INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr II/1/2017, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 495–507
Komisja Technicznej Infrastruktury Wsi

DOI: http://dx.medra.org/10.14597/infraeco.2017.2.1.037

ANALYSIS OF THE ATMOSPHERIC PRECIPITATION DEFICIENCIES IN THE SELECTED GROUND VEGETABLES CULTIVATION IN THE REGION OF BYDGOSZCZ

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Abstract

Vegetables are considered to be plants with high water requirements. A greater susceptibility to water deficit occurs in the periods of intensive growth and yield formation. At that time even a slight reduction in water supply can deteriorate yielding, thus those periods are referred to as critical periods in terms of water supply. The aim of this paper has been to analyse the pattern of precipitation deficits for the ground cultivation of cucumber, tomato, beans and peas in the Bydgoszcz region in the thirty-year period 1981-2010. The basic of analysis were results of standard meteorological measurements from the Research Station of the Faculty of Agriculture and Biotechnology ‚Mochełek', University of Technology and Life Sciences. Values of optimal precipitation for medium soils were calculated according to Klatt. Atmospheric precipitation deficits in subsequent month of selected vegetables cultivation were calculated by diminish between the real and optimal precipitation. The trends of deficiency of precipitation in the examined period were estimated too. Very frequent occurrence of the atmospheric precipitation deficits during the entire cultivation period of selected vegetables, and especially in critical periods was demonstrated. Slight decreasing tendency of precipitation deficits in a vegetation periods was indicated, however in a critical periods in terms of water supply, the trend line remains at

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a practically constant level. The results obtained indicate the necessity of the irrigation in the cultivation of peas, beans, cucumbers and tomatoes.

Key words: atmospheric precipitation, precipitation deficit, beans, peas, cucumber, tomato

INTRODUCTION

Fresh vegetables, depending on the species, cultivar and the usable area, contain 80 to 95% of water. It is assumed that for each kilogram of the dry weight produced, the plants use 200 to 900 dm^3 of water, of which only 0.5% is bonded in the yield, the rest gets lost in the process of transpiration (Kołota et al. 2007). Water is responsible for cell hydration and turgor pressure, transport of the nutrients uptaken from soil solution to all the tissues and cells; it is also indispensable in the processes protecting the plants from overheating and undercooling. Water requirements of the plant stand for the total amount of water it must consume over the vegetation period to produce yield. Vegetables, mostly due to a high level of tissue hydration and forming a large mass of over-ground parts, with a developed transpiration area, are considered to be plants with high water requirements. Additionally water requirements increase, in general, as a result of a poorly-developed root system 80-90% of the volume of which grows in topsoil with thickness up to 30 cm, and only few roots grow deeper than 50 cm. A poorly-developed and shallow root system under water deficit in soil cannot supply sufficient amount of water to strongly-developed aboveground parts of plants (Kaniszewski 2005a).

A greater susceptibility to water deficit occurs in the periods of intensive growth and yield formation. At that time even a slight reduction in water supply can deteriorate yielding, thus those periods are referred to as critical periods in terms of water supply (Karczmarczyk and Nowak 2006, Kaniszewski 2005a). Vegetables the edible part of which are made of vegetative organs require most water in the period of an intensive increase in vegetative mass and water deficits, except for a decrease in the yield size and quality, can also disturb important physiological processes. The vegetables the yield of which is made up of generative organs, react especially to water deficits from the moment of changing from vegetative to generative stage and then throughout a further period of yield formation. Water deficits result in shedding of flowers, fruit buds, poor seed-setting and in fruits becoming undersized. Higher water requirements are reported for the vegetables the rooting of which is shallow, e.g. cucumber and onion, or which produce a lot of aboveground mass, e.g. cabbage. The vegetables with high water requirements include, next to *Brassicaceae*, *Cucurbitaceae* and onion genus, also lettuce, celery and dwarf tomato cultivars. Low water requirements concern vegetables such as asparagus, beetroot and tall growing tomato cultivars (Bykowski 2004).

The amount of water available to vegetables is of key importance in the periods of an intensive growth and yield formation, however, soil moisture conditions at the start of cultivation affect further proportions between the aboveground part of plants and their root system – a high moisture inhibits root growth, triggering a faster development of aboveground parts, whereas moderate moisture helps a stronger root development and root overgrowth deep down the soil, allowing, in the period of a more intensive growth, for managing the seasonal water deficits more easily (Kaniszewski 2005a).

