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ASSESSMENT OF WATER DEFICIT AND OR SURPLUS DURING GROWING PERIOD OF VEGETABLE CROPS IN POLABÍ

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The paper deals assessment of water balance during growing period of vegetable crops in Polabí. The effect of surplus and/ or deficit of water depends on the kind of vegetable and its stage of development. Therefore, assessment of water stress for root vegetables (carrot and celeriac) and fruit vegetable (cucumber) is based on the crop coefficient, Penman evapotranspiration and rainfall during following stages: after emergence or after transplanting, ≥5 leaves for carrot (*Daucus carota* L.) and for celeriac ≥7 leaves (*Apium graveolens* L.), bulbous start to develop and 100% ground cover. For cucumber (*Cucumis sativus* L.*)* during developing flowers and start of harvest has been evaluated. This paper has connected daily metadata recorded in network weather stations from the Czech Hydrometeorological Institute and experimental data at the vegetable farm Hanka Mochov s.r.o. For roots vegetable species extreme fluctuation in moisture levels is damaging as it causes to split of taproot (mainly carrots). The maximum water surplus for cucumber during developing flowers for the entire reference period were recorded to be the following 1974, 1977, 1981, 2009 and 2010.

Key words: water balance, vegetable crops, crop coefficient, Penman evapotranspirace, Polabí

Introduction

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 (Zelenina, 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 (Zelenina, 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.

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. Polabí is the traditional name for a lowlands region located in the Central Bohemian region of the Czech Republic. 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 (Petříková et al., 2006).

Water is lost from a field as it evaporates from soil and plant surfaces (evaporation) and from inside plant leaves (transpiration). Together, evaporation (E) and transpiration (T) are called evapotranspiration (ET) (Droogers, Allen, 2002). Evapotranspiration can be measured or modeled by more or less complex techniques. Now, no universal method may be found. During the last fifty years, a large number of empirical methods have been developed and used to estimate evapotranspiration. All methods require local calibration and to have limited a global validity. However, it is clear that if we want to use a complex crop model to help growers in establishing the schedule and amount of their irrigation, we must make sure that the main equations of the water balance are adequate for the area and period of the year. On the one hand, direct crop evapotranspiration measurements methods are expensive and hard work demanding, and results only apply to exact conditions in which they were measured. Due to the fact that direct methods are impractical for permanent use on a large scale, therefore, in this study evapotranspiration theoretical is estimated.
The most known and used method to calculate crop evapotranspiration (ET_c) is the one based on the crop coefficient (K_c) and reference evapotranspiration (ET_c) approach (Allen et al., 1998). Therefore, as the K_c coefficient incorporates crop characteristics and averaged effects of evaporation from soil, while reference evapotranspiration is a measure of evaporative demand. The concept of K_c coefficient was introduced by Jensen (1968) and further developed by other researches (e.g., Allen et al., 1998). FAO and WMO experts have summarized such evolution in the "crop coefficient curve" to identify K_c value corresponding to the different crop development and growth stages (initial, middle and late). The crop coefficient values, in fact, were calculated only in the 10% of the countries of this fundamental agricultural area. Generally, information of the crop coefficient reported by FAO paper 56 is not available for the vegetable crops grown in the Czech Republic; at least for countries with have an appropriate crop management practices and climatic condition as in Czechia. Predominant information about K_c in European countries was tabulated for Mediterranean region. Consequently, for the Czech Republic determination of K_c curves for the major crops is needed.
The aim of this paper is to analyse water requirements during different development stages of vegetables by the BBCH scales based the crop evapotranspiration values (ET_c), which it was determined on the crop coefficient and of the reference evapotranspiration (ET_o) estimated through the FAO Penman Monteith method.

MATERIALS AND METHODS

This methodology was applied on the Czech study area located in Polabí (*Elbeland*) lowland, where one of the largest farmed especially in growing marketing vegetable crops. This paper has connected daily metadata recorded in network weather stations from the Czech Hydrometeorological Institute and experimental data was carried out over vegetable crops at the farm «Hanka Mochov s.r.o. ». The farm is located at Mochov village (φ=50º 08´ N, λ=14º 47´E, at 193 m ASL) in Central Bohemian Region, 28 km northeast of Prague (Fig. 1, 2a). The terrain model of crop plot is made by means of the Global Positioning System (GPS) and GIS approaches. (Fig. 2b). Kriging method is used for the interpolation elevation data collected in the field by GPS. It was selected an experimental plots and monitoring the meteorological parameters for fruit and root vegetables. The effects were monitored during vegetable growth period (April-October) with 10 minutes time intervals. The variables measured are air maximum and minimum temperature, soil temperature, air relative humidity and speed wind.

