ACTA SCIENTIARUM POLONORUM *Hortorum Cultus 2(2) 2003, 75-84*

DRIP IRRIGATION SYSTEM AS A FACTOR FOR DROUGHT MITIGATION IN VEGETABLE GROWING ON SANDY SOILS IN THE REGION OF BYDGOSZCZ

Stanisław Rolbiecki, Roman Rolbiecki, Czesław Rzekanowski, Jacek Żarski

Abstract: The objective of this study was to show the possibilities for drought mitigation in vegetable plant growing on loose sandy soils in the region of Bydgoszcz with the use of drip irrigation system. Drip irrigation used under such the soil-climatic conditions was the basic vegetable yield-creating factor, securing stable yields of the vegetable crops tested in period 1991–1999 (carrot, red beet, snap bean, squash, zucchini). The results indicated the decisive role of water on the outcome of yield and quality of vegetables cultivated on a soil of limited water holding capacity. The experiments proved that vegetables production on sandy soils was only possible with the use of supplemental irrigation. Using the elaborated formulas it is possible to determine critical periods for individual vegetable species, optimal rainfall during these periods as well as expected increases of yields caused by drip irrigation covering rainfall deficits. According to the elaborated dependences, the approximated estimation of average needs of drip irrigation and average production effects of irrigation in particular rainfall regions is also possible.

Key words: red beet, carrot, snap bean, squash, zucchini

INTRODUCTION

Poland's climate falls into the moderate zone of the warm transitory type. The summer half-year rainfall ranges from 300 mm in central Poland to more than 425 mm in the submontane and montain regions. The lowest rainfall occurs in central Poland, in general a lowland which includes the Large Valleys Region. The rainfall distribution in Poland is varied a lot more by time than by regional features, and thus it seldom reaches mean values in particular years. Dry years and periods occur more often in the regions with the lowest mean precipitation. The analysis of precipitation suggests that in Poland, also in its central part, it is possible to obtain a satisfactory high vegetable production. However, this concerns only the soils of high and medium water capacity. The problem looks other way around in case of arable grounds developed from sands, especially those with a loose sand bed and low level of ground waters. The main reason of their low productivity are seasonal water deficits. Sandy soils of the Large Valleys Region cover the total of 380,000 ha, comprising on average 44.8% arable grounds. Lack of rainfall for 10–14 days in the periods of late spring and summer under such soil conditions can cause a total growth inhibition as well as withering of vegetable plants [Grabarczyk et al. 1997]. The fluctuation of the vegetable production in Poland, as a result of the rainfall amount and course, described among others Kaniszewski and Cieślak-Wojtaszek [1994]. For example, in 1991 vegetable production in Poland reached a record level 6 million tons, while in the next year (1992) due to a strong negative influence of the dry growing season the obtained yields showed a decrease of over 20% (1.2 million tons).

Seasonal irrigation rate during the vegetation period should amount approximately from 100 to 200 mm in order to create optimum water coditions for stable and high yields of vegetables [Kaniszewski 1987, Dzieżyc 1988, Kaniszewski and Knaflewski, 1997]. Because water resources in Poland are limited, irrigation should be carried out with the use of water-saving systems (micro-irrigation) such as drip (trickle) irrigation and micro-sprinkler (micro-jet) irrigation.

The objective of this study is to show the possibilities for drought mitigation in vegetable plant growing on loose sandy soils in central Poland with the use of surface drip irrigation system. The second aim of the study is an attempt of the presentation of a simple model to solve the problem of the estimation of irrigation requirements and production results of irrigation of vegetable crops cultivated in Central Poland.

MATERIAL AND METHODS

The paper is based on the results of field experiments on drip irrigation of 5 species of vegetable crops, carried out during 1991–1999 at Kruszyn Krajeński near Bydgoszcz. Characteristic property of the experiment field is its localization in the area of the largest precipitation deficiency in the country [Grabarczyk et al. 1997]. The trials were established as one-factorial experiments including randomized blocks in four replications. The investigated factor was drip irrigation used in the following variants: W_1 – without irrigation (control plots), W_2 – with drip irrigation. The drip irrigation equipment was based on two types of emmiters. Grabarczyk's emmiters (pipe with microslits) [Grabarczyk 1977] were used for irrigation of snap bean, carrot and red beet. Drip line „T-tape" was used for irrigation of squash and zucchini. Distance between emmiters was 20 cm. Water output of a single emmiter ranged from 0.6 to 1 $dm^3 h^{-1}$. Terms of irrigation and water rates were established according to tensiometers indications. Irrigation was started at the moment when the sucking tension shown by the tensiometer was close to 0.03 MPa. During the dry periods irrigation was performed every 2–3 days with a single rate of 5–15 mm. The field experiments were as follows:

– carrot (*Daucus carota* L.) – in 1991–1994,
– red beet (*Beta vulgaris* L.) – in 1991–1994,
– snap bean (*Phaseolus vulgaris* L.) – in 1991–1993,

– winter squash (*Cucurbita maxima* Duch.) – in 1998–1999,
– zucchini squash (*Cucurbita pepo* L.) – in 1998–1999.

The following cultivars were examined: carrot cv. 'Perfekcja', red beet cv. 'Czerwona Kula', snap bean cv. 'Złota Saxa', squash cv. 'Bambino', zucchini cv. 'Astra'. All cultural practices were typical for the cultivation of the vegetables tested [Borna 1982]. The plot area for harvest was from 9 to 12 m^2, according to species and year of the study.

The multi-year (1891–1995) value of rainfall during the growing season (April–September) at the locality was 324 mm (tab. 1). Rainfall conditions during the period of the study were very contrasted, ranging in growing seasons (April–September) from 148 to 378 mm.

Table 1. Climatic conditions during the vegetation period (1 April – 30 September) and seasonal irrigation rates applied
Tabela 1. Warunki klimatyczne podczas okresu wegetacji (1 kwietnia – 30 września) i zastosowane sezonowe dawki wody

Specification Wyszczególnienie	Unit Jednostka	Period of the study – Okres badań				Long-term value Średnia wieloletnia
		Dry year – Rok suchy		Wet year – Rok mokry		
		A	B	A	B	
Air temperature Temperatura powietrza	°C	16.6	15.1	14.8	14.1	13.9
Rainfall Opady	mm	148	309	351	378	324
Irrigation rate Dawka nawodnieniowa	mm	180	154(174*)	30	91(95*)	-

A – for edible carrot, red beet and snap bean – dla marchwi jadalnej, buraka ćwikłowego i fasoli szparagowej
B – for squash and zucchini – dla dyni i cukinii
*data in brackets for zucchini – dane w nawiasach dla cukinii

Table 2. Water properties of the sandy soil at Kruszyn Krajeński
Tabela 2. Właściwości wodne gleby piaszczystej w Kruszynie Krajeńskim

Soil layer cm	Water storage, mm, for: Zapas wody, mm, dla:			RU mm	ERU mm
	PPW	WK	WTW		
0–25	33.7	16.1	7.5	26.2	17.6
25–50	23.8	12.1	7.0	16.8	11.7
0–50	57.5	28.2	14.5	43.0	29.3
50–75	14.0	9.6	3.2	10.8	4.4
75–100	15.5	6.3	1.4	14.1	9.2
0–100	87.0	44.1	19.1	67.9	42.9

PPW – field water capacity (pF = 2.0) – polowa pojemność wodna (pF = 2,0)
WK – critical humidity (pF = 3.2) – wilgotność krytyczna (pF = 3,2)
WTW – permanent wilting point (pF = 4.2) – wilgotność trwałego więdnięcia (pF = 4,2)
RU – useful water retention (RU = PPW – WTW) – retencja użyteczna
ERU – effective useful water retention (ERU = PPW – WK) – efektywna retencja użyteczna

The field experiments were carried out on a very light soil characterized by low capacity for water retention. The field water capacity in the topsoil 0–100 cm was only 87 mm (tab. 2). The mean content of floatable particles in a 1 m soil layer was 5%, while that of humus was 1.19%.

The obtained results were subjected to statistical analysis. Correlation and simple linear regression analyses were also used.

Dependences between increases in vegetable yields caused by drip irrigation and rainfall during the periods of increased water requirements of plants were investigated. Calculations were conducted according to methodics elaborated by Grabarczyk [Grabarczyk 1987]. The following equation of a general form was developed:

$$Q = k\,(P_o - P_A)$$

where: Q – yield increase caused by drip irrigation (kg ha^{-1}),
k – specific coefficient expressing the unitary increase in yield under influence of drip irrigation covering every 1 mm of rainfall deficit in relation to optimal rainfall (P_o) (kg ha^{-1}),
P_O – optimal rainfall during the critical period (mm),
P_A – actual rainfall during the critical period (mm).

