THE IMPACT OF DRY, WET AND HEAT EPISODES ON THE PRODUCTION OF VEGETABLE CROPS IN POLABÍ (RIVER BASIN)*

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This work evaluated the impact of meteorological extremes' variability on the growing of vegetables in the Labe river basin (Polabí), one of the Czech Republic's traditional vegetable growing regions. We analysed data for the majority of market vegetable crops presently cultivated in Polabí and their relationships with dry, wet and heat episodes. A higher number of tropical days caused reduced yield for the majority of vegetable crops, and the negative effect was especially significant for onion (r = –0.69), pea (r = –0.44), cabbage (r = –0.31), cauliflower (r = –0.32) and Savoy cabbage (r = –0.32). We found negative correlations between longer heatwaves and yields of pea and onion (r = –0.50), cauliflower (r = –0.42), carrot (r = –0.30) and celeriac (r = –0.40). Long-lasting extreme rainfall caused lower yields of garlic (r = –0.36), cucumbers (r = –0.30), and carrots (r = –0.44). Longer dry spells, meanwhile, caused lower yields in the majority of root vegetables (from r = –0.21 to r = –0.32). Nearly all vegetable crops (root, bulb and leaf vegetables) are sensitive to dry and wet spells during two periods: after sowing (planting) and the last 3 weeks before harvest. Important for fruit vegetables is that a wet period during June causes their yields to decrease. A tendency toward increased frequency of dry and heat episodes in Polabí is leading to decreased yields and increased yield variability. That, in turn, means rising costs for vegetable growing and economic losses for farmers.

meteorological extreme; vegetables crops; tropical days; heat wave; drought; wet episodes

INTRODUCTION

The largest global exporters of fresh vegetables are Spain and the Netherlands, followed by China. The main export commodities for all three countries are tomatoes, onions and root vegetables. Another prominent global exporter of fresh vegetables is Mexico, which exports mainly tomatoes, peppers and asparagus. France, Belgium and Italy are oriented primarily to exporting *Brassica* vegetables. Until 2005, Poland, whose main export commodities are tomatoes, mushrooms, peppers, spinach and the like, also had hold a prominent position in export (Vegetables, 2006). Some 150 kinds of vegetables are currently grown in Europe (Vogel, 1996; Rubatzky, Yamaguchi, 1999; Zohary, Hopf, 2000; Krug et al., 2002). Around 50 types are grown in the Czech Republic, of which approximately 30 are sold on the market. In the 19th century, on the territory of what is now the Czech Republic, only a small number of significant types of market vegetables were cultivated (cabbage, Savoy cabbage, kohlrabi, carrots, parsley, celeriac, onions). Some types of vegetables spread only in the second half of the 19th century (cucumber, cauliflower) (Bartoš et al., 2000). The cultivation of new types of vegetables was not established until the 20th century (tomatoes, peppers, Chinese cabbage, broccoli, courgette, iceberg lettuce). At present, certain types of vegetables are lucrative and the areas devoted to their cultivation predominate, while others are loss-making and the extent of their land area is being reduced. In the Czech Republic, *Brassica* vegetables (red cabbage, white-headed cabbage, Savoy cabbage, cauliflower and Chinese cabbage) are traditionally grown, though their land area has decreased by 3.2% annually over the last 2 years (Vegetables, 2007). According to data from the Czech Statistical Office, a historic low was reached in 2005 (year-on-year drop of 15%). After an unfavourable 2004, due to a general overproduction of vegetables, a high level of imports at low prices, and a sharp drop in vegetable prices, producers limited the extent of their cultivation in 2005 (Vegetables, 2006). In addition to market factors, extreme meteorological events also had a great impact. There occurred an uneven distribution of rainfall, and hot and dry months alternated with cold and damp months. A long and extreme winter period with abundant snow cover occurred in the second

*Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. MSM6046070901.

