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The Influence of Weather Conditions During Vegetation Period on Yielding of Twelve Determinate Tomato Cultivars

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Abstract

Tomato yield and biomass growth are closely linked to climatic conditions during vegetation period. Low temperatures and high precipitation in summer constitute the main cause of the large variability of field tomato yielding contributing to worsen the quality of the yield. The aim of the investigation was determining the influence of meteorological basic components in the growing season of the tomato to total and marketable yield of twelve determinate cultivars. Experiment took place in the open field in the Vegetable Experimental Station of Agricultural University of Mydlniki near Cracow in the years 2008 - 2010. A different sensitivity of examined tomato cultivars to the course of weather conditions was stated. 'Ondraszek' cultivar get the highest marketable yield in all years of investigation what indicate the most adaptation to variable weather conditions and cultivars 'Hetman', 'Hubal' and 'Babinicz' were the least adaptated and they gave the lowest yield. Analysis of the influence of weather condition on total and marketable yield of twelve determine tomato cultivars showed, that the sum and distribution of precipitation were decisive. High precipitations decreased total and marketable yield, whereas frequent and lower precipitations influenced favorable. Since from the third stage, i.e., the beginning of fruits setting to the beginning of ripening, a larger impact of meteorological factors on marketable than total yield had been observed. In the fruits ripening stage a marketable yield depended only on sum of temperatures.

Keywords: hydrothermal index, open field cultivation, precipitation, temperature

Introduction

Tomato yield and biomass growth are closely linked to environmental and climatic conditions (Kascjan Maršic *et al*., 2005; Konys, 1990). In the open field their geographic distribution are limited by sensitivity to low temperatures.

Cultivation areas for determinate tomatoes are often located in the climatic favorably Mediterranean region. According to Konys (1990) in years with climatic condition favorable for tomato yield ranged from 14-15 $t \cdot ha^{-1}$, in worse only to 5-7 $t \cdot ha^{-1}$. Konys (1990) observed that only in favorable conditions, traditional growing methods gave good results and increased yield.

Poland is the furthest north country in Europe, where tomato is grown in an open field on a production scale. Low temperatures and high precipitation in summer constitute the main cause of the large variability of field tomato yielding contributing to worsen the quality of the yield (Kascjan Maršic *et al*., 2005).

Depending on the species and the developmental stage meteorological elements have a differential impact to the height and the quality of yield of crop plants (Kalbarczyk, 2006; Kałużewicz *et al*., 2010; Licznar-Maleńczuk, 2004; Samborski, 2006; Skowera *et al*., 2007; Skowera and Kołodziej, 2003). This impact is included in the statistical modeling for numerous vegetable plants, including tomatoes (Kalbarczyk, 2010; Voican *et al*., 1995). In south Europe, in countries of Mediterranean region, the model tests concerning regionalization of the arable farming of the tomato, were being conducted by Voican *et al*. (1995). They confirm, that the crucial factors affected yield are environmental conditions, in particular weather conditions (the solar radiation, the air temperature and precipitation).

In conditions of the moderate climate, being characterized by a large temporal and spatial variability, the cultivar selection is a main element deciding about getting the satisfying yield (Bandurska *et al*., 2011; Kascjan Maršic *et al*., 2005).

In the growing season in Poland a big diversification of precipitation is observed, whereas thermal condition is smaller. In last years changes in the structure of precipitation and an increase in the frequency of extreme pluviothermal conditions are being observed (Bokwa and Skowera, 2009; Skowera and Wojkowski, 2003). In Poland numerous cultivars of determinate tomato are being used and therefore pointing out those genotypes, which are more resistant to climatic condition stress, will contribute to the profitability of the cultivation.

The aim of the investigation was determining the influence of meteorological basic components in the growing season of the tomato to total and marketable yield of twelve determinate cultivars.