Water deficits are commonly considered to be the key factor which limits the global plant production and which can seriously interfere with the global food security in the 21st century. Poland is a country with little water resources. It is assumed that the annual amount of water per person is about 1600 m^3, whereas in other European countries – 4560 m^3, which makes us come only twenty-third in Europe. The key source of water for crops in our country is precipitation (about 97%). What is essential; dry years occur, on average, every 5-6 years, and very dry – every 10-11 years (Mazurczyk 2009).

The vegetables acreage in the kujawsko-pomorskie province in 2015 was 24,500 ha (13.9% of the total country's vegetables acreage), providing 538,700 tonnes of vegetables (14.2% of the total country's production). As for the acreage, it makes us come second in Poland, and in terms of yield size – first (GUS 2016). The data points to a considerable scale of production of vegetables in the province.

Cucumber, producing a very big mass of aboveground parts and a large transpiration area, accompanied by a shallow-growing root system, is a vegetable with a high susceptibility to water deficit. A critical period starts at the beginning of April, namely mid-June, and it lasts throughout yielding, to the end of August. Water deficits at that time result in shedding of flowers and buds, and hence a decreased yield, while regular irrigation over precipitation deficit facilitates even a 20-50% yield. Tomato is considered to be a plant with moderate water requirements and the reaction to water deficits is cultivar-specific. The critical period starts about mid-June and lasts until mid-August and moisture deficits, at that time, cause the shedding of buds and fruits becoming undersized, the colouration of fruits still not enough grown and blossom-end rot. Starting from mid-August, for that species rainfall excess becomes very harmful, deteriorating yielding and increasing plant infestation with pathogens, especially by fungi. Beans and peas are not considered to be vegetables with especially high water requirements, however, one should remember that in the period of seed germination and emergence, and then from the beginning of April and throughout pod growth, the susceptibility of those plants to water deficit increases considerably. Moisture deficit in soil delays emergence and makes it uneven, results in shedding of flowers and fruit buds, and in pods – in fewer seed setting, and so the pods get shorter and the yield – lower. Additionally, in runner bean pods become fibrous, and in peas – seed over-ripening is faster. For beans the period of a greater susceptibility to water deficits occurs from mid June to the end of August, and for peas – from the beginning of May to the end of June (Kołota et al. 2007).

The amount of precipitation most favourable to the plants in specific soil and climate conditions is defined as optimal precipitation. Precipitation deficit stands for a difference between the water requirements indicators in plants and real rainfall throughout the vegetation period or at selected growth and development stages. Under temperate climate conditions it is important to calculate deficits in reference to the multi-year period, which allows for a thorough evaluation of the trends of their time variation (Rzekanowski et al. 2011, Żarski and Dudek 2009). The aim of this paper has been to analyse the pattern of precipitation deficits for the cultivation of cucumber, tomato, beans and peas in the Bydgoszcz region in light soil.

MATERIALS AND METHODS

The research was made with the standard meteorological measurements from the 1981-2010 thirty-year period, performed at Mochełek Research Station, developed and made available by the staff of the Department of Melioration and Agrometeorology UTP in Bydgoszcz. The measurement point was located about 20 km away from Bydgoszcz, on the south-eastern edge of the Krajeńska Upland (φ=53°13', λ=17°51', h=98.5 m above sea level). The research considered mean monthly temperatures and monthly precipitation totals, for each year April through September.

For the vegetable crops under study there was calculated optimal precipitation according to Klatt for medium soils in successive months of the vegetation period, for each 1ºC above or below mean monthly temperature recorded by Klatt, adding or subtracting 5 mm of precipitation, respectively (Grabarczyk 1983). The difference between real and optimal precipitation was applied to calculate precipitation deficits for respective months of the cultivation and total deficits for the vegetation period and critical period. The following were also calculated: mean, maximum and minimal water deficit in the vegetation period and the critical period, as well as standard deviation for deficits in a given period and the frequency of occurrence of the years with water deficits below 60 mm. To investigate a variation in precipitation deficits, trend lines of precipitation deficits for the vegetation period and the critical period were determined. For beans, for the vegetation period, the months May through August were assumed, with a critical period June through August. For peas those were the periods April through July and May through June, for cucumber – May through August and

June through August, and for tomato – May through September and June through August, respectively.