half of March. Abrupt thawing in combination with heavy rainfall led to a delay in the first sowings and plantings of vegetables. In some vegetable growing areas, late spring ground frosts caused considerable damage to the vegetation, and especially to early types of vegetables, and delayed the start of harvesting. In July, crops suffered tropic temperatures and extreme drought, while in August there came a rainy period that in turn caused roots to rot (Potop et al., 2010b). Drought is the greatest danger for farmers cultivating field crops. In extreme cases, the effects of drought can lead to serious damage to vegetation and to losses in crop yields. The greatest numbers of dry episodes in the Czech Republic appear in Žatecko (a dry area around the Krušné Hory Mts.), the Polabí Lowlands (encompassing the districts of Mělník, Nymburk, Kolín), and the South Moravian region. The number of dry episodes rises significantly with decreasing altitude (Tolasz et al., 2007). In the Czech Republic, field vegetables are predominantly grown in areas around the lowland basins of such rivers as the Elbe, Vltava, Ohře, Morava, Dyje and Svratka which are agriculturally the most productive, but in terms of precipitation the most uneven and often afflicted by drought (Malý et al., 1998). The Polabí lowlands are often afflicted by drought and thus it can experience increased wind erosion and require a higher level of irrigation. This can lead to the accumulation of salts in the surface layer of the soil profile. Agricultural crops that find themselves relatively suddenly in soils with a 'dry' moisture regime will be more susceptible to diseases and pests (Kapler et al., 2004; Kocmánková et al., 2008). In connection with the more frequent occurrence of drought as a result of climatic change, economic losses are expected to increase considerably (Trnka et al., 2007; Možný et al., 2009; Potop et al., 2009, 2010; Potop, 2010). According to the Intergovernmental Panel on Climate Change (IPCC, 2007), the occurrence of extreme meteorological events, particularly in the growing seasons of agricultural crops (incidence of spring and autumn frosts, heatwaves, drought, extreme rainfall) has increased over the past 10 years. At present, the impact of extreme meteorological phenomena on the cultivation of market vegetables is little studied. This study is complicated because it combines, on the one hand, the rising frequency of extreme phenomena resulting from the global variability of climate and, on the other, production, financial and market factors resulting from economic globalization.

Production risk is influenced especially by variability in the occurrence of hazardous agro-meteorological phenomena, the identification of which requires analysis of long-term meteorological data. In this study, therefore, we have designed a methodology for evaluating the impact from the variability of meteorological extremes on the cultivation of vegetables in the Polabí region, one of the traditional vegetable growing regions in the Czech Republic.

MATERIALS AND METHODS

In this study, we analysed data for the majority of market vegetable crops (celeriac, carrots, root parsley, kohlrabi, Savoy cabbage, cauliflower, cabbage, cucumber, tomato, onion, garlic, peas) presently cultivated in the Central Bohemian region and their relationships with observed dry/wet spells and summer heat episodes. This methodology was applied on the Czech study area located in the Polabí (Elbeland Lowlands), where one of the largest farmed especially in growing marketing vegetable crops. The Polabí is the traditional name for a lowlands region located in the Central Bohemian region of the Czech Republic. This paper has related daily metadata recorded in a network of climatological stations of the Czech Hydrometeorological Institute with annual vegetable yields as reported by the Czech Statistical Office. Assessment of water and heat stress is based on the following meteorological characteristics: tropical days, longest period of rainfall, longest periods without precipitation, average rainfall period, average length of time without precipitation and sunshine duration. To identify the occurrence of a particular risk, it is necessary to analyse long-term time series (1961–2009) of daily temperatures, precipitation and sunshine in the Polabí lowland region.

In this work, the longest dry spell is considered to be the highest number of consecutive days registering a daily precipitation level less than or equal to 0.1 mm. The longest period of precipitation is defined as the highest number of consecutive days registering a daily precipitation level greater than 0.1 mm. Assessment of an extremely hot summer in the Polabí is based on heatwaves and tropical days. Tropical days are those with T_{max} reaching or exceeding 30.0°C. A heatwave is defined using the heatwave duration index (HWDI) as the maximum period greater than five consecutive days with maximum air temperature (T_{max}) > 5°C above the 1961–1990 daily T_{max} normal (IPCC, 2007). Sunshine duration (or just sunshine for short, *Ss*), is the interval between sunrise and sunset during which the solar disc is not covered by clouds (Tolasz et al., 2007). *Ss* is a reliable agrometeorological parameter that also indicates the incidence of cloud at a given location. *Ss* duration depends on both length of day and incidence of cloud cover and fog.