Material and methods

Experiment took place in the open field in the Vegetable Experimental Station of Agricultural University of Mydlniki near Cracow in the years 2008 - 2010 on the brown soil. A completely randomized block design with four replicates and 40 plants for plot were used. Dates of sowing and seedlings planting in years were following: 2008 - April 8 sowing, planting 16 May, 2009 - April 16 sowing, planting 21 May, 2010 - March 31 sowing, planting 26 May. Plants spacing was 80×60 cm. During the growing season typical treatments, as weeding and chemical diseases protection, were carried out according to current recommendations.

During vegetation period detailed observation of developmental stages of tomato plant were done. Terms of beginning of flowering, fruit setting and fruit ripening and term of harvesting were noted. Harvesting was performed once, at the stage of maturity of individual cultivar. The yield (kg/per plant) and its structure was calculated. Number of days (L) and sum of precipitation (P)> 0.1 mm and also sum of temperature (∑t) >0°C were calculated. These data were measured by automatic meteorological station installed on experimental plots.

Average monthly air temperatures and sums of precipitation in investigated years were compared to multiannual means 1961-1990 (Kossowska-Cezak *et al*., 2000).

In order to analyzing meteorological conditions on tomato developmental stages Sielianinow's hydrothermal index (K) were used. K is known as a co-efficient of provision plant in water. The index is computed as follows:

$K = P / 0.1 \sum t$

where: P is sum of monthly precipitation in mm. ∑t is sum of daily mean air temperatures >0°C. Skowera and Wojkowski (2003) cited nine classes of the hydrothermal index K:

extremely dry	(ss)	$K \leq 0.4$
very dry	(bs)	$0.4 < K \leq 0.7$
dry	(s)	$0.7 < K \leq 1.0$
relatively dry	(ds)	$1.0 < K \leq 1.3$
optimal	(o)	$1.3 < K \leq 1.6$
relatively humid	(dw)	$1.6 < K \leq 2.0$
humid	(w)	$2.0 < K \leq 2.5$
very humid	(bw)	$2.5 < K \leq 3.0$
extremely humid	(sw)	$K > 3.0$

Analysis of the total and marketable yield of examine cultivars were based on the Duncan test.

The statistical dependence of the total yield and marketable yield of tomato plants from meteorological elements were analyzed. Taking into account length of developmental stages. A general model for the multiple regression (forward selection) predicted total and marketable yield were proposed.

Total yield = b_0+ b_1·sum of temperature +b_2 sum of precipitation +b_3 number of days with precipitation;

Marketable yield = b_0+ b_1·sum of temperature +b_2 sum of precipitation +b_3 number of days with precipitation.

In the first step the variable with the highest impact on tomato yield (the highest squared correlation) was added to the regression equation. Next the partial F statistic for each possible remaining variable was computed and if the variable with the highest F statistic passed a criterion (α=0.05), it was added to the regression equation. Then, it was checked whether the variable in the regression equation passed the criterion for significance. If so, they remained in the equation, otherwise they were removed from the equation. The procedure went on until no variable that passed the criterion for significance could be found. The calculation were made in the Statistica 10.

Results and discussion

Meteorological conditions during vegetation in investigated years 2008-2010 were diversified very much and

Tab. 1. Mean monthly air temperature and sum of precipitation during vegetation period 2008-2010 on based of multiannual means 1961-1990 (Kraków-Balice)

Years	Meteorological factors	May	June	July	August	September
Period 1961-1990	t	13.1	16.2	17.5	16.9	13.7
	p	83.0	97.0	85.0	87.0	54.0
2008	t	13.7	18.5	18.8	18.2	12.6
	p	25.9	26.9	144.0	42.9	98.8
2009	t	13.5	16.0	19.9	18.7	15.1
	p	97.8	140.2	82.6	53.1	35.0
2010	t	12.8	17.5	20.7	18.4	12.1
	p	299.0	135.1	105.2	127.5	116.3

t-temperature (°C), p- sum of precipitation (mm) they modified the tomato height and a development in individual stage (Tab. 1 and 2). Many authors observed this influence (Abdul-Baki *et al*., 1996; Kascjan Maršic *et al*., 2005; Konys, 1990). Even in the Mediterranean region, which is regarded as the most climatically supporting the cultivation of the industrial tomato, a dependence of yielding on the course of the weather is noticed (Kascjan Maršic *et al*., 2005).

