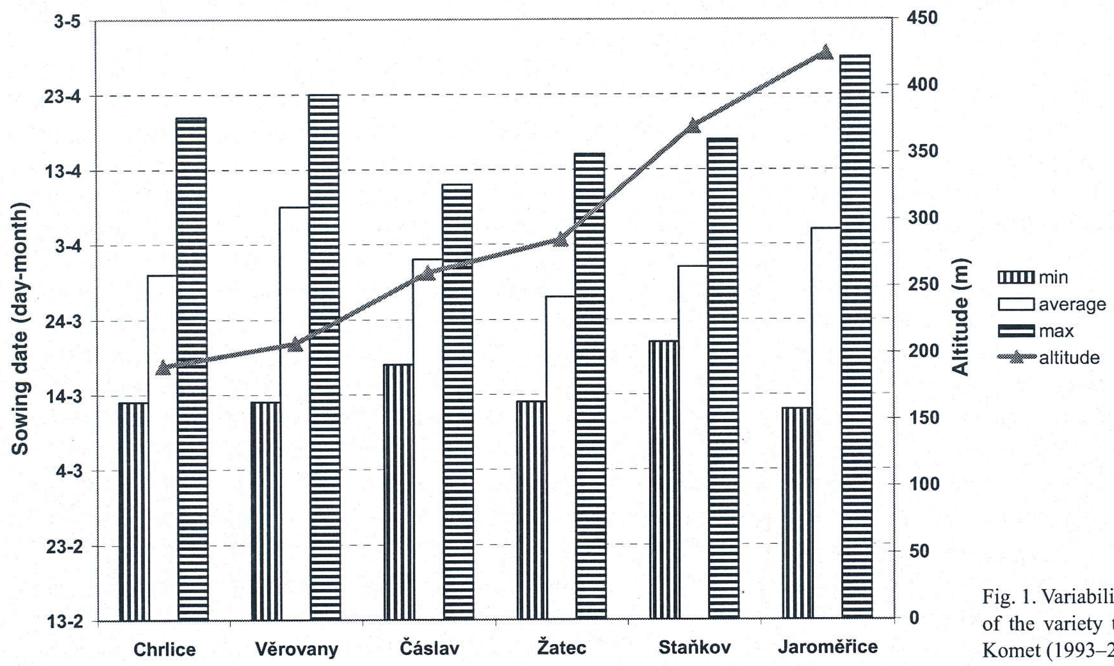

Fig. 1. Variability of sowing dates of the variety trials ÚKZÚZ for Komet (1993–2003)

Table 3. Correlation coefficients of duration of the pea-phenology stages, the crop yield and selected meteorological parameters (results from 6 stations in 1993–2003, variety Komet)

Stage/Parameter	Sowing date – Emergence	Emergence – Beginning of flowering	Beginning – End of flowering	Beginning of flowering – Maturity	Sowing date – Maturity
Crop yield	–0.08	0.31	–0.10	0.44	0.32
t	–0.73	–0.77	–0.70	–0.67	–0.77
Σt	0.45	0.58	0.96	0.87	0.75
Days with t > 30 °C	–	0.19	–0.18	–0.12	–0.16
Days with t < 15 °C	0.97	0.85	0.80	0.65	0.87
Days with precipitation	0.87	0.57	0.78	0.81	0.83
Σp	0.66	0.16	0.47	0.72	0.70

t – average temperature in particular period, Σt – sum of average temperature in particular period, Σp – sum of precipitation in particular period

Table 4. Coefficients variability of the phenology stages and the crop yield of the variety Komet (1993–2003)

Station of ÚKZÚZ	Altitude (m)	Coefficients variability (%)						Yield ($t.ha^{-1}$)
		S-EM	EM-BF	BF-EF	BF-M	S-M	Yield	
Chrlice	190	37.4	14.0	45.2	13.3	11.7	26.8	5.35
Věrovany	207	37.4	10.2	31.3	15.6	11.5	21.1	5.18
Čáslav	260	27.5	7.6	40.8	10.0	6.3	11.3	6.21
Žatec	285	28.5	11.5	41.3	14.4	8.2	24.8	4.59
Staňkov	370	22.2	8.1	39.0	12.3	4.7	14.8	4.67
Jaroměřice	425	43.7	8.8	50.0	16.4	14.7	22.2	4.97

S – sowing date, EM – emergence, BF – beginning of flowering, EF – end of flowering, M – maturity

vegetation period, or only on generative period, was found in increasing the daily average.

