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THE YIELD FORMATION OF SUNFLOWER INFLUENCED BY TEMPERATURE AND MOISTURE CONDITIONS OF EXPERIMENTAL FIELD

TVORBA ÚRODY SLNEČNICE ROČNEJ VPLYVOM TEPLOTNÝCH A VLHKOSTNÝCH PODMIENOK PESTOVATEĽSKEJ LOKALITY

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Field polyfactorial experiments with sunflower (conventional, medium-late hybrids: NK Brio, Alexandra PR, NK Ferti, NK Alego) were realized on the experimental base of Center of Biology and Ecology of Plants FAFR SUA in Nitra Dolná Malanta. Experimental area is located in corn production region, characterized as warm and slightly dry with mild winter and long sunshine, in altitude 250 m, with brown soil. The influence of both temperature and moisture conditions of experimental area on sunflower yield of achenes (conventional, medium-late hybrids: NK Brio, Alexandra PR, NK Ferti, NK Alego) was observed. Fore crop of sunflower (*Helianthus annuus* L.) was wheat (*Triticum aestivum* L.). Technological system of sunflower cultivation was realized in accordance with conventional technology of cultivation. The basic fertilization was made by balance method on the base of agrochemical soil analysis for expected yield 3 t ha^{-1}. During experimental years the change of inner energy (ΔU) was evaluated for thermodynamic characteristic analysis (security of the temperature and moisture) and the impact of changes on yield forming with maximal yield (Y_{max} in 2008) and minimal yield (Y_{min} in 2009). Achieved value of yield from thermal and precipitation energy introduces concrete energy amount, which is available in given period for concrete amount of yield. From the results follow that the sunflower has got critical thermodynamic phase in the period of months July and August. For the yield formation it is necessary, that input power of precipitation prevailed over the thermal during the months July and August. Achieved results confirmed statistically high significant dependence of the yield on weather conditions. It is necessary to consider potential change of agro technological measures in sunflower cultivation because of large annual variations in climate characteristics.

Key words: sunflower, thermodynamic conditions, yield of achenes

The process of yield formation of field crops is significantly affected by presence and abundance of many factors. Where agro ecological factors are dominant, their mutual interaction influences respectively. The yield variability and final production of crops is influenced mainly by the weather conditions. The influence of weather conditions is decisive in the yield creation process of oilseeds and other crops. Their interaction leads to regulation of particular growth phase, due to its forming quantity and quality of yield-forming elements (Brandt et al., 2003; Macák et al. 2007; Fecák et al. 2009).

According to Kudrna (1985) the inner energy (ΔU) as the criterion reviewing the influence of basic agro-climatic conditions (temperature, water, radiation, etc.) during the field crops vegetation in system solar radiation energy $\rightarrow$ phytocenosis energy, introduces this part of cell structures energy, which keeps the transformation processes on the move.

The evaluation of the effect of basic climatic quantity (temperature and water) on yield formation of field crops is very complicated. Water from biologic and physiologic (Švihra, 1984; Passioura, 2002, 2007; Chaves et al., 2003) aspects and point of view of agro climatic regionalization (Fischer and Turner, 1978; Špánik et al., 2002) is irreplaceable factor of life on the Earth. The water regime is considered to be a main indicator of environment production performance (Passioura, 2002).

Aiken (2006) and Švelucha (1982) consider water demand as a determining factor for yield creation of field crops. The sunflower grades the requirements on the water during the vegetation period. Therefore, the disproportion between physiological requirements to the water and real precipitation in season can get to the status, which we evaluate as water deficient.

The growth of sunflower is significantly limited under drought (Murillo, 1998). The plant consumes (of total water demand) approximately 23 % to the formation of head, 60 % from establishment to fertilization and 17 % to the full maturity. Water stress of plants affects not only reduction of yield but participates in the decrease of total oil content and oil composition in the sunflower achenes (Hussain, 2008).

Brandt et al. (2003) consider also the air temperature a decisive climatic factor beside water. The soil temperature and temperature of soil solution depends on it.

In the optimal agroecological regions the sum of active temperatures should be more than 10 °C for sunflower cultivation during growing season 120 – 150 days (Fábry, 1992). The sunflower increases demands on the temperature from growth stage of flowering to maturation of achenes. Therefore the average temperature should not be less than 18 °C at night and average daily temperature less than 24 °C during the season from July to half August. Sunflower requires average temperature more than 15 °C at night and daily more than 20 °C in the end of August and in September (Beard and Geng, 1982).