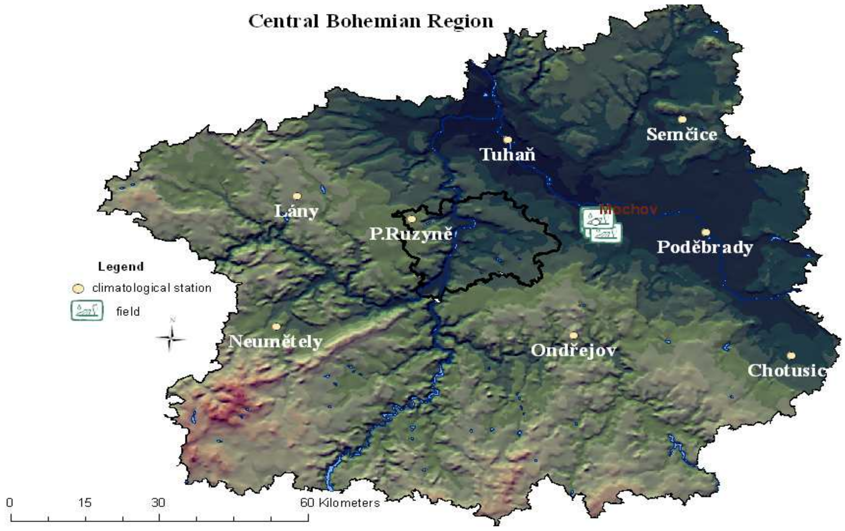
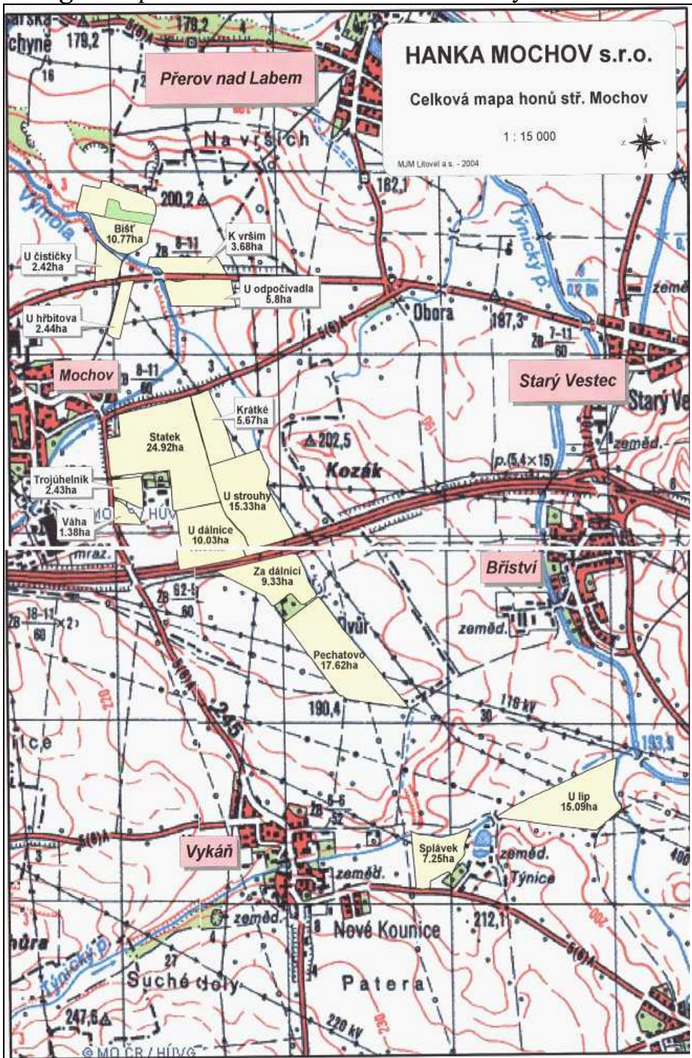


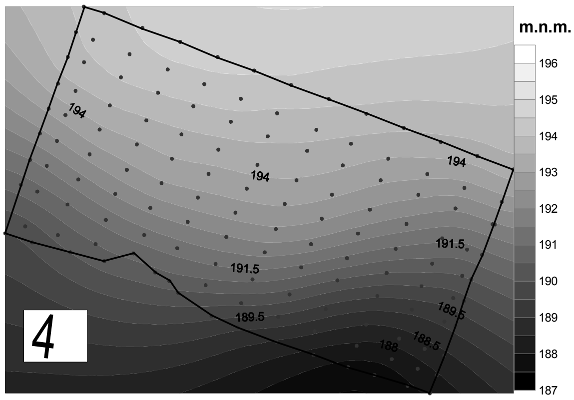
Fig.1 Map of weather stations surround study area located in Central Bohemian Region.