More detailed analysis was made of the average vegetable yields (t/ha) and planted areas (ha) derived from all districts in the Central Bohemian region. Impacts of extreme weather events on the production of vegetables were determined using detrended yields and their residuals:

Table 1. Overview on the length of growing period of vegetable crops and their risk of drought by Petříková et al., 2006; Malý et al., 1998

Type of vegetables		Growth periode (days)	Planting or sowing period (month)	Harvest period (month)	Risk period	Drought tolerance
Root vegetables						
Apium graveolens L. var. *rapaceum*	celeriac	150–180 (P–H)	April	Sep–Oct	seed germination, root enlargement	L
Daucus carota L. ssp. *sativus*	carrots late	150–170 (S–H)	April – ½ May	Sept–Oct		M–H
Petroselinum crispum Mill. convar. *radicosum*	coot parsley	170–200 (S–H)	March	Sep–Oct		M–H
Brassicas vegetables						
Brassica oleracea L. convar. *acephala* var. *gongylodes*	kohlrabi early	75–80 (P–H)	½ March – ½ April	End of May – Jun	head development	L
Brassica oleracea L. convar. *capitata* var. *sabauda*	savoy cabbage summer	100–120 (P–H)	½ April – ½ May	Aug–Sep		M
Brassica oleracea L. convar. *botrytis* var. *botrytis*	cauliflower late	85–100 (P–H)	½ May – Jun	Sep–Oct		L
Brassica oleracea L. convar. *capitata* var. *capitata*	cabbage late	120–160 (P–H)	May – Jun	Sep–Oct		M
Fruit vegetables						
Cucumis sativus L.	cucumbers for pickling	80–130 (S–H)	End of April – 1/2May	Jul–Sep	early flowering, enlargement	L
Lycopersicon lycopersicum L.	tomato indeterminate	150 (P–H)	1/2May	Jul–Sep		L
Bulb vegetables						
Allium cepa L.	onion	120–130 (S–H)	March – beginning of August	Aug	bulb enlargement	L
Alium sativum L.	spring garlic	120–150 (S–H)	cloves March	Aug		L
Legumes vegetables						
Pisum sativum L. convar. *medullare* ALEF.	peas	68–90 (S–H)	March	May–Jun	seed enlargement flowering	M

Drought tolerance: L – low, needs frequent irrigation; M – moderate, needs irrigation in most years; H – high, seldom needs irrigation.

[a]Growing periods are distinguished as being the time from sowing until harvest (S–H) or the time from planting until harvest (P–H)

$$Y_i = Z_i/S_z \quad (1)$$

where Y_i – a vegetable's yield residual, Z_i – the detrended yield, and S_z – the standard deviation of the detrended yield;

and

$$Z_i = Y_i - [a + b\,(i - 1989)] \quad (2)$$

where Y_i – the yield for year i, a – the intercept of the trend line, b – the slope, and 1989 – the origin of the x-axis.

Detrending yield data is important because historical crop yield data integrates a number of factors in addition to adverse weather, including economic cycles and technological advances. A positive residual indicates a better crop year compared to the average expected yield for that year since the actual yield is higher than the trend line. On the other hand, negative residuals indicate below average crop years. The effect of extreme weather events was quantified by linear regression analysis. The periods of crop growth when an adequate supply of water is critical for high-quality vegetable production are shown in Table 1, where we have also classified vegetables for drought tolerance.