RESULTS AND DISCUSSION

As for beans growing, the highest mean rainfall deficits were noted in June, and the lowest – in May. Throughout the vegetation period, the mean deficit was – 40.2 mm and in a critical period – 37.9 mm. The level of satisfying the water requirements of plants from precipitation ranged, on average, from 74.7% in June to 95.5% in May, throughout the vegetation period it accounted for 85.4%, and in a critical period – for 83.0%. The maximum precipitation deficit was noted in July 1994 and the maximum surplus – in August 1985. Maximum precipitation deficits, both throughout the cultivation period and for the critical period, occurred in 1992, while the maximum surpluses – in 1985 (Table 1). In the thirty-year period the number of years with precipitation deficits was 20, both throughout the cultivation period of beans and the critical period. Interestingly, although throughout the cultivation period of that vegetable one can observe a slight decreasing tendency of precipitation deficits, in a period critical for yield formation, the trend line remains at a constant level (Fig. 1).

Table 1. Precipitation deficiencies in the beans cultivation in the region of Bydgoszcz in 1981-2010

	V	VI	VII	VIII	V-VIII	VI-VIII
Real precipitations (mm)	49.3	52.8	69.8	62.6	234.5	185.2
Optimal precipitations (mm)	51.6	70.7	82.9	69.5	274.7	223.1
Average deficiency	2.3	17.9	13.1	6.9	40.2	37.9
Needs covering (%)	95.5	74.7	84.2	90.1	85.4	83.0
Maximum deficiency (year)	53.9 (1988)	62.5 (2008)	97.0 (1994)	72.5 (1992)	212.6 (1992)	197.8 (1992)
Maximum excess (year)	55.7 (1996)	56.4 (1991)	59.6 (2001)	144.5 (1985)	188.0 (1985)	162.9 (1985)
Standard deviation	33.5	32.0	43.0	48.0	87.5	65.9
Frequency of years (%) with precipitation deficiency above 60 mm					43.3	40.0

For peas April was the month with the lowest precipitation deficits, whereas the highest deficits occurred in June, and in July even precipitation surpluses were reported. The mean precipitation deficit for the entire cultivation period was 25.6 mm, and in the critical period – 40.1 mm. Precipitation satisfied the plant requirements from 69.7% in June to 145.7% in July; in the vegetation period, satisfying the needs accounted for 88.6%, and in a critical period – for 71.8%. The maximum precipitation deficit and surplus were noted in May 1988 and July 2001, respectively. The maximum deficits and surpluses for the entire vegetation period occurred in 1992 and 2001, and for the critical period – in 2008 and 1991, respectively (Table 2). In the thirty-year period there were recorded 18 years with precipitation deficits throughout the peas vegetation period, however, in the critical period – there were as many as 24 already and the trend line for that period shows only a minimal decreasing tendency (Fig. 2).

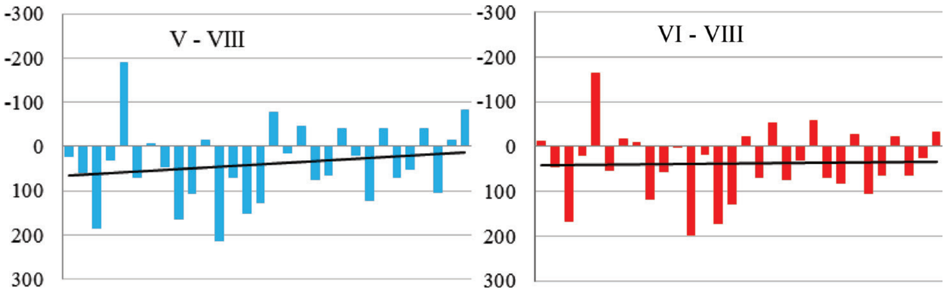

Figure 1. Precipitation deficiencies in the beans cultivation in the region of Bydgoszcz in 1981-2010 during growing season (left) and critical period (right)

Table 2. Precipitation deficiencies in the peas cultivation in the region of Bydgoszcz in 1981-2010

