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OPTIMAL PRECIPITATION FOR FIELD-CULTIVATED VEGETABLES

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Summary

Based on available literature, we collected and presented in tables the values of optimal precipitation (for some field-cultivated vegetables) which are still sometimes used in Poland. We also included a short summary of how they are defined and how the necessary corrections are introduced. Included optimal precipitation values have been developed by: Dzieżyc*et al*., Grabarczyk, Klatt and Press. Therefore, it is possible to define (estimate) precipitation deficits for specific species of vegetables depending on the temperature or soil weight classification (light, medium, heavy) in various regions of Poland. By recognising optimal precipitation, we can plan, design or introduce irrigation and manage it. The formulas developed by Grabarczyk offer an additional possibility of calculating expected average increase (growth) of vegetable crops as a result of irrigation within various precipitation zones in Poland.

Key words: optimal precipitation, field-cultivated vegetables, irrigation, Poland

INTRODUCTION

It is possible to define the amount of required water for various plants, including vegetables, based on optimal precipitation (Nyc 2006). According to the quoted author, optimal precipitation is the amount of water required by plants to ensure high crops. Dzieżyc (1988) stated that optimal precipitation for a given plant is the amount of precipitation which enables achieving high crops in specific climate, soil and technical conditions. Its size can be defined for various time periods. It is possible to define optimal precipitation within: a year, a growing season, a month, a decade or a pentad. Today in Poland, we are still using optimal precipitation according to Klatt (Dzieżyc 1974), Press (1963) or Dzieżyc *et al*. (1987) and, for some fruit tree, according to Kemmer and Schulz (Dzieżyc 1988, Treder & Pacholak 2006). According to Dzieżyc (1988), values of optimal precipitation once defined by Woltman, Freckman and Hohendorf are no longer used. Nonetheless, authors of newer studies (Żakowicz & Hewelke 2002, Żakowicz *et al*. 2009) still include, apart from Klatt's (for some field-cultivated plants) and Press' data (only for fruit plants) Hohendorf's optimal precipitation as well.

It need be stressed that it is extremely difficult to define the volume of optimal precipitation and any resulting deficit or excess as it depends on various factors. Dzieżyc (1988) listed, e.g.: water required by specific species or varieties of plants, distribution of temperature, size of water accumulation in the soil, amount of water absorption, surface flow etc. Thus, any values must be treated as estimates and require the necessary corrections for specific conditions.

The goal of this study was to collect and list in one location all optimal precipitation values for field-cultivated vegetables.

MATERIAL AND METHODS

Based on available literature, we collected and presented in tables the values of optimal precipitation for field-cultivated vegetables in one study. We also included a short summary of how they are defined and how the necessary corrections are introduced. The study includes optimal precipitation values developed by Dzieżyc *et al*. (1987), Grabarczyk, Klatt and Press.

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Optimal precipitation according to Klatt (Dzieżyc 1974)

Optimal precipitation according to Klatt (Dzieżyc 1974) are dependent on temperature in such a way that for monthly temperatures higher by 1°C from the temperatures used as base temperatures, the monthly precipitation norm must be increased by 5 mm. For lower temperatures the required amount of water must be decreased respectively by 5 mm per 1°C. Since the data in the table of optimal precipitation applies to medium soils (sand-clay), it is necessary to increase the figures by 15% for light soils and decrease by 15% for heavy soils.

Table 1. Optimal rainfall amounts for vegetable crops in the open field $\mathbf{P_k}$ according to Klatt (mm) (Dzieżyc 1974, Ostromęcki 1973, Żakowicz & Hewelke 2002, Żakowicz *et al*. 2009)

No.	Vegetable	Months						Σ (mm)
		IV	V	VI	VII	VIII	IX	
		Temperature $\mathbf{t_k}$ (°C)						
		8	13	16	18	17	15	-
1	Broad bean	50	70	90	60	-	-	270
2	Early rutabaga	50	70	70	-	-	-	190
3	Late rutabaga	-	-	-	90	80	60	230
4	Bean	-	50	65	80	65	-	260
5	Pea	40	65	70	45	-	-	220
6	Early cauliflower	50	70	100	80	-	-	300
7	Late cauliflower	-	-	-	90	110	90	290
8	Early kohlrabi	50	70	70	-	-	-	190
9	Late kohlrabi	-	-	-	90	80	60	230
10	Early cabbage	50	70	90	80	-	-	290
11	Late cabbage	-	60	70	90	90	60	370
12	Early carrot	45	60	80	60	-	-	245
13	Late carrot	45	50	70	80	80	60	385
14	Cucumber	-	50	60	70	60	-	240
15	Tomato	-	50	60	70	60	50	290
16	Celery	-	60	70	90	85	75	380
17	Early spinach	65	-	-	-	-	-	65
18	Late spinach	-	-	-	-	80	70	150
19	Early potato	-	60	80	60	-	-	200
20	Late potato	-	50	60	80	70	-	260

Kaca (1988) offered a formula based on which it is possible to calculate the size of optimal precipitation according to Klatt:

$$P_{opt} = \mu \cdot (P_K + 5 \cdot (t - t_K)) \quad (1)$$

where:

P_{opt} – optimal precipitation according to Klatt for soil and temperature conditions of the analysed farm (mm),

P_K – optimal precipitation according to Klatt for medium, sand-clay soils and appropriate average monthly temperatures (Table 1) (mm),

μ – correction coefficient according to the type of soil,

$\mu = 1.15$ for light soils,
$\mu = 1.00$ for medium sand-clay soils,
$\mu = 0.85$ for heavy soils,
t – average monthly temperature (°C),
t_K – average monthly temperature value provided by Klatt (Table 1) (°C).