Variability of weather conditions is illustrated by average monthly air temperatures and sums of precipitation on based of multiannual means 1961-1990 (Tab. 1.) and also enclosed in the Tab. 2 calculated climatic indicators, i.e. Sielianinow's hydrothermal index (K) and the number of days with precipitation (L). Sielianinow's hydrothermal index higher than 1.6 determines excessively humid conditions, whereas 1.0 to 1.6 indicates relatively

Tab. 2. Sielianinow hydrotermal index value (K) and number of days of precipitation (L) during succeeding developmental stages

Cultivar	Year	Developmental stage							
		1*		2		3		4	
		K	L	K	L	K	L	K	L
'Sokal F_1'	2008	0.5	9	0.4	5	1.8	20	0.8	10
	2009	2.7	14	4.5	10	1.3	18	0.3	6
	2010	3.9	6	1.2	11	1.6	20	2.1	7
'Batory F_1'	2008	0.5	9	0.7	7	2.4	18	0.8	9
	2009	2.6	15	4.9	9	1.0	18	1.6	7
	2010	2.1	6	1.5	10	1.8	15	2.1	7
'Rejtan F_1'	2008	0.5	9	0.7	7	2.0	18	0.9	9
	2009	2.3	17	3.0	15	0.8	15	2.3	3
	2010	4.3	6	1.2	11	1.6	20	2.2	4
'Hetman'	2008	0.6	10	0.7	6	2.0	18	1.3	7
	2009	2.1	18	3.2	14	0.8	15	2.5	6
	2010	3.3	9	1.0	8	1.6	20	2.1	7
'Lubań'	2008	0.5	9	0.7	7	2.3	18	0.8	10
	2009	2.6	20	2.8	12	0.9	12	1.2	6
	2010	4.3	6	1.2	11	1.7	16	2.2	6
'Babinicz'	2008	0.6	9	0.6	2	1.2	11	1.6	19
	2009	2.8	12	3.2	15	1.0	17	1.5	6
	2010	4.3	6	1.5	10	1.7	12	1.8	11
'Awizo F_1'	2008	0.5	9	0.7	7	2.0	18	1.1	7
	2009	2.3	17	3.2	11	1.0	18	1.6	4
	2010	4.8	6	1.1	11	1.6	19	1.8	5
'Mieszko F_1'	2008	0.5	9	0.7	7	2.0	18	0.8	10
	2009	2.7	14	3.5	13	0.9	16	1.9	6
	2010	3.9	6	1.2	11	1.7	21	1.8	6
'III A F_1'	2008	0.6	9	0.6	2	1.5	21	1.1	12
	2009	2.6	15	2.9	13	1.0	18	1.3	6
	2010	4.3	6	1.2	11	1.8	13	1.9	9
'Ondraszek'	2008	0.5	9	0.8	2	2.0	16	1.4	9
	2009	2.4	16	2.9	13	1.0	17	1.5	4
	2010	4.8	6	1.2	11	1.8	13	1.5	4
'Hubal'	2008	0.6	10	0.6	6	2.0	18	0.9	9
	2009	2.5	16	3.8	11	1.1	15	0.5	4
	2010	4.3	6	1.2	11	1.7	15	1.7	8
'Talon'	2008	0.5	9	0.4	5	1.8	20	1.1	7
	2009	2.7	13	4.5	10	1.0	19	1.7	7
	2010	3.1	9	1.2	9	1.7	18	1.6	3
Mean	2008	0.6	9.2	0.6	5.3	1.9	17.8	1.0	9.8
	2009	2.5	15.6	3.4	12.2	1.0	16.5	1.4	5.4
	2010	3.9	6.5	1.2	10.4	1.7	16.8	1.9	6.8

1. Planting-beginning of flowering, 2. Beginning of flowering-beginning of fruits setting, 3. Beginning of fruits setting-beginning of ripening, 4. Beginning of ripening-harvest