(a)

(b)

Size of field: 1.8ha and geographical position: φ=50.246 N, λ=14.606 E, h=192 m



Size of field: 3.2ha and geographical position: φ=50.146 N, λ=14.806 E, h=187 m

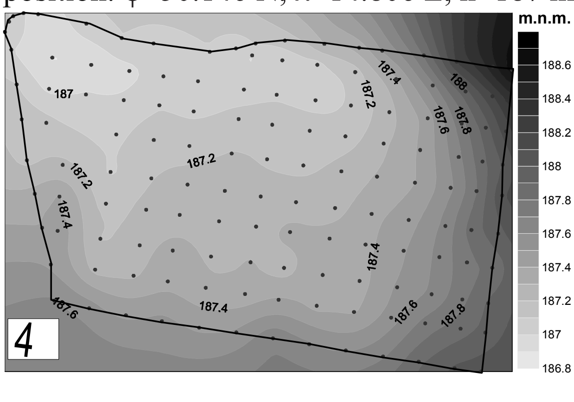


Fig. 2a-b Topographic map of location fields at the farm Hanka Mochov s.r.o. (a) and interpolation of the elevation data of selected field in the horizontal plane created by GIS (b).

The daily meteorological dataset records of 8 weather stations available for 50 years (1961-2010) are included: maximum air temperature, minimum air temperature, mean air temperature, amount of precipitation, amount of sunshine and speed wind.

Table 1a Overview on the crop coefficient (Kc) for selected the vegetables during stages of development by the BBCH scales (according to Meier, 2001).

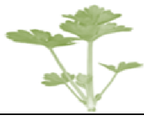
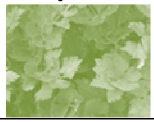
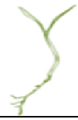
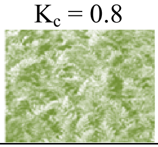
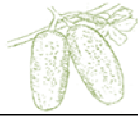
Type of vegetables		1st Stage	2nd Stage	3rd Stage	4th Stage
***Apium graveolens* L. var. rapaceum**	**Celeriac**	***after transplanting*** $K_c = 0.5$ 	***≥7 leaves*** $K_c = 0.8$ 	***bulb start to develop*** $K_c = 1.1$ 	***100 ground cover*** $K_c = 1.4$ 
***Daucus carota* L. ssp. sativus**	**Carrots**	***after emergence*** $K_c = 0.3$ 	***≥5 leaves*** $K_c = 0.6$ 	***100 ground cover*** $K_c = 0.8$ 	-
***Cucumis sativus* L.**	**Cucumbers**	***after emergence*** $K_c = 0.5$ 	***developing flowers*** $K_c = 0.8$ 	***start of harvest*** $K_c = 1.1$ 	-

Table 1b 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 period days	Planting or sowing period (month)	Harvest period (month)	Risk period	Drought tolerance
			Root vegetables			
***Apium graveolens* L. var. rapaceum**	**Celeriac**	140-150 (P-H)	April	Sep-Oct	Seed germination, root enlargement	L
***Daucus carota* L. ssp. sativus**	**Carrots**	100-170 (S-H)	April	Jul-Oct		M-H
			Fruit vegetables			
***Cucumis sativus* L.**	**Cucumbers**	80-130 (S-H)	1/2May	Jul-Sep	Early flowering, enlargement	L

Drought tolerance: L = low, needs frequent irrigation; M = moderate; 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).

The effect of surplus and / or deficit of water depends on the kind of vegetable and its stage of development. Therefore, assessment of water balance for root vegetables (*Daucus carota* L and *Apium graveolens* L.), and fruit vegetable (*Cucumis sativus* L.) is based on the crop coefficient, Penman reference evapotranspiration and crop evapotranspiration during stages (Table 1a). Because of crop coefficient information in the Czech Republic is not available, thereby, K_c for vegetable crops is taken from Geisenheim Irrigation Scheduling (at available: www.campus-geisenheim.de). Therefore, it was used crop coefficient during stages of development by the BBCH scales for carrot: – after emergence (BBCH 09), during ≥5 leaves (BBCH 15) and 100 % ground cover (BBCH 43); for celeriac: - after transplanting (BBCH

12-13), during ≥7 leaves (BBCH 17), bulb start to develop (BBCH 42) and 100% ground cover (BBCH 46); for cucumber: after emergence (BBCH 09), developing flowers (BBCH 61) and start of harvest (BBCH 71). The periods of crop growth when an adequate supply of water is critical for high-quality vegetable production are shown in Table 1b, where we have also classified vegetables for drought tolerance.

In order to evaluate water balance of root and fruit vegetables is based on the following approaches: 1) to calculate reference evapotranspiration (ET_o); 2) then to calculate crop evapotranspiration (ET_c); and 3) the accumulation of deficit and/ or surplus of water balance ($P-ET_c$).