Grabarczyk (1983) included additional corrections to Klatt's optimal precipitation for specific climate regions in Poland (Table 2).

Table 2. Corrections for optimal rainfall amounts of Klatt for separated climatic regions of Poland[1] according to Grabarczyk (1983)

Regions	Months					
	IV	V	VI	VII	VIII	IX
Baltic	-10	-10	-5	-5	-5	-5
Lakeland	-10	-5	-5	-5	-5	-10
Land of the Great Valleys	-5	0	+5	0	0	-5
Central Highlands	0	0	0	0	0	-5
Submontane Lowlands and Basins	0	+5	+5	+5	+5	0
Montain and Submontane	-10	-10	-10	-10	-10	-15

[1] – rounded to 5 mm

Optimal precipitation according to Dzieżyc *et al.* (1987)

Dzieżyc *et al*. (1987) define optimal precipitation (precipitation needs) as the volume of precipitation and its distribution which ensured maximum crops in long-term national (SOO or COBORU) variety experiments (Dzieżyc 1988). Therefore, the authors considered, depending on the species of plants, between a few dozen to several hundred one-year experiments and they used data from a period of 25-30 years for around 140 precipitation stations for calculating optimal precipitation. Dzieżyc *et al*. (1987) provided the volume of optimal precipitation, within a period from sawing (or start of vegetation) until the end of harvest of a given plant, for three soil types (light, medium or dense) and for 7 climate and hydrology regions specified in the country (Table 3). In other studies authors from Wrocław listed optimal precipitation for specific decades of growing seasons of specific species of vegetables – for example (Dzieżyc 1988, Buczak 1989).

Table 3. Optimal precipitation for some field-cultivated vegetables[1] in the lowland part of Poland according to Dzieżyc *et al*. (1987), Dzieżyc (1988) (mm)

No.	Vegetables	Soils		
		heavy	medium	light
1	Tomato	200-250	250-300	300-350
2	Pea	250-300	250-300	300-350
3	Early potato	-	250-300	250-300
4	Medium earlypotato	300-350	300-350	350-400
5	Medium latepotato	350-400	350-400	400-450
6	Late potato	300-350	350-400	400-450
7	Onion	300-350	350-400	400-450
8	Celery	350-400	-	400-450
9	Cucumber	350-400	400-450	450-500
10	Red beet	400-450	400-450	450-500
11	Carrot	450-500	400-450	450-500
12	White cabbage	450-500	450-500	> 500
13	Red and Italiancabbage	450-500	450-500	> 500

[1] – from sawing (or start of vegetation) until the end of harvest of a given plant

Table 4. Ten-day indices of rainfall requirements of some vegetable crops cultivated on the medium soil in the Land of the Great Valleys (mm) (Dzieżyc *et al.* 1987)

Vegetable	IV	V			VI			VII			VIII			IX			X			Total
	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Cucumber			21	21	23	26	26	26	31	32	21	16	16	15						274
Tomato			20	20	22	28	28	28	29	30	27	19	17	16	14					298
Late carrot		19	21	22	23	25	25	28	29	29	31	25	19	18	15	14	14			457
Red beet	17	18	20	24	26	27	27	27	29	30	26	19	18	17	15	15				355
Celery			20	20	21	25	25	25	28	30	26	24	21	16	16	15	15	15	15	357
Late cabbage				20	22	25	25	25	31	36	34	27	25	19	17	16	16	16	16	370

Optimal precipitation according to Press

Many older (Ostromęcki 1973) and newer studies (Żakowicz & Hewelke 2002, Żakowicz *et al*. 2009) provide Press optimal precipitation only for fruit trees: apple trees, pear trees and wild cherry trees, sour cherry trees and plum trees. Below, please find a table with precipitation according to Press for selected species of vegetables (Table 5).