The extending of the growth period is dependent on precipitation conditions, specifically on number of days, in which there were measured precipitations values above 1 mm ($r = 0.57–0.87$). Low temperatures, in our case temperatures under 15 °C with correlation coefficient r = 0.65–0.97, have a positive influence on the extending of growth phases in pea (retarding of ageing process). Also they have a positive influence on yield formation as was proved by Stanfield (1966). The optimum temperature for emergence period, according to the author, is 21/16 °C and in the generative period 16/10 °C. High average daily temperatures shorten the growth periods.

A very variable factor is sowing date (Fig. 1). Timely pea sowing is considered as a yield stabilizing factor (Siddique, Wright, 2004). Its dependence on weather conditions and high variability of emergence period length can be one of the causes of yield instability. The period from pea sowing to emergence is the most variable growth stages, with average number of days from 16 to 21. Variability, related to pea stand establishment, is high and coefficients of variance (Table 4) are between 22.0–43.7%. The second least stable period is anthesis, with variability of length of this period between 31.3 to 50.0%. Lengths of other growth periods in pea are less variable.

Environmental conditions can be very different between localities. Results show high yield stability for one locality (Čáslav). The highest yield variability is reached in warm and dry areas. The amount of precipitation in dry areas, during all the vegetative period, was less than 180 mm and its insufficiency is a critical factor, especially during the generative period. Typical is a shorter seed forming period and accelerated stand maturation. Water for optimal growth must be considered as a main factor of plant production ability (Ittersum, Rabbinge, 1997). Performed evaluation places peas among water demanding crops.

Validity of statistical calculations was compared with parameters of monitored factors of weather, for the whole data set, with classifying yields into defined categories (Table 5). The use of 4 yield levels proved differences in meteorological criteria in cultivar Komet. For category up to 4.0 $t.ha^{-1}$ was a characteristic shorter vegetation period, especially shorter generative period. Another typical trait is higher average daily temperature, or higher number of tropical days. Contrary, common trait for yield categories above 4.0 $t.ha^{-1}$ was longer growth period, higher sum of temperatures, higher number of days with temperatures to 15 °C and more favourable precipitation conditions, i. e. number of days with precipitations above 1.0 mm. The same method was used to evaluate the favourable and non-favourable year for pea yield. By comparing results of the relationship between weather and yield in a favorable year 1996 (6.57 $t.ha^{-1}$) with parameters of unfavourable year (year 2000 with yield of 4.40 $t.ha^{-1}$), the former mentioned conclusions were confirmed.

Table 5. Characteristic of temperature and precipitation conditions in the main grow periods of the variety Komet for different category of the yield (results from 6 stations in 1993–2003)