Firstly, the FAO Penman-Monteith model used to estimate ET_o, the reference evapotranspiration is expressed as:

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

where,

ET_o	reference evapotranspiration [mm d^{-1}],
R_n	net radiation at the crop surface [MJ m^{-2} d^{-1}],
G	soil heat flux density [MJ m^{-2} d^{-1}],
T	mean air temperature at 2 m heght [°C],
u_2	wind speed at 2m height [m s^{-1}],
e_s	saturation vapour pressure [hPa],
e_a	actual saturation vapour pressure [hPa],,
$e_s - e_a$	saturation vapour pressure deficit [hPa],
Δ	slope vapour pressure curve [hPa $°C^{-1}$],
γ	psyhrometric constant [hPa $°C^{-1}$],

Secondly, crop evapotranspiration is calculated by multiplying K_c and ET_o is expressed as:

$$\mathbf{ET_c = K_c * ET_o} \qquad (2)$$

where,

ET_o	reference evapotranspiration [mm d^{-1}],
ET_c	crop evapotranspiration [mm d^{-1}],
K_c	crop coefficient [-],

Thirty, a simple form of water balance of crop vegetable (WB) is calculated as following:

$$\mathbf{WB = P - ETc} \qquad (3)$$

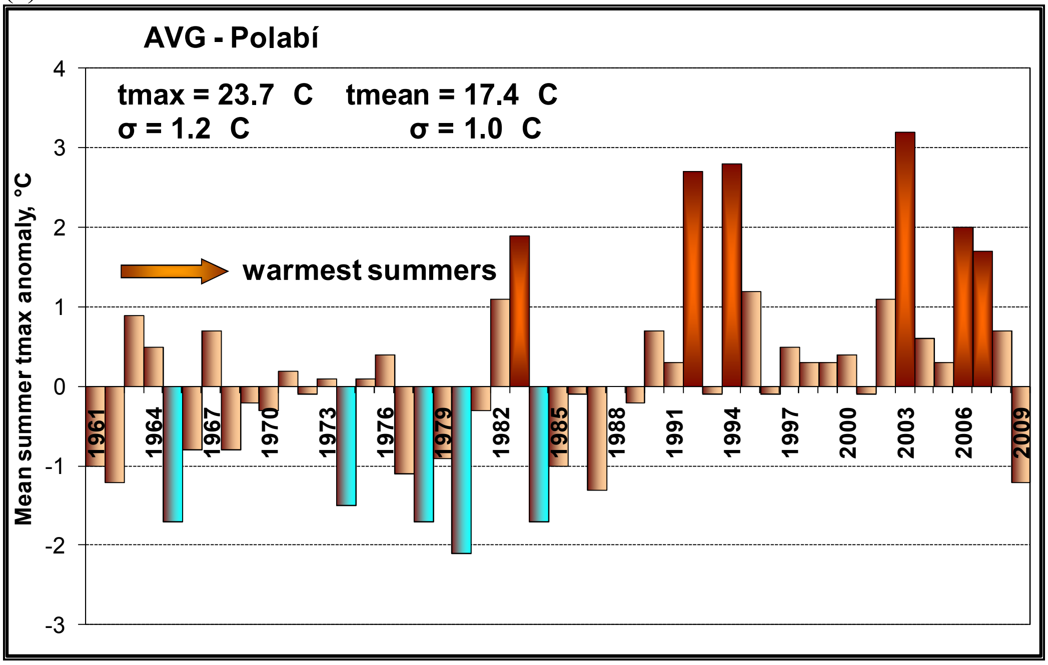
where,

P	precipitation [mm],
ET_c	crop evapotranspiration [mm d^{-1}],
WB	water balance [mm],

RESULTS AND DISCUSSION

The climatic condition in this region is dependent on the individual frequency of droughts, whose occurrence has increased in the last two decades. The lack of precipitation in the vegetation period in dry years corresponds to between 200 and 300 mm. A significant excess of precipitation during some periods can result in flooding while, on the other hand, a long-term lack of precipitation contributes to the incidence of drought spells (Fig. 3b). Moreover, extremes in temperature, particularly through occurrences of prolonged hot and/or cold events during planting or flowering can have significant impacts on yield of vegetables. Departures from summer averages of daily maximum temperatures are presented in Fig. 3a. The monthly average reference evapotranspiration has been calculated as presented in Fig. 3b, which shows the evaporative power of the atmosphere e.g., in July in this region.

(a)



(b)