	IV	V	VI	VII	IV-VII	V-VI
Real precipitation (mm)	27.0	49.3	52.8	69.8	198.9	102.1
Optimal precipitation (mm)	34.3	66.6	75.7	47.9	224.5	142.2
Average deficiency	7.3	17.3	22.9	-	25.6	40.1
Needs covering (%)	78.7	74.0	69.7	145.7	88.6	71.8
Maximum deficiency (year)	43.6 (2009)	68.9 (1988)	67.5 (2008)	62.0 (1994)	146.9 (1992)	122.0 (2008)
Maximum excess (year)	46.5 (2006)	40.7 (1996)	51.4 (1991)	94.6 (2001)	90.4 (2001)	50.1 (1991)
Standard deviation	18.4	33.5	32.0	43.0	68.1	46.8
Frequency of years (%) with precipitation deficiency above 60 mm					33.3	36.7

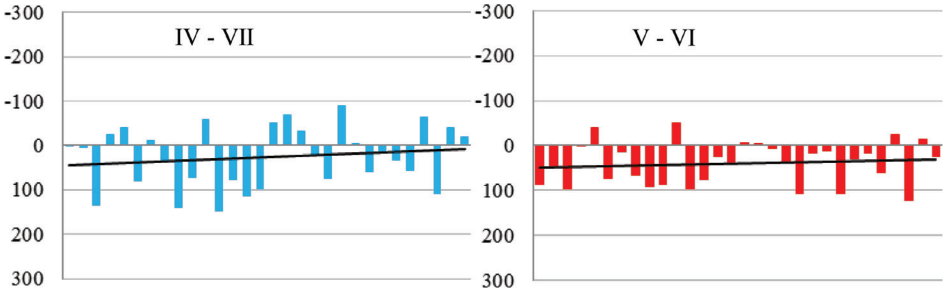

Figure 2. Precipitation deficiencies in the peas cultivation in the region of Bydgoszcz in 1981-2010 during growing season (left) and critical period (right)

Table 3. Precipitation deficiencies in the cucumber cultivation in the region of Bydgoszcz in 1981-2010

	V	VI	VII	VIII	V-VIII	VI-VIII
Real precipitation (mm)	49.3	52.8	69.8	62.6	234.5	185.2
Optimal precipitation (mm)	51.6	65.7	72.9	64.5	254.7	203.1
Average deficiency	2.3	12.9	3.1	1.9	20.2	17.9
Needs covering (%)	95.5	80.4	95.7	97.1	92.1	91.2
Maximum deficiency (year)	53.9 (1988)	57.5 (2008)	87.0 (1994)	67.5 (1992)	192.6 (1992)	177.8 (1992)
Maximum excess (year)	55.7 (1996)	61.4 (1991)	69.6 (2001)	149.5 (1985)	208.0 (1985)	182.9 (1985)
Standard deviation	33.5	32.0	43.0	48.0	87.5	65.9
Frequency of years (%) with precipitation deficiency above 60 mm					26.7	23.3

The research has demonstrated that the mean precipitation deficits for growing cucumber were not high and ranged from 1.9 mm in August to 12.9 mm in June, which satisfied the requirements of the plants from 80.4 to 97.1%. The mean deficit was 20.2 mm in the vegetation period and 17.9 mm in a critical period and satisfying the water requirements of plants accounted for 92.1 and 91.2%, respectively. The maximum precipitation deficit occurred in July 1994 and surplus – in August 1985. Both for the vegetation period and the critical period, the year 1992 was the year with the maximum precipitation deficits, whereas the maximum surpluses were recorded in 1985 (Table 3). Throughout the cucumber cultivation period there were identified 19 years with precipitation deficits; for the critical period the number was 17. In the vegetation period one could observe a slight decreasing tendency for deficits, however it cannot be stated by analysing the trend line for precipitation deficits in the critical period (Fig. 3).

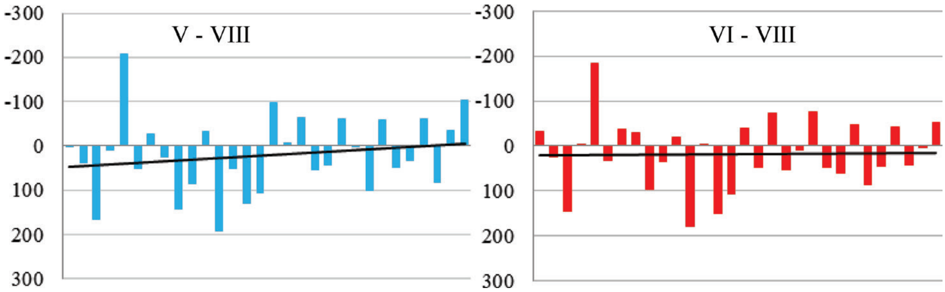

Figure 3. Precipitation deficiencies in the cucumber cultivation in the region of Bydgoszcz in 1981-2010 during growing season (left) and critical period (right)