Global changes relating to precipitation decrease and rising of temperatures involved from climatic system analysis (Repa and Špánik, 1999) and from respecting of sunflower temperature and moisture demands for medium geographic areas. However, both finding and consciousness of these facts can have significant impact on decreasing of yield and quality of sunflower production (Loomis and Connor, 1992).

Table 1 Agrochemical soil analysis

Parameters (1)		Year (2)		
		2008	2009	2010
N_{an} (by Kjeldahl method) (3)	$mg.kg^{-1}$ of soil (9)	7.2	8.7	11.4
P (by Mehlich III method) (4)	$mg.kg^{-1}$ of soil (9)	45.30	38.00	61.20
K (by Mehlich III method) (5)	$mg.kg^{-1}$ of soil (9)	421.00	395.00	433.00
Humus (by Tjurin method) (6)	%	1.05	0.35	2.19
Carbonates (7)	%	0.87	1.51	0.36
pH/KCl (8)		6.25	6.34	6.20

Tabuľka 1 Agrochemický rozbor pôdy
(1) parametre, (2) rok, (3) N_{an} (Kjeldahl metóda), (4) P (Mehlich III metóda), (5) K (Mehlich III metóda), (6) humus (Ťjurin metóda), (7) uhličitany, (8) pH/KCl, (9) $mg.kg^{-1}$ pôdy

The aim of contribution is to point out, from results of experimental years 2008 – 2010, an impact of temperature and moisture conditions of experimental area on amount of yield of sunflower achenes (*Y*).

Material and method

Field polyfactorial experiments with sunflower (conventional, medium-late hybrids: NK Brio, Alexandra PR, NK Ferti, NK Alego) were realized on the experimental base of Center Biology and Ecology of Plants FAFR SUA in Nitra Dolná Malanta. Experimental area is located in corn production area, characterized as warm and slightly dry with mild winter and long sunshine. The trials were carried out on brown soil.

The fore crop of sunflower (*Helianthus annuus* L.) was winter wheat (*Triticum aestivum* L.). Basic fertilization was made using the balance method on the base of agrochemical soil analysis for amount of yield 3 tons per hectare.

Tillage (stubble ploughed under, deep autumn plowing), the way of setting up of sunflower (sowing date II. decade of April, interline distance 0.70 m, distance in row 0.22 m), treatment during the vegetation (preemergent herbicide application, double application of fungicides) and harvesting 2008 (Y_{max}) – III. decade of September, 2009 (Y_{min}) – I. decade of October, non-desiccated canopy, were made by conventional technology of sunflower cultivation.

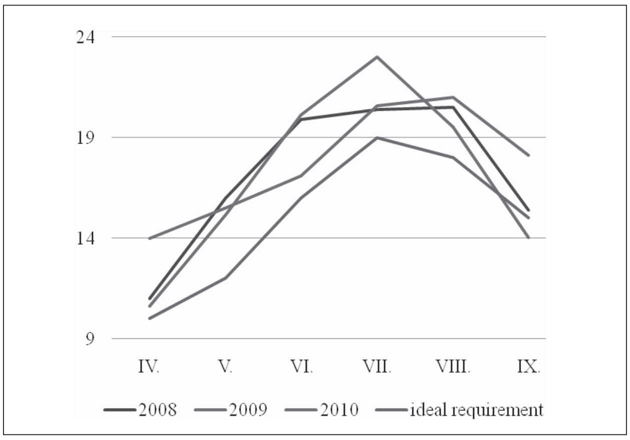

Figure 1 The process of temperature conditions in °C in experimental years in comparison with ideal requirement
Obrázok 1 Priebeh teplotných podmienok v °C experimentálnych rokov v porovnaní s ideálnou potrebou

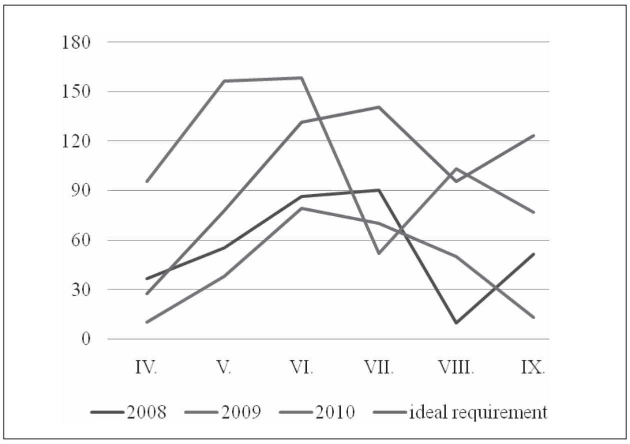

Figure 2 The process of water conditions in mm in experimental years in comparison with ideal requirement
Obrázok 2 Priebeh vlhkostných podmienok v mm experimentálnych rokov v porovnaní s ideálnou potrebou

Basic meteorological data (monthly precipitation in mm, average daily temperature in °C) were obtained from Horticulture and Landscape Engineering Faculty at Slovak University of Agriculture (Fig. 1 – 2).