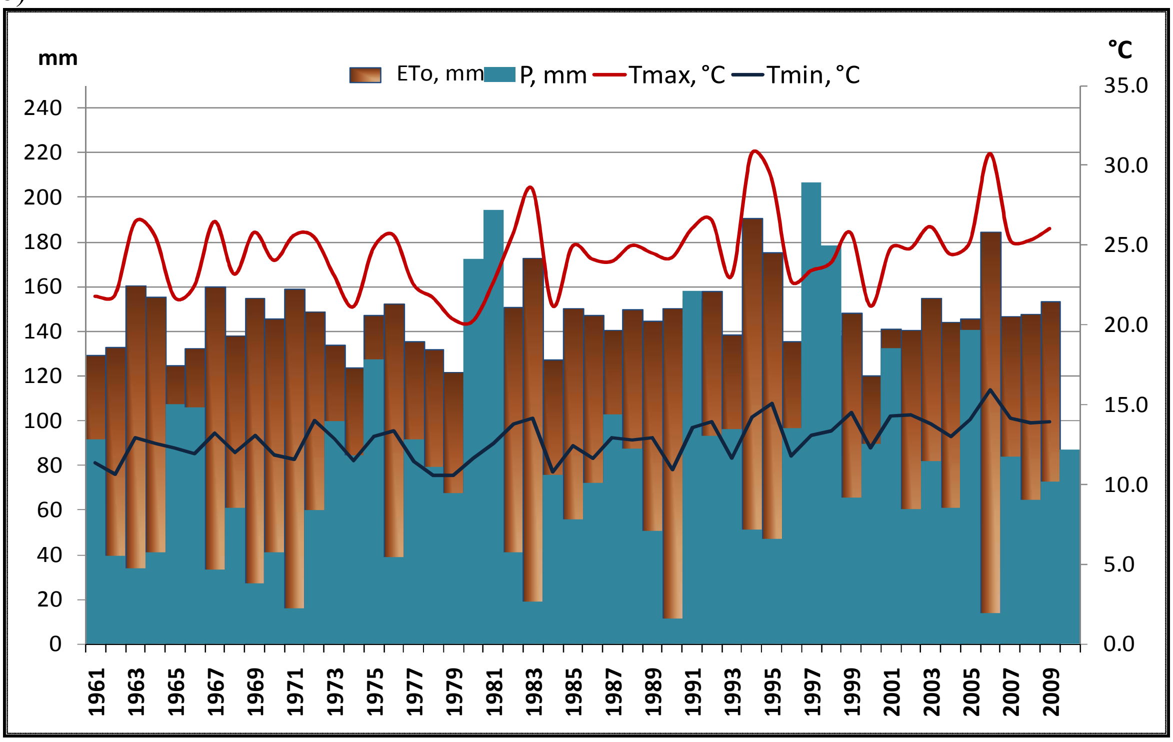


Fig. 3a-b. Departures from mean air maximum summer temperature in Polabí (1961–2009); and evolution of monthly reference evapotranspiration, maximum air temperature, minimum air temperature and rainfall in July.