Tab. 3. The length of succeeding developmental stages (days)

Cultivar	Year	Developmental stage				Vegatation period**
		1*	2	3	4	
'Sokal F_1'	2008	25	10	42	39	116
	2009	21	14	35	22	92
	2010	15	24	42	12	93
'Batory F_1'	2008	25	17	31	38	111
	2009	22	13	46	15	96
	2010	12	19	40	11	82
'Rejtan F_1'	2008	25	17	35	34	111
	2009	26	24	39	7	96
	2010	14	24	46	8	92
'Hetman'	2008	27	15	35	10	87
	2009	28	22	39	12	101
	2010	19	20	42	12	93
'Lubań'	2008	25	17	31	43	116
	2009	31	19	33	15	98
	2010	14	23	35	10	82
'Babinicz'	2008	24	9	23	40	96
	2009	18	22	43	12	95
	2010	14	20	31	17	64
'Awizo F_1'	2008	25	17	34	19	95
	2009	26	20	41	10	79
	2010	13	25	41	10	89
'Mieszko F_1'	2008	26	16	35	39	116
	2009	21	19	41	12	93
	2010	15	24	43	11	93
'III A F_1'	2008	24	9	37	46	116
	2009	22	24	40	15	101
	2010	14	23	30	15	82
'Ondraszek'	2008	25	8	37	26	96
	2009	24	22	40	11	97
	2010	13	24	30	15	82
'Hubal'	2008	27	15	35	34	111
	2009	23	17	34	13	87
	2010	14	24	40	15	93
'Talon'	2008	25	10	41	19	95
	2009	21	14	46	14	95
	2010	20	20	38	11	89

* See Tab. 2, **vegetation period was calculated from sowing date

dry and optimal. Index lower than 1.0 means deficiency of precipitation. Podleśny (2009) pays attention, that in our climate, influence of the water factor on the yield of plants is larger than thermal factor. He regards that the deliberations about the influence of weather conditions on crop plants yielding should be based mainly on analysis of the distribution of precipitation and the rate of Sielianinow's hydrothermal index. The value of climatic indicators included in Tab. 2 showed, that in 2008 in stage 1 and 2 (planting until beginning of flowering and beginning of flowering until beginning of fruits setting) very dry conditions were appeared. As a result of it the irrigation of plants were done. During stage 3 (beginning of fruits setting till beginning of ripening) relatively humid, and stage 4 (beginning of ripening till harvest) relatively dry conditions were observed. In the 2009 year two first stage were characterized by excessively high humidity (very humid and extremely humid), however stage 3 and 4 occurred relatively dry and dry 2010 year was characterized by extremely humid stage 1, relatively dry stage 2 and relatively humid stage 3 and 4.

The length of vegetative period was strongly diversified in years of investigation(Tab. 3) . The examined cultivars needed 13-28 days on average to the appearance of the first flowers. The second stage (from the beginning of flowering till beginning of fruits setting) lasted from 8 up to 25 days. The third stage was the longest. Fruits needed from 23 up to 46 days for ripening. The fourth stage was the most diversified for each cultivars. It was possible to harvest 'Rejtan' cultivar in 2009 already after 7 days from the beginning of ripening, and the 'III AF$_1$' line needed as many as 46 days in 2008 for achieving the full maturity. A course of the weather affected the duration of individual developmental stages (Tab. 1 to 3). These results are confirmed by Podleśny (2009) research, who noticed that length of developmental stages of the faba bean depended mainly on an amount and a distribution of precipitation.

Marketable yield of examined cultivars (average for three years) varied from 0.81 kg at the 'Hetman' to 3.88 kg at the 'Ondraszek'. Obtained yield was adequate to those received by Kacjan Maršic *et al*. (2005) in Slovenia. Authors examined the influence of various climatic condition on fruit yield and quality of 10 determine tomato cultivars.