In outdoor tomato cultivation the lowest mean precipitation deficits occurred in September (0.3 mm), and the highest – in June (12.9 mm). The mean deficit for the entire cultivation period and in the critical period was 19.9 and 17.6 mm, respectively. Satisfying the water requirements of plants for the thirty-year period was relatively high, ranging from 80.4 to 100.7%, however, for the vegetation period and the critical period, the level of satisfying the requirements accounted for 93.4 and 92.9%, respectively. The maximum deficit was noted in 1994, and surplus – in 1985. Both throughout the cultivation period and in the critical period the maximum precipitation deficits were noted in 1992, and the surpluses – in 1985 (Table 4).

In the thirty-year period there were noted 18 years in total with precipitation deficits in the vegetation period of tomato and 17 – with deficits in the critical period, however for the second period the trend line almost did not show any decreasing tendencies (Figure 4).

Under the conditions of temperate climate, characteristic for Poland, a considerable variation in the weather elements in respective years and months occurs, especially a variation in precipitation. It is the reason of the occurrence of water deficits and surpluses interchangeably, which is very harmful, especially for vegetable production (Łabędzki 2016). In some years water deficits can range from 200 to 300 mm, with the highest ones occurring in the central part of the country and in the north-eastern and south-western regions (Rożek 2005), nevertheless irrigation is applied as intervention operations and it is only to supplement the seasonal precipitation deficits in semi-drought periods (Żarski et al. 2013).

Table 4. Precipitation deficiencies in the tomato cultivation in the region of Bydgoszcz in 1981-2010

	V	VI	VII	VIII	IX	V – IX	VI-VIII
Real precipitation (mm)	49.3	52.8	69.8	62.6	46.0	280.5	231.2
Optimal precipitation (mm)	51.6	65.7	72.9	64.5	45.7	300.4	248.8
Average deficiency	2.3	12.9	3.1	1.9	0.3	19.9	17.6
Needs covering (%)	95.5	80.4	95.7	97.1	100.7	93.4	92.9
Maximum deficiency (year)	53.9 (1988)	57.5 (2008)	87.0 (1994)	67.5 (1992)	52.9 (1982)	219.1 (1992)	177.8 (1992)
Maximum excess (year)	55.7 (1996)	61.4 (1991)	69.6 (2001)	149.5 (1985)	86.6 (2001)	201.1 (1985)	182.9 (1985)
Standard deviation	33.5	32.0	43.0	48.0	33.8	101.5	76.4
Frequency of years (%) with precipitation deficiency above 60 mm						33.3	23.3

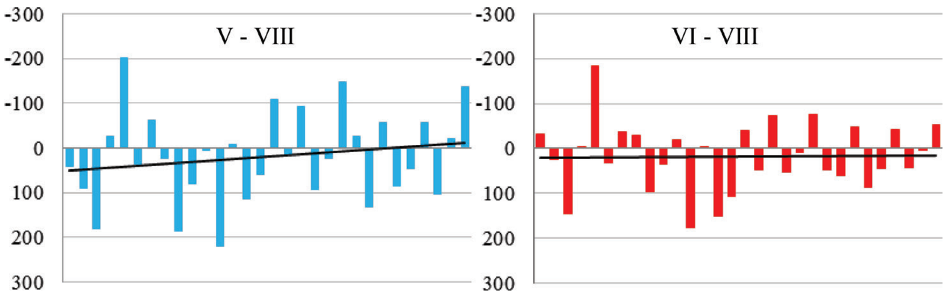

Figure 4. Precipitation deficiencies in the tomato cultivation in the region of Bydgoszcz in 1981-2010 during growing season (left) and critical period (right)

The available data on irrigation of field vegetable crops in Poland is not cohesive; literature offers information that regular irrigation concerns, depending on the source, from 3-5% even up to about 20% of the acreage (Spiżewski 2004, GUS 2007). Unfortunately, it has been still the acreage which is too small since irrigation should be a standard practice on each farm which focuses on high, stable and high-quality yields (Grucel, 2004).