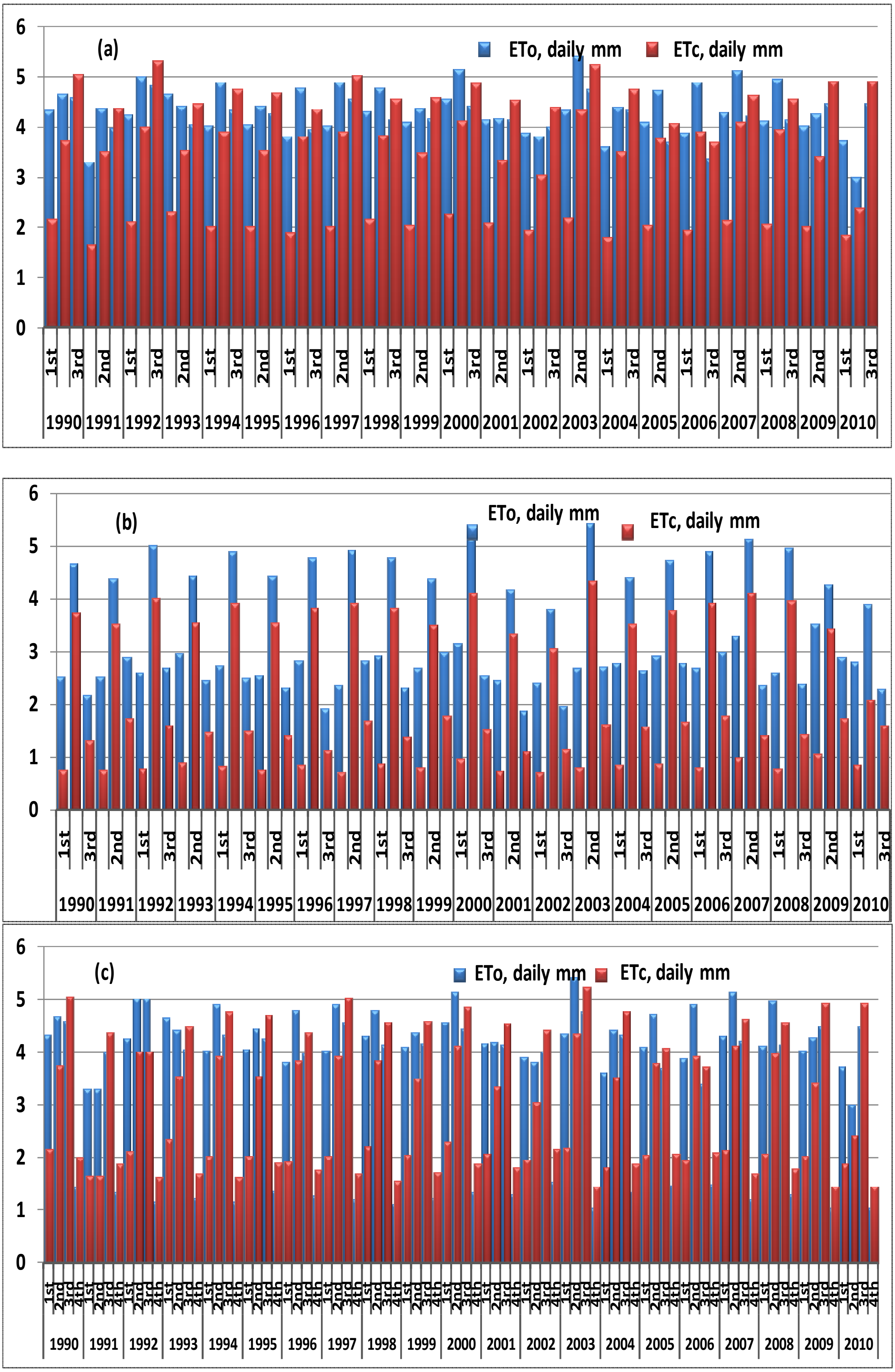


Fig. 4 Differences between reference evapotranspiration (ET_o) and crop evapotranspiration (ET_c) during 1st, 2nd, 3rd and 4th stages: a) cucumber, b) carrot and c) celeriac.

Crop evapotranspiration relates to the amount of water that is lost through reference evapotranspiration at a particular development stage. The ET_c are calculated based on the existing cropping patterns for carrot, cucumber and celeriac. The some results are tabulated in Table 2 and graphically displayed in Fig. 4. The resulting ET_c can be used to help an irrigation manager schedule.

Knowing how much irrigation water to apply to a crop is particularly important during a drought, and knowing the rate at which water is lost from the plant as it grows (ET_c) is helpful in determining how much water to apply.

For roots vegetable species extreme fluctuation in moisture levels is damaging as it causes to split of taproot (mainly carrots) (Vogel, 1996). 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. The maximum water surplus for cucumber during developing flowers for the entire reference period were recorded to be the following 1974, 1977, 1981, 2009 and 2010. A deficiency of water at critical stages can have a very negative impact on plants' further development, and thus it is necessary to fully ensure sufficient water in the soil (Malý et al., 1998).

The most variability of water moisture balance was recorded in 2009 in Polabí. In the Czech Republic during meteorological 2009 year the driest month was recorded in April (Potop, 2010). At this time in Polabí still were recorded days with $tmax \geq 25$ °C (Fig. 5). Analysing the occurrence of drought in this region showed that during the growing period in the 2009 year severe drought was also detected by SPEI index in April, but in August and September was recorded moderate drought (Fig. 7). In contrast, the wet month for the entire vegetable period was recorded in June (Potop, Možný, 2011). The warmest month was observed in August (it is about 2 °C higher than normal). At this time the highest is also detected both reference evapotranspiration (ET_o = 154 mm) and deficit of water balance ($P\text{-}ET_o$ = -105.4 mm), Fig. 6. The greater proportion of decreases in fruit vegetable yields occurred in years with extreme wet spells in June or August (e.g. 1997 [3 wet months], 2006 [August – cold and wet] and 2009 [June – wet]).

Evapotranspiration and crop coefficient varies in the course of season because morphological and eco-pysiological characteristics of the crop do change over time (Mier, 2001; Krug et al., 2002; Vogel, 1996; Rubatky et al., 1999). An evapotranspiration decrease was observed on e.g., *Beta vulgaris, Brassica napus* at the end of the vegetative period due to abiotic factors changes (Pivec and Brant, 2009; Pivec et al., 2010). Values of K_c for most agricultural crops increase from a minimum value at planting until maximum K_c is reached at about full canopy cover. Crop coefficients are affected by irrigation management practices and change as the crop grows and ages. Late in the season, the ET_c of many agronomic crops declines relative to ET_o because of aging, so the K_c decreases. For instance, from vegetable species *Apium graveolens* has the same patterns, which after bulb start to develop stage ET_c still drops (Table 2). In contrast, the most the vegetable crops are harvested before aging affects ET_c and therefore there is no late period decrease in K_c. This fact can be seen in 3th stages of *Cucumis sativus*, which K_c is 1.1 and average daily crop evapotranspiration (ET_c = 4.9 mm) is the highest than reference evapotranspiration (ET_o = 4.5), Table 2 and Fig. 4c.