Table 2. Risk level of combination type of extreme weather events during growing period of vegetable crops

Year	TD (day)	Duration of heat waves (day)	CWD (day)	The longest wet spell (start day–end day)	CDD (day)	The longest dry spell (start day–end day)	W	N	D
1989	7	5	0	0	8	22 May–29 May	0	5	1
1990	14	7	5	23 Apr–27 Apr	26	11 Jul–5 Aug	2	2	2
1991	7	6	9	1 Apr–9 Apr	17	25 Aug–10 Sep	1	4	1
1992	22	7	0	0	21	12 May–1 June	0	4	2
1993	9	0	7	30 Aug–8 Sep	16	16 Aug–26 Aug	1	2	3
1994	30	17	6	23 May–29 May	18	20 Jul–6 Aug	0	3	3
1995	20	11	0	0	12	2 Aug–13 Aug	2	2	2
1996	6	7	0	0	10	14 Apr–23 Apr	4	2	0
1997	16	9	7	15 Jul–21 Jul	9	19 Aug–27 Aug	3	2	1
1998	11	7	7	11 Sep–17 Sep	31	25 Apr–25 May	1	5	0
1999	6	0	5	28 Aug–2Sep	17	21 Jul–6 Aug	0	6	0
2000	17	9	6	25 Mar–30 Mar	17	1 May–17 May	1	3	2
2001	11	6	5	22 Mar–26 Mar	8	19 May–26 May	3	3	0
2002	17	13	5	25 May–29 May	9	5 Apr–13 Apr	1	3	2
2003	29	11	0	0	9	3 Aug – 11 Aug	0	3	3
2004	9	0	5	20 Sep–24 Sep	10	2 Aug–11 Aug	1	4	1
2005	6	0	0	0	23	23 Aug–14 Sep	1	5	0
2006	27	14	7	1 Aug–8 Aug	8	8 Jun–15 Jun	1	3	2
2007	17	7	5	5 May–9 May	13	4 Apr–16 Apr	1	2	3
2008	15	6	7	17 May–23 May	8	24 Aug–31 Aug	0	4	2
2009	10	0	8	23 Jun–30 Jun	17	31 Mar–16 Apr	1	2	3

TD – number of tropical days; CWD – consecutive wet days; CDD – consecutive dry days; W – number of wet months; N – number of normal months and D – number of drought months

RESULTS AND DISCUSSION

Assessing risk of wet, dry and heat episodes during 1961–2009 growing seasons

Considering vegetables' high demand for distribution of precipitation during vegetation, atmospheric precipitation in the Polabí region is a limiting factor in the production of vegetables. Table 2 presents an assessment of the risk of dry and wet episodes to occur during the growing period of field vegetables over the period 1961–2009. Analysing the occurrence of drought in the Polabí region showed that during the growing period in the years 1961–2009 extreme drought was detected during 5 years in April (2009, 2007, 2000, 1993 and 1961), 3 years in May (2002, 1988 and 1992), 1 year in June (2003), 4 years in July (1994, 2006, 1995, 1983), 5 years in August (1992, 2003, 2009, 1990 and 2000) and 4 years in September (1982, 1975, 2006, 2009). These findings indicate that the driest month for the entire studied period was July 1994, followed by August 1992, April 2007, June 2003 and September 1982. The most extreme wet months for the entire reference period were recorded to be the following: April 1997, May 1965, June 1974, July 1981, August 1977 and September 2001.

The majority of vegetable species respond to drought by reducing their quality and yields or even by total production loss, often even in case of only a brief drought. If a dry period occurs during vegetables' initial development stages, ripening for market is often delayed and yield reduced. If drought develops at the end of the growing period, it is predominantly the vegetables' quality for market that is often reduced (Kee et al., 1992). Protraction of periods without precipitation or their increased frequency significantly affects the costs of producing market vegetables. In the Polabí region, the longest dry spell during vegetables' growing period varied between 8 and 31 days (Table 3). In the growing period of *Brassicas*, more frequent occurrence of dry periods has a damaging effect especially during the planting and formation of the stem bulb in kohlrabi, setting of the flower in cauliflower, and head formation in cabbage. The average duration is 12 days, with a maximum of 30 days (Table 3). It is precisely at this time that greater and evenly distributed moisture is required in the soil.