Table 5. Optimal rainfall amounts for some vegetable crops in the open field according to Press, P_p (mm) (Press 1963)

Vegetable		IV		V		VI		VII		VIII		IX		Σ	Vegetation period	
		°C	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm	mm	beginning	end
(1) Broad bean	I	6	40	11	60	14	70	16	55					225	III-IV	VII-IX
	II	8	50	13	70	16	80	18	60					260		
	III	10	60	15	80	18	90	20	70					300		
(2) Pea	I	6	40	11	50	14	60	16	40					190	III-IV	End of VII
	II	8	45	13	65	16	70	18	45					225		
	III	10	50	15	75	18	75	20	50					250		
(3) Dwarf bean	I			11	40	14	70	16	70	15	60			240	V	VII-VIII
	II			13	50	16	80	18	80	17	65			275		
	III			15	55	18	90	20	90	18	70			305		
(4) Early cauliflower	I	6	40	11	60	14	90	16	70					260	Beginning of IV	VI-VII
	II	8	50	13	70	16	100	18	80					300		
	III	10	60	15	80	18	110	20	90					340		
(5) Late cauliflow-er	I							16	60	15	100	12	80	240	VII	IX
	II							18	70	17	110	14	90	270		
	III							20	80	19	120	16	100	300		
(6) Early kohlrabi	I			11	60	14	70							120	Beginning of V	VI
	II			13	70	16	80							150		
	III			15	80	18	90							170		
(7) Late kohlrabi	I							16	80	15	80	12	80	240	VII-IX	X
	II							18	85	17	90	14	90	265		
	III							20	90	19	95	16	95	280		
(8) Early cabbage	I	6	40	11	60	14	80							180	Beginning of IV	VI
	II	8	50	13	70	16	90							210		
	III	10	60	15	80	18	100							240		
(9) Late cabbage	I	6	40	11	60	14	80	16	80	15	90	12	60	400	IV – V	VIII-IX
	II	8	50	13	70	16	90	18	90	17	90	14	70	460		
	III	10	60	15	80	18	100	20	100	19	100	16	80	520		
(10) Cucumber	I			11	40	14	70	16	80	15	80	12	60	330	Mid-V	VIII-IX
	II			13	50	16	80	18	90	17	90	14	70	380		
	III			15	55	18	90	20	100	18	100	16	80	425		

Vegetable		IV		V		VI		VII		VIII		IX		Σ mm	Vegetation period	
		°C	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm		beginning	end
(11) Celery	I			11	60	14	60	16	70	15	80	12	70	340	Mid-V	VIII-IX
	II			13	70	16	70	18	80	17	90	14	80	390		
	III			15	80	18	80	20	90	18	100	16	90	440		
(12) Late potato	I	6	30	11	40	14	50	16	80	15	70	12	40	315	IV	IX
	II	8	40	13	45	16	55	18	90	17	80	14	50	365		
	III	10	45	15	50	18	60	20	100	19	90	16	55	410		

Optimal precipitation according to Press, as in the case of precipitation according to Klatt, depends on temperature and soil type. For sandy soils it is necessary to increase precipitation by 20% while for clays or loess it is necessary to decrease it by 20%.

Optimal precipitation according to Grabarczyk (1986)

Grabarczyk (1986 1987), based on the analysis of the results of various exact field experiments with plant irrigation, concluded that crop increase as a result of sprinkling (on light soils) are linearly reverse proportional to the sum of precipitation within a period of intense demand for water, according to the formula:

$$Q = (P_{opt} - P_{rz}) \cdot q \qquad (2)$$

where:

Q – growth of crops as a result of sprinkling,

P_{opt} – optimal precipitation within a period of intense water demand (calculated using the regression equation) (mm),

P_{rz} – actual precipitation within a period of intense water demand (mm),

q – growth of crops as a result of sprinkling expressed in kg per 1 ha per 1 mm of precipitation deficit ($kg \cdot ha^{-1} \cdot mm^{-1}$).

The mathematical formula (regression equation) specific for the above-mentioned relationship indicates that the growth of crops as a result of irrigation exist for precipitation lower than that for which the calculated growth was null. Thus, the volume of precipitation can be treated as optimal in a given period of growth and harvest for a give plant.

For example, Żarski *et al*. (1997) stated the following equation for the medium-early potato (which is considered as a vegetable):

$$Q = (205 - P_{VI\text{-}VIII}) \cdot 170 \qquad (3)$$

It shows that for precipitation (from 1 June to 31 July) of 205 mm, the crops of the potato, as a result of sprinkling, would not increase any further. Therefore, it was possible to treat that sum as a value similar to the optimal value for the cultivated one in Mila variety experiment. Other examples of similar equations which include optimal precipitation defined according to Grabarczyk's method for other species of vegetables are included in some studies from Bydgoszcz (e.g., Rolbiecki & Rolbiecki (1998), Rolbiecki *et al*. (2000, 2003), Żarski (1989)).

SUMMARY AND CONCLUSIONS

We collected and presented – on the basis of available literature – the values of optimal precipitation for some field-cultivated vegetables which are still used in Poland. We also included a short summary of how they are defined and how the necessary corrections are introduced. Included optimal precipitation values have been developed by: Dzieżyc *et al*. (1987), Grabarczyk, Klatt and Press.

It is possible to define (estimate) precipitation deficits for specific species of vegetables depending on the temperature or soil weight classification (light, medium, heavy) in various regions of Poland.

By recognising optimal precipitation, we can plan, design or introduce irrigation and manage it. The formulas developed by Grabarczyk (1986) offer an additional possibility of calculating expected average increase (growth) of vegetable crops as a result of irrigation within various precipitation zones in Poland.

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