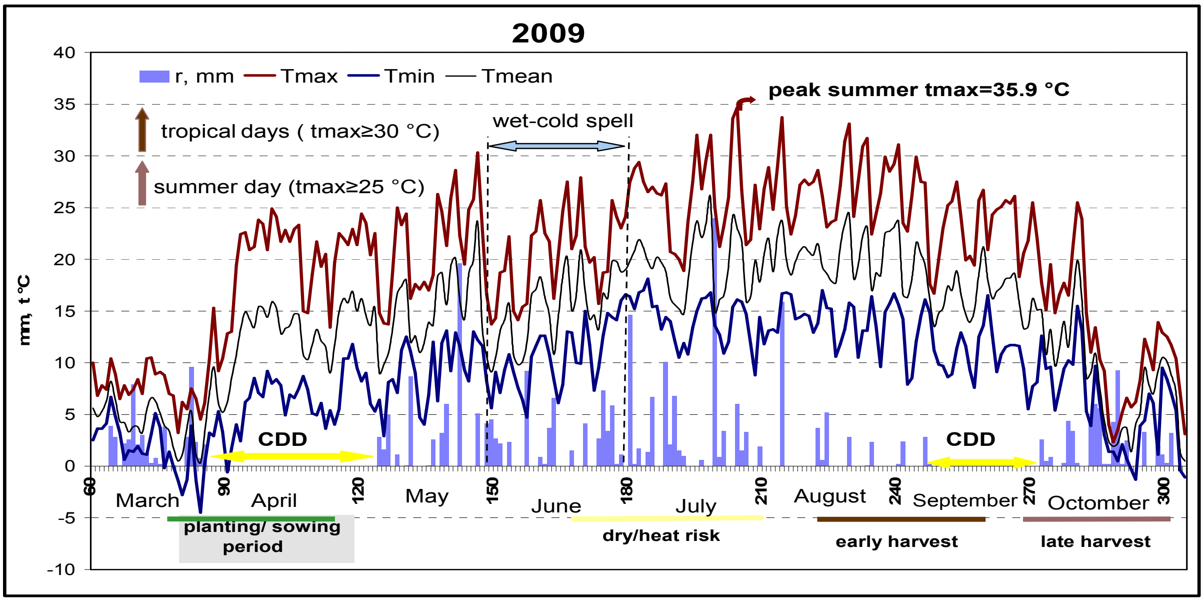


Fig. 5 Distribution of daily maximum temperature (Tmax), minimum temperature (Tmin), average temperature (Tmean) and daily rainfall during growing period of vegetable crops. CDD = consecutive dry days

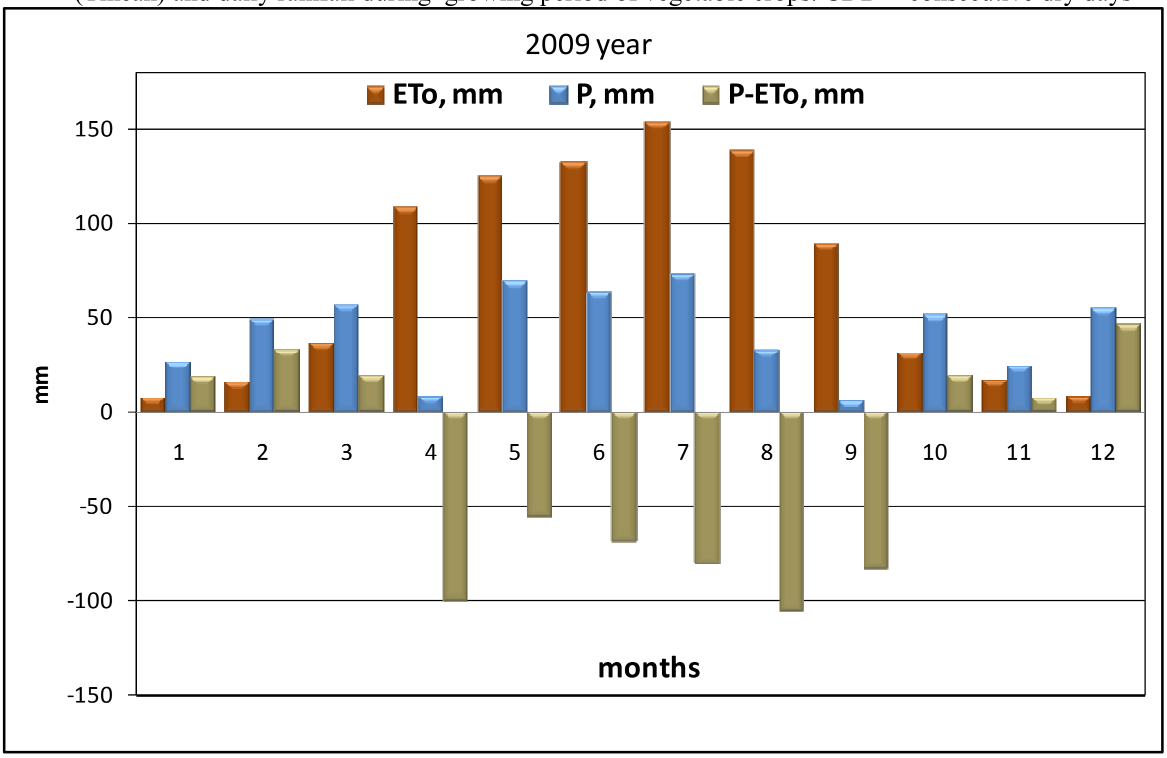


Fig. 6 Distribution of monthly reference evapotranspiration, precipitation and water balance during 2009 year