Table 3. Assessment of the frequence of wet and dry episodes during the growing period of field vegetables from 1961 to 2009

	The longest CWD (day)	The longest CDD (day)	The average length of CWD (day)	The average length of CDD (day)	Number of dry spells	Number of wet spells
Root vegetables						
Sowing/planting	8	21	6	9	14	13
Risk period	13	19	7	9	20	6
Harvest	19	30	7	10	19	10
Brassicas vegetables						
Sowing/planting	14	31	6	9	14	13
Risk period	19	30	7	12	17	17
Harvest, early (late)	14 (15)	22 (29)	6 (7)	9 (10)	15 (17)	12 (10)
Fruit vegetables						
Sowing/planting	14	22	7	9	15	14
Risk period	19	30	7	12	17	17
Harvest	19	30	7	10	19	9
Bulb vegetables						
Sowing/planting	19	19	7	10	18	14
Risk period	19	30	7	12	17	17
Harvest	19	30	7	10	19	9
Seed vegetables						
Sowing/planting	19	22	6	10	12	13
Risk period	13	13	7	8	12	11
Harvest	19	30	7	10	11	11

CDD – consecutive dry days; CWD – consecutive wet days

During sowing and planting, root and bulb vegetables are less affected by even the longest dry spell. Fruit vegetables are exposed to the risk of impact from a longer dry spell during flowering and formation of the first fruit.

Although the majority of vegetable species require sufficient moisture, excessive moisture can in some cases be unfavourable, and especially because under such conditions a plant's roots suffer from a deficiency of essential atmospheric oxygen. For certain vegetable species, extreme fluctuation in moisture levels is damaging as it causes heads (cabbage and Savoy cabbage), roots (particularly of carrots) and fruits (mainly tomatoes) to crack or split open. The average length of wet spells during the growing period of vegetables is 5–6 days, with the longest being 19 days. The maximum wet spell duration falls during the sowing of bulb vegetables and legumes (Table 3). In reality, this precipitation period concurs with the requirements of bulb vegetables as they demand greater moisture at the start of the growing period. Later, irrigation is used only in the case of an extended drought.

If a longer period of insufficient sunshine is followed by intense sunshine, even thermophilic vegetable species, such as, peppers and tomatoes, may become damaged (Adams, Valdés, 2002). In some years, cooking onions experience sunstroke when the bulbs are left lying exposed in the field after being removed from the soil and thus become damaged (e.g., in August 2003). Sunshine combined with exposure of the external succulent layers causes the bulbs to turn green. Similarly, carrot roots may turn green when the tops of the roots are exposed to sunlight. During cold weather, however, not chlorophyll but anthocyanins are produced in the sunlit parts and they thus turn a purplish colour (Petříková et al., 2006). An extraordinary and longer than average duration of sunshine was observed in April 2007 and 2009. On average, 288 hours of sunlight, i.e. 166% of the normal amount (up to twice the norm for April), was recorded. During April 2007 and 2009, considering the prolonged period of sunshine, the longest dry spell occurred (19–25 days). The longest periods of sunshine were recorded in June 2006 and August 2003 (155% of the normal amount). The shortest periods, on the other hand, occurred in July 2000 (54% of the norm) and June 1980 (80% of the norm). Periods of enduring sunshine had the opposite effect compared to total precipitation, which indicates that the duration of sunshine gets longer as the number of days with precipitation becomes less. Moreover, the longest periods of sunshine were accompanied by incidence of tropical temperatures. In agreement with the regression model, we can state that sunshine has a positive effect on yields of root parsley ($r = 0.44$) and onion ($r = 0.30$) (Table 4). Heat episodes such as tropical

Table 4. Relationships between weather events and yield residuals for vegetable crops

Type of vegetables crops	Tropical days (Tmax ≥ 30ºC)		Duration of heat waves (day)		Maximum consecutive wet (day)		Sunshine duration (h)		Maximum consecutive dry (day)	
	r	R2 (%)	r	R2 (%)	r	R2 (%)	r	R2 (%)	r	R2 (%)
Garlic	–0.17	3	0.16	3	–0.36*	13	0.22	5	0.10	0
Pea	–0.44*	19	–0.50*	25	0.22	5	0.19	3	0.10	7
Onion	–0.69*	48	–0.50*	26	0.00	0	0.34*	20	–0.17	3
Cucumbers	0.10	6	0.11	1	–0.30*	20	0	0	–0.19	15
Cabbage	–0.31*	20	–0.16	2	–0.32	10	0.26	7	–0.17	3
Cauliflower	–0.32*	19	–0.42*	18	–0.16	3	0.24	6	–0.22	5
Savoy cabbage	–0.32*	21	–0.28	8	–0.25	6	0	0	–0.15	2
Kohlrabi	0.25	6	0.01	72	–0.18	3	0.30	10	–0.18	3
Root parsley	0.22	5	0.14	2	–0.10	1	0.44*	20	–0.21*	15
Carrots	–0.25	6	–0.30*	10	–0.44*	20	–0.27*	14	–0.29*	12
Celeriac	–0.22	5	–0.40*	16	–0.10	1	0	0	–0.32*	25