The dependence of total and marketable yield (Tab. 4 and 5) and the course of weather parameters during vegetation clearly showed, that cultivar was the crucial determining yielding factor. The studies of Rożek *et al*. (2011) showed that in spite of significantly higher yield observed in the year 2009 compared to yield in 2010, cultivar was the factor determining yielding level. Every year 'Dyno F$_1$' was the highest-yielding cultivar, whereas 'Benito F$_1$' was the lowest one. Todorov and Pevicharova (2003) reported that hybrid tomato cultivars showed higher variation of fruit yield, good adaptability, high yield potential and good quality compared to common cultivars. In our investigation such relations weren't being observed.

Depending on hydrothermal conditions during succeeding developmental stages yield of tomato cultivar varied (Tab. 1 to 5). Comparing the course of the weather in individual developmental stages it was noticed, that for the best cropping 'Ondraszek' cultivar (the highest marketable yield) the course of hydrothermal conditions was a little bit more beneficial than in case of the 'Hetman', which had the lowest marketable yield. At the Hetman cultivar the third stage, in which fruits developed, lasted 35-42 days, in which 15-20 days with precipitation. At the best cropping 'Ondraszek' cultivar this stage extended to 30-40 days in which 13-18 days with precipitation. Hydrothermal conditions in case of both cultivars in investigated years were similar, appropriately from 0.8 to 2.0. It means that 'Ondraszek' cultivar reacts better to high and frequent precipitations. In the first developmental stage precipitation impacted the total and marketable yield, that means that more frequent precipitation and low were more favorable at this stage.

It was proved by calculated correlation coefficients (0.63 and 0.60) and the value of F - statistic (7.12, 6.13), (Tab. 6 and 7).

Confirmation of the differential impact of the weather conditions, in the different stages, multiple regression equations were obtained. There were selected only these factors which had a statistically significant influence on the amount of total and marketable yield (Tab. 6 and 7). These equations show the quantitative effect of thermal and precipitation on crop yields.

In the second developmental stage (beginning of flowering - beginning of fruits setting), it turned out that the water needs were the most significant to tomato cultivar. The regression equation also confirmed the sum precipitation were statistically significant impact on total yield. The calculated value of correlation coefficients and F - statistics were smaller than in the other stages, but they were still significant (R= 0.52, a F= 3.97). It can be stated that the weather factor was less significant impact on total yield than in the other stages and it was not important to amount of marketable yield.

In the third developmental stage (beginning of fruits setting) all meteorological factors were considered statistically significant effect on total and marketable yield. According to the obtained regression equation the number of days with precipitation had the most positive impact to yield.

Tab. 4. Total yield (kg per plant)

Cultivar	2008	2009	2010
'Sokal F$_1$'	6.02 a-d	6.37 a-d	3.34 ab
'Batory F$_1$'	5.97 a-d	6.77 a- d	5.73 a-d
'Rejtan F$_1$'	7.66 b-d	9.43 cd	5.69 a-d
'Hetman'	4.99 a-c	5.77 a-d	1.94 a
'Lubań'	5.54 a-d	7.09 b-d	6.24 a-d
'Babinicz'	3.94 ab	5.73 a-d	3.74 ab
'Awizo F$_1$'	5.86 a-d	6.44 a-d	6.97 b-d
'Mieszko F$_1$'	6.19 a-d	4.95 a-c	4.74 a-c
'III A F$_1$'	5.58 a-d	7.87 b-d	4.36 ab
'Ondraszek'	7.74 b-d	10.22 d	4.71 a-c
'Hubal'	4.75 a-c	4.01ab	3.19 ab
'Talon'	4.66 a-c	6.90 a-d	4.27 ab
Mean	5.74 b	6.80 b	4.58 a

Note: Values in the same column followed by different letters are significantly different (LSD test, p<0.05)

Tab. 5. Marketable yield (kg per plant)