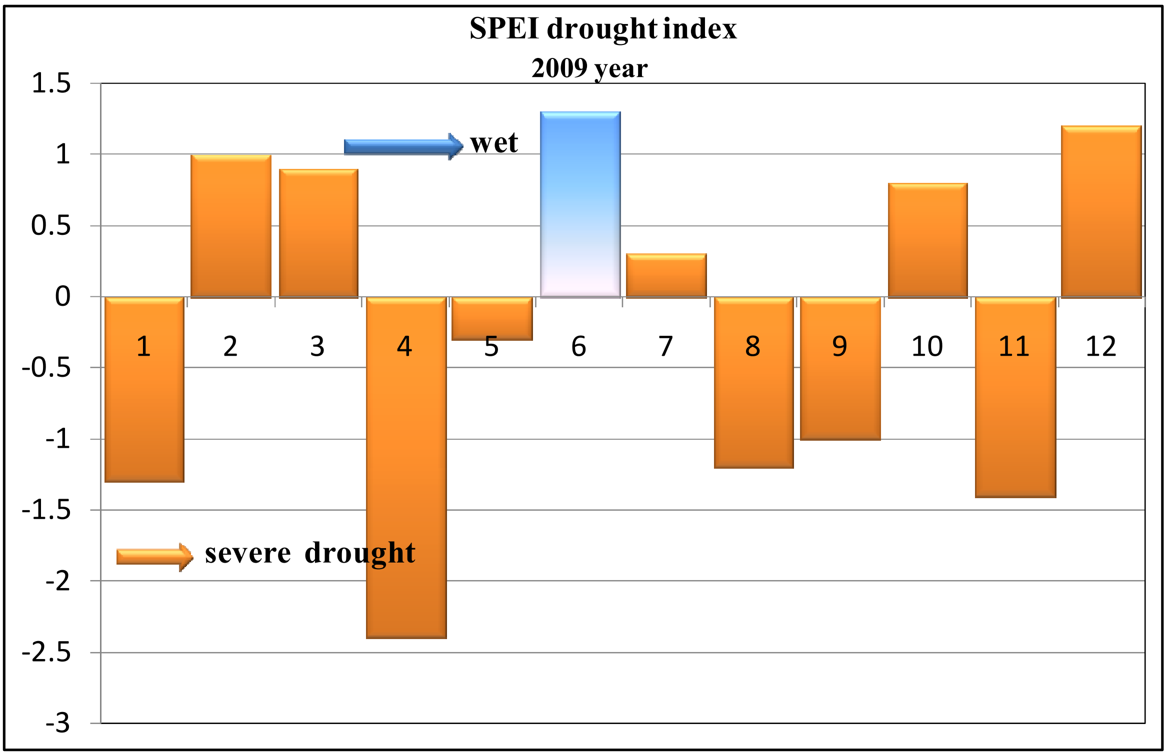


Fig. 7 Distribution of drought, normal and wet months during 2009 year by SPEI drought index.

Table 2 Averaged daily crop water use per stages for selected vegetables during 2009

	1st Stage	2nd Stage	3rd Stage	4th Stage
	Apium graveolens (celeriac)			
K_c	0.5	0.8	1.1	1.4
ET_o, mm d^{-1}	4.0	4.3	4.5	1.0
ET_c, mm d^{-1}	2.0	3.4	4.9	1.5
P, mm	2.3	2.1	1.1	2.0
P-ET_c, mm	0.3	-1.3	-3.8	0.5
	Daucus carota (carrots)			
K_c	0.3	0.6	0.8	
ET_o, mm d^{-1}	3.5	4.3	2.9	
ET_c, mm d^{-1}	1.1	3.4	1.7	
P, mm	0.0	2.1	0	
P-ET_c, mm	-1.1	-1.3	-1.7	
	Cucumis sativus (cucumber)			
K_c	0.5	0.8	1.1	
ET_o, mm d^{-1}	4.0	4.3	4.5	
ET_c, mm d^{-1}	2.0	3.4	4.9	
P, mm	2.3	2.1	1.1	
P-ET_c, mm	0.3	-1.3	-3.8	

As can be seen from Table 2, on average daily values of ET_c per stages of *Apium graveolens* and *Cucumis sativus* ranging from 1.5 mm to 4.9 mm/day, the maximum reached in the 3rd stage. At the same time was detected the highest deficit of water balance (P-ET_c), which was recorded during a large number of tropical days and drought conditions (Fig. 5). The negative water balance whole vegetable period for *Daucus carota* due to the highest temperature and drought conditions, mainly in April and August was observed.

Conclusion

In this research was used the FAO Penman-Monteith method to try assess evaporation loss from the vegetables grown in Polabí. Thereby, in this study is integrated monthly reference evapotranspiration and simply water balance to estimate the evaporative power of atmosphere under standard cover (grass) in Polabí region and daily vegetables crop evapotranspiration to distinguish the evaporative rates the field crop to reference grass.
Due to the fact that the vegetables in Polabí region are often grown under white-colored textile field conditions, it can be conclude that further research is necessary to determine crop coefficient both under and without field white-colored textile on the crop growth stage of vegetables. Given this fact that can be led to further improve accuracy in the estimate crop evapotranspiration (real water use of the crop) for the vegetable crops.

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