Tmax – maximum air temperature; *P ≤ 0.05; P ≥ 0.05; 0 indicates no relationship between variables

days (r = –0.69) and duration of heatwaves (r = –0.50) showed the greatest significance (48% and 26%) in reducing onion yield (Table 4).

Regional yields variability and extreme weather events

The trends in average annual yields of vegetable crops during the evaluated period of 20 years (1989–2009) are included in Table 5. The greater anomaly from the detrended yields was attributed primarily to the variability in hazardous meteorological phenomena and was distinguished from lower anomalies (attributed to changes in technologies and management). Production decreases and increases determined under these conditions were observed in an analysis of the long term development in vegetables production in Central Bohemia. As is apparent from Table 5, both garlic (by 2.5 t/ha, with an initial trend value of 5.7 t/ha and a final trend value of 3.2 t/ha) and cauliflower (by 2.2 t/ha) showed sharp drops in yield. A slight decrease over the past 20 years was observed in tomatoes (1.6 t/ha) and root parsley (1.2 t/ha). The highest growth trend, on the other hand, was registered in root vegetables, especially carrots (18.3 t/ha), followed by *Brassica* vegetables such as cabbage (15 t/ha) and by fruit vegetables such as cucumbers (11 t/ha). Such vegetable species as kohlrabi, Savoy cabbage, peas and onion maintained stable yield trends. It seems that this stabilisation was found in the vegetables with lower percentage values of yield variability (Cv), i.e. in vegetables for which yields were already more stable than others (Table 5). The largest decreases in yields of bulb vegetables were recorded in years with extraordinarily warm and dry

Table 5. Dynamic model and tendency of change in vegetable yields in Central Bohemian region

Type of vegetables	b-slope	P-value	R2	Average yield (t/ha)	Y1 (t/ha)	Y2 (t/ha)	Cv (%)	Planting area S1 (ha)	Planting area S2 (ha)
Celeriac	0.383	0.01	0.31	19.8	16.2	23.4	20	233	172
Carrots	0.961	0.01	0.73	23.5	14.3	32.6	29	1247	242
Root parsley	–0.063	0.05	0.45	11.3	11.9	10.7	14	161	132
Kohlrabi	0.833	0.01	0.38	16.4	16.3	16.5	19	238	110
Savoy cabbage	0.157	0.05	0.46	18.1	16.6	19.6	16	165	59
Cauliflower	–0.117	0.05	0.35	14.8	15.9	13.7	11	557	121
Cabbage	0.791	0.02	0.52	35.8	28.3	43.3	18	487	249
Cucumbers	0.626	0.03	0.51	11.4	5.4	17.3	45	462	20
Tomato	–0.084	0.05	0.55	15.2	16.0	14.4	30	131	2
Onion	0.192	0.04	0.32	16.6	17.7	18.3	19	1953	942
Garlic	–0.134	0.05	0.54	4.5	5.7	3.2	22	149	10
Pea	0.049	0.05	0.39	4.2	3.8	4.7	24	430	130

Y1 – is a yield of starting period of trend; Y2 – ending period of trend, Cv – coefficient of variation is calculated from the average and standard deviation of yield, S1 – is starting period of planting area by linear trend, S2 – ending period of trend