The sources of natural water supply to plants are soil resources, which are a direct source, and precipitation – an indirect source, although most frequently the major one, since more than half of the land under agricultural use in Poland are soils with low retention, with a deep level of ground waters (Karczmarczyk and Nowak 2006). For the right water supply to plants, not only the annual total precipitation is essential but also the precipitation distribution and amount in the vegetation period, especially in critical periods (Rzekanowski 2009). In the vegetation period the precipitation is, most often, too low. Precipitation deficit is at that time 100-200 mm on average and it mostly coincides with the period of the most intensive growth, which stands for considerable fluctuations in the vegetable yield size and quality in respective years (Kaniszewski 2005a, Kaniszewski 2005b). Air and soil semi-droughts are one of the most important unfavourable phenomena affecting the climatic risk to plant cultivation in Poland; for that reason the necessity of applying irrigation in vegetables is unquestionable (Żarski and Dudek 2009, Dudek et al. 2009, Radzka et al. 2009). Precipitation water deficit concerns the area of the entire Poland, and the region of Bydgoszcz is located in the zone with the highest precipitation deficits (Żarski 2011).

For tomato irrigation is recommended after planting, to make them acclimatise better and then from full flowering to the beginning of ripening if the yield is to be allocated to processing or until fruits to eat fresh are collected. Processing tomatoes, if shorter irrigated, forms fruits with a lower mass; similarly the yield is lower, however, fruits are better coloured and contains more extract (Kaniszewski 2005a, Karczmarczyk and Nowak 2006). Regular irrigation over flowering and yielding facilitates a greater number of fruits and a higher yield, even by almost 30% (Monte et al. 2013, Podsiadło et al. 2005). In the thirty-year period under study September was most abundant with precipitation and June – least. Such precipitation distribution is very unfavourable for that plant; it is in June when flowering and fruiting start, when water requirements increase, whereas in September an excessive precipitation increases plant infestation with pathogens, especially fungi, which also deteriorates the yield quality (Cabral et al. 2013). Besides, one should also consider the trend lines for precipitation deficits in the period critical for tomato yielding which, in the period under study, shows only minimal decreasing tendencies.

As for cucumber, water deficit, especially when combined with a high temperature, decreases the number of female flowers and deteriorates the uptake of mineral nutrients from soil (Yaghi et al. 2013). A regular supply of low water rates results in a faster increase in plant biomass in cucumbers and the formation of a greater number of laterals and, as a consequence, an enhanced yielding. As for growing pickling cultivars, depending on the precipitation distribution in a given year and soil moisture, a 14 – 160% higher yield can be produced; however, better irrigation effects are reported in drier years (Spiżewski and Knaflewski 2009). This study has identified slight precipitation deficits in the period of cucumber growing, nevertheless the years with deficits constituted a majority; besides, the analysis of the pattern of the trend line showed that precipitation deficits in the period critical for the yield do not decrease, which can be essential for the necessity of introducing regular irrigation to outdoor cucumber.

When cultivating beans, the irrigation effect considerably depends on the initial soil moisture (Petrova et al. 2013). A yield increase is mostly a result of the setting, with plant irrigation, of a greater number of seeds, which immediately translates into the length, width and the mass of pods (Podsiadło et al. 2005, Sezen et al. 2008). The considerable precipitation deficits reported in the present study, both in terms of the entire vegetation period and the period critical for yielding, totally confirm the justifiability of regular irrigation of that vegetable crop, which can not only increase the yield size but also enhance its quality.

The results of numerous research show that regularly irrigated peas grown for green seed yield grows taller, sets more pods, and its seeds achieve a higher mass, which, as a result, produces a higher yield (Dogan et al. 2015). Especially when cultivated in light soil, applying irrigation, the pod length and seed mass can be even 2-times higher (Wahba et al. 2016). In the present study it was found that in the 1981-2010 thirty-year period, in most cases, the years with precipitation deficits were reported, especially in the periods critical for the yield size and quality, which can be a confirmation of the results and conclusions of other reports pointing to the justifiability of applying irrigation when growing that crop.

CONCLUSIONS

1. In the thirty-year examined period in Bydgoszcz region years with atmospheric precipitation deficit predominated, especially in critical periods in terms of the water supply.
2. Larger climatic risk of cultivation due to precipitation deficit in the peas and beans cultivation was demonstrated.
3. In the entire cultivation period of beans, peas, cucumber and tomato precipitation deficits demonstrated a slight decreasing tendency, however in a critical periods in terms of water supply, the trend line remains at a practically constant level.

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Received: 15.02.2017
Accepted: 25.04.2017