Grow period	Parameter	Unit	Yield (t.ha^{-1})			
			< 4.0	4.0–5.0	5.0–6.0	> 6.0
S-EM	average temperature	°C	10.1	7.7	8.8	9.9
	sum of average temperature	°C	164.2	168.4	172.6	163.9
	days with temperature < 15 °C	days	15.6	21.8	20.5	16.5
	days with precipitation	days	5.5	7.8	9.2	7.9
	sum of precipitation	mm	19.1	31.7	28.4	28.0
	duration of period	days	17.9	22.5	21.7	18.4
EM-BF	average temperature	°C	15.6	14.3	14.5	14.6
	sum of average temperature	°C	623.7	610.9	620.5	649.2
	tropical days (> 30 °C)	days	0.6	0.4	0.5	0.9
	days with temperature < 15 °C	days	16.8	24.8	23.8	24.0
	days with precipitation	days	12.2	17.6	15.0	17.6
	sum of precipitation	mm	49.7	77.2	71.8	81.0
	duration of period	days	40.4	42.9	43.0	44.7
BF-EF	average temperature	°C	19.4	17.1	17.0	18.4
	sum of average temperature	°C	200.9	260.6	221.7	199.9
	tropical days (> 30 °C)	days	1.6	1.1	0.5	1.0
	days with temperature < 15 °C	days	2.2	4.7	4.6	2.3
	days with precipitation	days	2.3	5.8	6.8	4.6
	sum of precipitation	mm	12.3	24.3	43.1	25.4
	duration of period	days	10.6	15.4	13.5	11.3
BF-M	average temperature	°C	18.9	18.7	17.7	17.9
	sum of average temperature	°C	720.8	817.6	818.2	857.9
	tropical days (> 30 °C)	days	6.3	6.7	3.9	3.7
	days with temperature < 15 °C	days	7.0	7.6	10.5	9.9
	days with precipitation	days	13.8	16.7	21.9	21.7
	sum of precipitation	mm	68.6	87.1	146.9	141.5
	duration of period	days	38.6	44.3	47.1	48.1
S-M	average temperature	°C	15.7	14.6	14.6	15.1
	sum of average temperature	°C	1508.5	1600.6	1625.4	1671.1
	tropical days (> 30 °C)	days	6.9	7.1	4.3	4.6
	days with temperature < 15 °C	days	39.4	54.0	55.1	50.4
	days with precipitation	days	31.5	42.3	46.8	47.3
	sum of precipitation	mm	137.4	195.9	249.7	250.6
	duration of period	days	96.9	109.7	111.8	111.1

REFERENCES

BEWLEY, J. D. – BLACK, M.: Seeds. Physiology of Development and Germination. London, Plenum Press 1994. 445 pp.

COPELAND, L. O. – McDONALD, M. B.: Principles of Seed Science and Technology. Chapman and Hall 1995. 393 pp.

DUTHION, C. – PIGEAIRE, A.: Seed lengths corresponding to the final stages in seed aboration of three grain legumes. Crop Sci., *31*, 1991: 1579–1583.

HOSNEDL,V.: Vliv počasí na biologický a hospodářský výnos luskovin. In: PETR, J. et al.: Počasí a výnosy. Praha, SZN 1987: 249–261.

ITTERSUM, M. K. – RABBINGE, R.: Concept in production ecology for analysis and quantification of agricultural input-output combination. Field Crop Res., *52*, 1997: 197–208.

JOERNSGARD, B. – HALOMOEB, S.: Intra-field yield variation over crops and years. Eur. J. Agron., *19*, 2003: 23–33.

KLABZUBA, J. – KOŽNAROVÁ, V.: Agrometeorologické hodnocení ročníku nebo kratšího období. I. část – přístrojové vybavení a metodika měření. Sborník VŠZ v Praze, FA, *55*, 1993: 93–106.

MATHE-GASPAR, G. – FOROT, N. – POKOVAI, K. – KOVACÍ, G.: Crop modelling as a tool to separate the influence of the soil and weather on crop yields. Phys. Chem. Earth, *30*, 2005 (1–3): 165–169.

MUNIER-JOLAIN, N. G. – MUNIER-JOLAIN, N. M. – ROCHE, R. et al.: Seed growth rate in grain legumes – I. Effect of photoassimilate availability on seed growth rate. J. Exp. Bot., *49*, 1998: 1963–1969.

PETR, J. – HOSNEDL, V.: Formation of economic yield of pulses. In: PETR, J. – ČERNÝ, V. – HRUŠKA, J. et al.: Yield Formation in the Main Field Crops. Amsterdam, Elsevier 1988: 201–217.

PETR, J. – COUFAL, V. – BRYCHTOVÁ, H.: The effect of weather on yield formation in winter wheat. Rostl. Výr., *33*, 1987: 141–152.