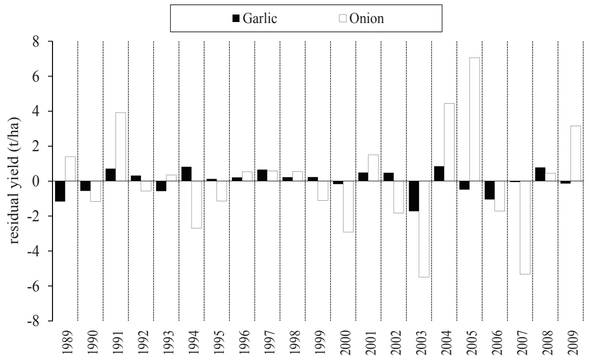

Fig. 1. Bulb vegetables: departures of annual yield calculated for individual crops

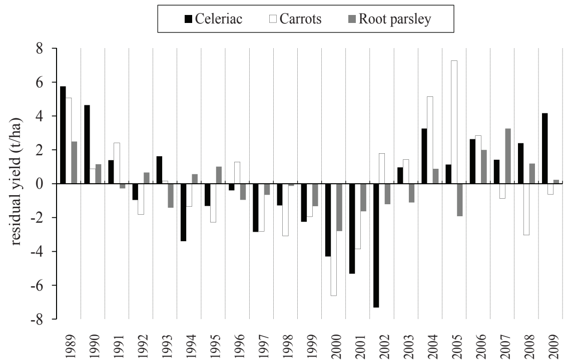

Fig. 2. Root vegetables: departures of annual yield calculated for individual crops

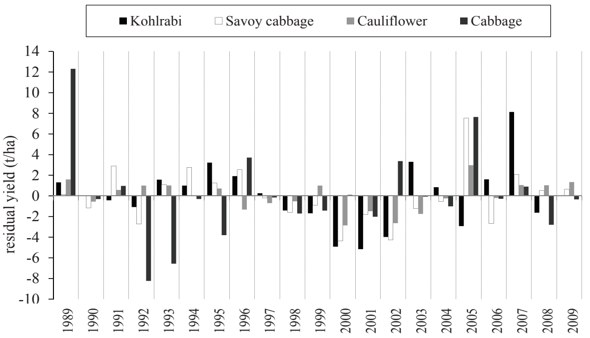

Fig. 3. Leaf vegetables: departures of annual yield calculated for individual crops

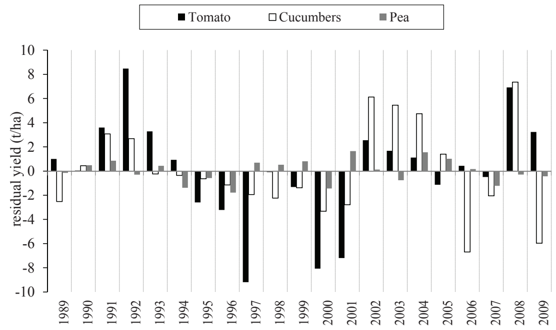

Fig. 4. Fruit and legume vegetables: departures of annual yield calculated for individual crops

summers, such as 1994 (–2.7 t/ha), 2003 (–5.5 t/ha) and 2007 (–5.3 t/ha) (Fig. 1). Root vegetables showed the highest negative variance in yield in the years 2000 (–6.6 t/ha – carrots) and 2002 (–7.3 t/ha – celeriac) (Fig. 2). During the growing period in 2000, two extreme dry episodes occurred (in May and August), while September exhibited extreme rainfall (Table 2). In 2002, extremely dry months (April and August) were separated by an extremely wet July. Among *Brassica* vegetables, the largest negative change in the detrended yield was –8.2 t/ha (cabbage) in 1992 (Fig. 3). In that year there occurred two extraordinarily dry months (May and August). In terms of fruit vegetable yields, tomatoes recorded their greatest loss in 1997 (by –9.1 t/ha), while cucumbers recorded their highest losses in 2006 and 2009 (–6.7 t/ha and –6.0 t/ha, respectively) (Fig. 4). The greater proportion of decreases in fruit vegetable yields occurred in the years with extreme wet spells in June or August (e.g. 1997: 3 wet months, 2006: August – cold and wet, and 2009: June – wet).