Experiments were carried out by the split plot design with randomized complete blocks base design (Ehrenbergerová, 1995). Statistical evaluation of the experimental factors was processed by the multifactor analysis of variance.

Using form to review the influence of climatic conditions is value of internal energy (ΔU).

The amount of transformed kinetic energy into potential energy is expressed:

$$T = \frac{Y_{prod}}{t_c} \qquad S = \frac{Y_{prod}}{h_s}$$

where:
T – temperature coefficient
S – precipitation coefficient

$$Y_t = T \cdot t_{cn} \qquad Y_h = S \cdot h_h$$

where:
Y_t – term energy for yield formation
Y_{hs} – precipitation energy for yield formation
Y_{prod} – productive yield ($t.ha^{-1}$)
hs – month precipitation sum per crop vegetation (mm)
h_{sn} – precipitation in monitored period (e.g. month, decade, pentade, etc.) (mm)

t_c – month temperature sum per crop vegetation (°C)
t_{cn} – temperature in monitored period (e.g. month, decade, pentade, etc.) (°C)

The yield value *Yt* or *Yhs* represents the energy quantum in system solar radiation energy – phytocenosis energy (Kudrna, 1989), which is defined time available for yield, so for change of total inner energy system (ΔU). The total inner energy system change (ΔU) is next formulated as:

$$\Delta U = \frac{Y}{tc} tcn - \frac{Y}{hs} hsn = T \cdot cn - S \cdot hsn = Yt - Yhs$$

Results and discussion

The formation of sunflower yield is significantly affected by both temperature and moisture requirements during the vegetation. Thermodynamic conditions of individual experimental years were differentiated by temperature and moisture conditions (Figure 1 – 2, table 2). In year 2008, when the yield of achenes was highest (Y_{max} = 3.88 t ha^{-1}), the process of weather conditions was most favourable for formation of sunflower yield during individual growth seasons (precipitation per vegetation was 329.3 mm; average temperature was 17.2 °C). In year 2009, when the lowest yield was achieved (Y_{min} = 2.67 t ha^{-1}), the tendency of weather conditions in comparison with physiological ones was less responding (precipitation per vegetation is 260.0 mm; average temperature is 17.7 °C). The differences show statistically high significant dependence on the weather conditions in the achene yield (Y_{max} and Y_{min} 1.21 t ha^{-1}) in years 2008 – 2010.

Increasing of achene yield is influenced not only by total precipitations but also by their uniform distribution during vegetation period, i.e. during growth stages, when the crop uses them effectively. The sunflower requires higher precipitation during the formation of assimilatory apparatus with maximum in growth stage of flowering and formation of heads, i.e. during July in our region. Deficit of precipitation influenced metabolism process deregulatory in the season of increased physiological moisture requirement, what increased differences between potential and real yield of achenes (Crithley, Siegert and Chapman, 2003).

The differences between achene yields were significantly influenced not only by precipitation but also by temperatures. Higher values in comparison with long-term normal (1961 – 1990) are caused by increased transpiration and evapotranspiration, it impacts on total nutrient intakes and performance of assimilation. For optimal process of yield formation it is decisive, that precipitation increases with rising daily temperatures for appropriate conditions to growth and development. On the other hand, in the end of vegetation period, gradual decline of average temperatures and precipitations is appropriate (Fábry, 1982), which partially confirmed our results.

Kudrna (1985) presents that maximum yields of many crops are reached in conditions of maximum growth intensity and high stability between biological processes and climatic factors. The optimal running of the biological processes in the plant cells needs concrete thermo-dynamic conditions in various

Table 2 The thermal and moisture conditions for formation of sunflower inner energy in years with maximum and minimum yield