SIDDIQUE, A. B. – WRIGHT, D.: Effects of date of sowing on seed yield, seed germination and vigour of peas and flax. Seed Sci. Technol., *32*, 2004: 455–472.

STANFIELD, B. – ORMROD, D. P. – FLETCHER, H. F.: Response of peas environment. II. Effects of temperature in controlled environment cabinets. Can. J. Plant Sci., *46*, 1966.

TOMIŠKA, Z. – SLÁDKOVÁ, J. – VAŇKOVÁ, L.: Bodové hodnocení produkční schopnosti půd (vybraná stanoviště ČR). [Final Report of Research Project.] Praha, Výzkumný ústav meliorací a ochrany půdy 2003: 176–179.

Received for publication on March 21, 2007
Accepted for publication on April 30, 2007

FACHADAS HRACHOVINOVÁ, J. – HOSNEDL, V. – MEZLÍK, T. (Camposol II., Lda, Vila Nova de Milfontes, Portugal; Česká zemědělská univerzita, Fakulta agrobiologie, potravinových a přírodních zdrojů, Praha, Česká republika; ÚKZÚZ, Brno, Česká republika):

Vliv počasí na nestabilitu výnosů hrachu (*Pisum sativum* L.).

Scientia Agric. Bohem., *38*, 2007: 117–122.

Hlavní příčinou výnosové nestability hrachu je vysoká citlivost na méně příznivé podmínky prostředí, především podmínky meziroční a stanovištní. Cílem výzkumu bylo studium fenologické odezvy rostlin a variability výnosů na tyto podmínky. Metoda dynamického hodnocení počasí ve vztahu k růstovým obdobím umožnila přesnější výpočty korelačních vztahů i vyjádření variability každého faktoru. Fenologická a výnosová data pro odrůdu Komet (1993–2003) a odrůdu Bohatýr (1980–1994) byla získána z odrůdových pokusů ÚKZÚZ. Meteorologická data poskytl Český hydrometeorologický ústav.

Porovnáním výnosů odrůd za celé sledované období na všech stanovištích byly zjištěny limitní hranice nejvyšších výnosů na úrovni 7,53 $t.ha^{-1}$ (Komet) a 6,83 $t.ha^{-1}$ (Bohatýr). Ve sledovaných časových řadách se výnosy hrachu v polních pokusech pohybovaly v rozmezí 38 až 100 % uvedených maximálních hodnot. Metodika odrůdových pokusů ÚKZÚZ umožnila (při vyrovnané půdní úrodnosti) označit počasí za rozhodující faktor variability výnosů. Proměnlivost teplotních a srážkových podmínek má vliv na počátek růstových období a jejich délku. Pozitivně na prodloužení určité fenologické fáze hrachu působí nižší teploty. V našem případě pro vztah délky těchto období k průměrným denním teplotám pod 15 °C platí korelační koeficienty $r = 0,65–0,97$. Povětrnostní podmínky ovlivňují termín setí a následně rychlost a vyrovnanost vzcházení. Pro období vzcházení byly zjištěny vysoké variační koeficienty (22,0–43,7 %). Nejvýrazněji úrovní výnosu reaguje porost hrachu na podmínky prostředí v generativním období, souvisejícím s kvetením a zráním plodiny ($r = 0,44$).

Prokázán byl významný vliv stanoviště na stabilitu výnosů hrachu a citlivost odrůd k vyšším teplotám a k nedostatku srážek. Odlišnou stabilitu výnosů hrachu u hodnocených stanovišť dokazují variační koeficienty, které dosahují od 10,0 % (oblasti s výnosovou stabilitou hrachu) až do 26,8 % na lokalitách s velmi nestabilními výnosy. Hrách je plodinou vysoce citlivou na prostředí a výsledky dokazují rizikovost některých lokalit pro jeho pěstování.

hrách; počasí; fáze růstu; výnosy; variabilita výnosu; korelace

Contact Address:

J. Fachadas Hrachovinová, Camposol II, Apt. 123, Vila Nova de Milfontes, 7645, Portugal