Effect of extreme dry, wet and heat episodes on yield vegetable crops

We estimated correlations between the yields of particular vegetable crops and extreme weather events over 20 years (Table 4). The coefficient of determination (R^2) indicates to what extent the model as fitted explains how extreme weather events reduced yield of vegetable crops during the growing period, whereas the correlation coefficient (r) indicates negative or positive effects of extreme weather events on yield residuals of vegetable crops. A higher number of tropical days caused reduced yield for the majority of vegetable crops, and the negative effect was especially significant for onion (r = –0.69), pea (r = –0.44), cabbage (r = –0.31), cauliflower (r = –0.32) and Savoy cabbage (r = –0.32). We found negative correlations between longer heatwaves and yields of pea and onion (r = –0.50), cauliflower (r = –0.42), carrot (r = –0.30) and celeriac (r = –0.40). During dry and heat episodes there was also more sunshine. For example, during hot and dry August 2003 and July 2006, sunshine caused a lower yield of carrots (r = –0.27). Sunshine correlates positively only with the yields of onion (r = 0.34) and root parsley (r = 0.44). Long-lasting extreme rainfall caused lower yields of garlic (r = –0.36), cucumbers (r = –0.30), and carrots (r = –0.44). For example 1997's CWD was 7 days (in June) with the amount of rainfall reaching 94 mm. Longer dry spells, meanwhile, caused lower yields in the majority of root vegetables (from r = –0.21 to r = –0.31).

CONCLUSION

This study has for the first time analysed in detail the occurrences of extreme weather events and their effects on yields of vegetable crops during the growing season in the Polabí. We can conclude that the study of vegetable yields indicates relatively stable yields for *Brassica* vegetables. Fruit vegetables, on the other hand, recorded significant decline in planting area and productivity. The trend of increasing frequency of dry and heat episodes in the Polabí is leading to reduced yields and greater yield variability for vegetables. This results in rising costs for growing vegetables and economic losses for farmers. Detailed analysis of a total of 12 vegetables showed that the negative impacts of drought and heatwaves over the past 20 years were evident in the production of vegetables especially in the years 1992, 1994, 2000, 2003 and 2006. The majority of vegetables (root*,* *Brassica,* bulb) cultivated in the Polabí region are most sensitive to dry and wet conditions during two particular periods: after planting and the last 3 weeks before harvesting. For fruit vegetables, a wet spell occurring in June causes a reduction in yields.

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Received for publication on December 17, 2010
Accepted for publication on May 19, 2011

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Vliv suchých a vlhkých period a období veder na pěstování zeleniny v Polabí

Scientia Agric. Bohem., *42*, 2011, 93–101

Tato práce hodnotí vliv variability meteorologických extrémů na pěstování zeleniny v Polabí, které je jednou z tradičních zelinářských oblastí v České republice. Byla analyzována data pro většinu tržních zeleninových druhů, které jsou v současné době v Polabí pěstovány, a byl studován jejich vztah k extrémním událostem, týkajícím se sucha, srážek a tropických dnů. Vyšší počet tropických dnů způsobil snížení výnosu u většiny zeleninových druhů. Negativní účinek byl obzvláště významný pro cibuli (r = –0,69), hrách (r = –0,44), zelí (r = –0,31), květák (r = –0,32) a kapustu (r = –0,32). Byla nalezena negativní korelace mezi výnosy a delším obdobím vedra u hrachu a cibule (r = –0,50), květáku (r = –0,42), mrkve (r = –0,30) a celeru (r = –0,40). Dlouhotrvající srážkové období způsobilo nižší výnosy u česneku (r = –0,36), okurek (r = –0,30), a mrkve (r = –0,44). Nejdelší období sucha způsobilo nižší výnosy u většiny druhů kořenové zeleniny (od r = –0,21 až r = –0,32). Téměř všechny druhy zeleniny (kořenové, cibulové a listové) jsou citlivé na suché a vlhké periody ve dvou termínech během vegetace: po výsevu (výsadbě) a poslední 3 týdny před sklizní. Pro plodovou zeleninu je významné, že vlhké období v průběhu června způsobuje pokles výnosu. Častější výskyt suchých a horkých epizod v Polabí vede ke snížení výnosů a zvýšení výnosové variability, což zvyšuje náklady na pěstování zeleniny a vede k ekonomickým ztrátám.

meteorologické extrémy; polní zelenina; horké vlny; tropický dny; suché; vlhké období

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