Month (1)	Normal (n) 1961 – 1990 (2)		Ideal requirement (5)		Y_{max} (6) 3.88 t.ha^{-1} (2008)		Y_{min} (7) 2.67 t.ha^{-1} (2009)	
	∑mm (3)	X_{td} °C (4)	∑mm (3)	X_{td} °C (4)	∑mm (3)	X_{td} °C (4)	∑mm (3)	X_{td} °C (4)
IV.	39.0	10.4	27.5	10.0	36.4	11.0	10.0	14.0
V.	58.0	15.1	77.6	12.0	55.4	16.0	38.0	15.5
VI.	66.0	18.0	131.6	16.0	86.2	19.9	79.0	17.1
VII.	52.0	19.8	140.6	19.0	90.0	20.4	70.0	20.6
VIII.	61.0	19.3	95.4	18.0	9.8	20.5	50.0	21.0
IX.	40.0	15.6	123.2	15.0	51.5	15.4	13.0	18.0

Tabuľka 2 Teplotné a vlahové podmienky pre tvorbu vnútornej energie slnečnice ročnej v rokoch s minimálnou a maximálnou úrodou
(3) sum of precipitation, (4) average daily temperature, (6) maximum yield in t.ha^{-1}, (7) minimum yield in t.ha^{-1}
(1) mesiac, (2) klimaticky normál, (3) suma zrážok, (4) priemerná denná teplota, (5) ideálna potreba, (6) maximálna úroda v t.ha^{-1}, (7) minimálna úroda v t.ha^{-1}

Table 3 Changes of inner energy for ΔU for sunflower

Month (1)	Y_{max} 3.88 t.ha^{-1} (2008) (2)			Y_{min} 2.67 t.ha^{-1} (2009) (3)		
	Y_t	Y_{hs}	ΔU (6)	Y_t	Y_{hs}	ΔU (6)
IV.	0.41	0.42	-0.01	0.35	0.10	+0.25
V.	0.60	0.65	-0.05	0.38	0.38	0.00
VI.	0.74	1.01	0.27	0.42	0.81	-0.39
VII.	0.76	1.06	-0.40	0.51	0.71	-0.20
VIII.	0.77	0.11	+0.66	0.52	0.51	+0.01
IX.	0.57	0.60	-0.03	0.45	0.13	+0.32

Tabuľka 3 Zmeny vnútornej energie pre slnečnicu ročnú
(2) maximum yield of achenes, (3) minimum yield of achenes, (4) temperature energy needed for yield formation, (5) rainfall energy needed for yield formation, (6) change of inner energy
(1) mesiac, (2) maximálna úroda v t.ha^{-1}, (3) minimálna úroda v t.ha^{-1}, (4) energia teploty potrebná na formovanie úrody, (5) energia zrážok potrebná na formovanie úrody, (6) zmena vnútornej energie

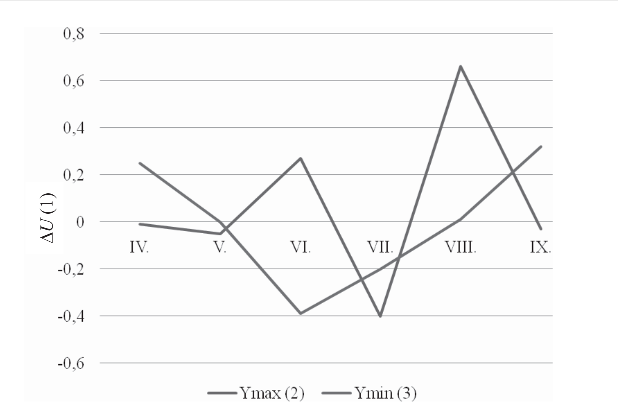

Figure 3 Characteristic thermodynamic curve line of inner energy for maximum and minimum yield of sunflower
(1) ΔU – values of internal energy, (2) Y_{max} – maximum yield, (3) Y_{min} – minimum yield

Obrázok 3 Charakteristická termodynamická krivka vnútornej energie pre maximálnu a minimálnu úrodu slnečnice ročnej
(1) ΔU – hodnoty vnútornej energie, (2) Y_{max} – maximálna úroda, (3) Y_{min} – minimálna úroda

phases of growth and development. Maximum dry matter accumulation is defined by maximum accumulation of inner energy of systems. Metabolic activity as an aspect of inner energy of systems is deactivated under deficit of precipitation in conditions without irrigation what results in sunflower yield decrease. Kudrna (1985) considers the change of an inner energy (ΔU) as a basic criterion of energy transformation of thermodynamic characteristics. From the point of maximum yield of achenes formation it is important that the values of inner energy should be negative during the critical thermo-dynamic growth. That means that it predominates the energy input from precipitation (Y_{hs}) over the energy from temperatures (Y_t) during formation of achenes. Balance changes between both temperatures and precipitation cause the disproportion in reached yields.