Cultivar	2008	2009	2010
'Sokal F$_1$'	3.12 h-k	3.86 j-k	0.63 abc
'Batory F$_1$'	2.76 e-j	3.01 g-j	2.11 a-j
'Rejtan F$_1$'	3.43 i-k	2.94 f-j	0.79 a-d
'Hetman'	1.05 a-f	0.73 a-d	0.33 a
'Lubań'	2.87 e-j	2.40 c-j	1.34 a-h
'Babinicz'	1.43 a-h	2.16 a-j	1.51 a-h
'Awizo F$_1$'	2.86 e-j	2.58 d-j	1.29 a-h
'Mieszko F$_1$'	2.32 b-j	2.11 a-j	1.00 a-e
'III A F$_1$'	2.72 e-j	1.01 a-e	1.17 a-g
'Ondraszek'	4.79 k	4.83 k	1.34 a-h
'Hubal'	1.50 a-h	1.57 a-i	0.44 ab
'Talon'	2.28 b-j	3.55 jk	1.55 a-i
Mean	2.59 b	2.56 b	1.13 a

Note: Values in the same column followed by different letters are significantly different (LSD test, p<0.05)

Tab. 6. Total yield dependence on meteorological factors

Stage	Regration equation	R^2	R	F	p	Est. err.
1*	$y_o = 6.72 - 0.03\,P + 0.32\,L$	0.40	0.63	7.12	0.0008	1.40
2	$y_o = 6.34 + 0.05\,P$	0.27	0.52	3.97	0.016	1.55
3	$y_o = 7.11 - 0.01\,\Sigma t - 0.04\,P + 0.45\,L$	0.40	0.63	7.12	0.0008	1.40
4	$y_o = 6.97 + 0.01\,\Sigma t$	0.20	0.45	2.75	0.058	1.62
1÷4	$y_o = 4.02 - 0.02\,P + 0.23\,L$	0.34	0.58	5.47	0.0038	1.48

Stage: see Tab. 2, y_o - total yield, P - sum of precipitation, Σt - sum of mean daily air temperature, L - number of days with precipitation, R - correlation, F - Fisher value, p - probability

Tab. 7. Marketable yield dependence on meteorological factors

Stage	Regration equation	R^2	R	F	p	Est. err.
1*	$y_h = 3.10 - 0.02\,P + 0.15\,L$	0.36	0.60	6.13	0.002	0.96
2	Not significant impact of the weather on marketable yield					
3	$y_h = 3.53 - 0.63\,\Sigma t - 0.58\,P + 0.77\,L$	0.38	0.61	6.47	0.0015	0.94
4	$y_h = 2.20 + 0.72\,\Sigma t$	0.22	0.47	3.04	0.045	1.05
1÷4	$y_h = 5.39 - 0.67\,P + 0.40\,L$	0.38	0.62	6.64	0.0013	0.94

See Tab. 2 and 6, y_h - marketable yield

The negative signs of the sums of precipitation and temperature indicate that too high temperatures and high precipitation have affected the total and marketable yield in the studied years (R=0.63; 0.61 and F-statistic=7.12; 6.47).

In the last stage - fruit ripening and harvest, the regression analysis showed that only the thermal conditions determined the amount of the total and marketable yield. It seems that the thermal conditions influenced on the marketable yield more than the total yield (R=0.45; 0.47 and F- statistic=2.75; 3.04).

Taking into account the growing seasons in 2008-2010 the amount of yield was inversely proportional to the sum of precipitation, and directly proportional to the number of days with precipitation. It means that tomato reacted positively on frequent but low precipitation.

Conclusions

A different sensitivity of examined tomato cultivars to the course of weather conditions was stated. 'Ondraszek' cultivar gets the highest marketable yield in all years of investigation what indicate that it is the most adaptated to variable weather conditions and cultivars 'Hetman', 'Hubal' and 'Babinicz' were least adaptated and yielded the lowest. Analysis of the influence of weather condition on total and marketable yield of twelve determine tomato cultivars showed that the sum and distribution of precipitation were decisive. High precipitations decreased total and marketable yield, whereas frequent and lower influenced favorable. Since from the third stage, i.e. the beginning of fruits setting to the beginning of ripening a larger impact of meteorological factors on marketable than total yield had been observed. In the fruits ripening stage a beneficial effect on marketable yield of only a sum of temperatures was stated.

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