Critical period of growing and development of the sunflower shows a maximum intensity of growing heads and achenes. For achievement of maximum yield it is necessary to reach maximum change of inner energy (ΔU) by both maximum temperatures and maximum precipitations. The course of characteristic curves in individual months of vegetation period confirms that critical periods with lowest values of inner energy are united with intensive growth of field crops. This period is predestined to temperature gradients, when the plant grows intensively. Calculated changes of the level of ΔU and their influences on yield formation are given in Table 3 and in Figure 1 by thermodynamic curve lines

Analyzed data show the real situation of inner energy on axis of coordinates for vegetation period of sunflower, where prevails the influence of precipitation over temperatures by achievement Y_{max}, resp. Y_{min}. For formation of the maximal yield, more significant influence of precipitation in July and August was found. On the other hand, values of inner energy relating to the minimum yield formation show shift of period with prevailing influence of precipitation over the temperatures in May and June and dominance of temperatures in August, what we consider important from this analysis.

Conclusions

From the point of yield formation, the analysis of thermodynamic locality conditions represents one of alternatives for study of production process forming the field crops. The aim of work is to show an impact of both temperature and moisture conditions on sunflower yield of achenes from experiment results of years 2008 – 2010 (Y).

From analysis of thermodynamic conditions of sunflower cultivation it is proved that maximum yield of achenes (Y_{max}) was achieved in the year 2008, where the precipitation was 329.3 mm during the vegetation period and average temperature was 17.2 °C. The lowest yield (Y_{min}) was reached in the year 2009, where the precipitation was only 260.0 mm and average temperature was 17.7 °C. The difference between the precipitations in experimental years was 69.3 mm and between yields of achenes 1.21 t ha^{-1} (statistically highly significant).

The value of inner energy was negative for the formation of maximum yield (2008) in critical growth periods. On the other hand, the input power of thermal energy dominated over precipitation formed of minimum yield. In year with maximum yield the sunflower showed higher requirements on moisture in July and August, however, in the year with minimum yield the highest requirements were in May and June.

Súhrn

Poľné polyfaktorové pokusy boli realizované v rokoch 2008 – 2010 na experimentálnych pozemkoch Strediska biológie a ekológie rastlín FAPZ SPU v Nitre Dolná Malanta. Záujmové územie je lokalizované v kukuričnej výrobnej oblasti (klimatická oblasť: teplá; klimatická podoblasť: suchá; klimatický okrsok: teplý, suchý s miernou zimou a dlhým slnečným svitom) pri nadmorskej výške 250 m, na hnedozemi kultizemnej. V experimentoch bol sledovaný vplyv teplotných a vlahových podmienok experimentálneho stanovišťa na výšku úrody nažiek slnečnice ročnej (konvenčné, stredne neskoré hybridy: NK Brio, Alexandra PR, NK Ferti, NK Alego). Predplodinou slnečnice ročnej bola pšenica letná forma ozimná (*Triticum aestivum* L.). Technologický systém pestovania slnečnice ročnej bol realizovaný v súlade so zásadami konvenčnej technológie pestovania. Základné hnojenie bolo uskutočnené bilančnou metódou na základe agrochemického rozboru pôdy na predpokladanú výšku úrody 3 t.ha^{-1}. Základné meteorologické údaje boli získané z Fakulty záhradníctva a krajinného inžinierstva Slovenskej poľnohospodárskej univerzity. V priebehu pokusných rokov bola pre analýzu termodynamických charakteristík (teplotná a vlahová zabezpečenosť) hodnotená zmena vnútornej energie (ΔU) a vplyv sledovaných zmien na formovanie úrody v rokoch s úrodou maximálnou (Y_{max}: 2008) a úrodou minimálnou (Y_{min}: 2009). Získanú hodnotu úrody z energie tepla alebo zrážok predstavuje konkrétne množstvo energie, ktoré je v určitom danom období k dispozícii pre určitú výšku úrody. Z výsledkov vyplýva, že slnečnica ročná má vo vegetačnom období kritickú termodynamickú fázu v období mesiacov júl – august. Z hľadiska tvorby úrody je preto potrebné, aby v uvedených mesiacoch vegetačného obdobia prevládal príkon energie zo zrážok nad teplotami. Dosiahnuté výsledky potvrdili štatisticky vysokú závislosť úrody na priebehu poveternostných podmienok ročníka. Pre značné medziročné rozdiely v klimatických charakteristikách je potrebné uvažovať o potenciálnej úprave agrotechnických opatrení technologického systému pestovania slnečnice ročnej.

Kľúčové slová: slnečnica ročná, termodynamické podmienky, úroda nažiek

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