Table 3. Water needs and water deficits of vegetable crops in the region of Bydgoszcz according to the balance method of Drupka [1976] for the period 1971–1995
Tabela 3. Potrzeby wodne i deficyty wody upraw warzywnych w rejonie Bydgoszczy według metody bilansowej Drupki [1976] w okresie 1971–1995

Specification Wyszczególnienie		Months of the growing season – Miesiące okresu wegetacji						
		IV	V	VI	VII	VIII	IX	IV–IX
Long-period averages – Średnie wieloletnie								
Rainfall Opady	mm	27	46	71	71	57	47	319
Air temperature Temperatura powietrza	°C	8.0	14.0	17.0	19.0	18.4	13.6	15.0
Water needs Potrzeby wodne	mm	60	93	108	121	98	58	538
Water deficits Deficyty wody	mm	33	47	37	50	41	11	219
Years characterized by the lowest rainfall (occurrence probability P = 20%) Lata cechujące się najniższymi opadami (prawdopodobieństwo wystąpienia P = 20%)								
Rainfall Opady	mm	22	41	32	25	31	27	178
Air temperature Temperatura powietrza	°C	8.7	14.4	17.6	20.9	19.9	14.9	16.1
Water needs Potrzeby wodne	mm	60	93	110	138	110	60	571
Water deficits Deficyty wody	mm	38	52	78	113	79	33	393

Data processing in the paper was restricted to calendar months because of limited data on rainfall amount which were accessible for the use. Selection criterion of the best relationships between increases in yield caused by drip irrigation and rainfall during the two- (or three-) month periods was the quantity of correlation coefficient. The formula presented above $Q = k\,(P_o - P_A)$ is a simple transformation of a linear regression equation from a general form y = –ax + b to the form y = a(b/a – x). So, the value of the optimal rainfall (P_o) is obtained from the quotient of the free term in regression equation (b) and regression coefficient (a). Similar yield-irrigation relationships were previously elaborated for sprinkler irrigation [Żarski 1989, Rolbiecki and Rolbiecki 1998, Rolbiecki et al. 2000]. Water needs of vegetable crops cultivated in the region of Bydgoszcz are the highest during the months: June, July and August (tab. 3).

RESULTS AND DISCUSSION

The use of drip irrigation in vegetable growing under sandy soils conditions resulted in differentiated productive effects as dependent on different amount and distribution of rainfall during the period of the study.

Red beet. Marketable yields of red beet grown on control (non-irigated) plots ranged from 0.87 to 21.4 t ha^{-1} in dry and wet year, respectively (fig. 1). Drip-irrigated red beet yields were stabilized, amounting over 20 t ha^{-1} every year. Yields on control plots were directly proportional to amounts of rainfall in July (in the range 29–99 mm) (fig. 2A). Increases in yields caused by drip irrigation were inversely proportional to rainfall of July in the same range (fig. 2B).

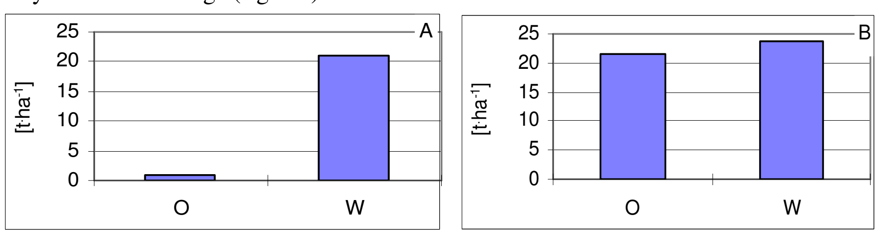


Fig. 1. Effect of drip irrigation on marketable yields of red beet on a sandy soil in dry [A] and wet [B] growing season: O – non-irrigated plants, W – drip-irrigated plants

Rys. 1. Wpływ nawadniania kroplowego na plony handlowe buraka ćwikłowego na glebie piaszczystej w suchym [A] i wilgotnym [B] sezonie wegetacji: O – nienawadniane rośliny, W – kropelkowe nawadnianie roślin

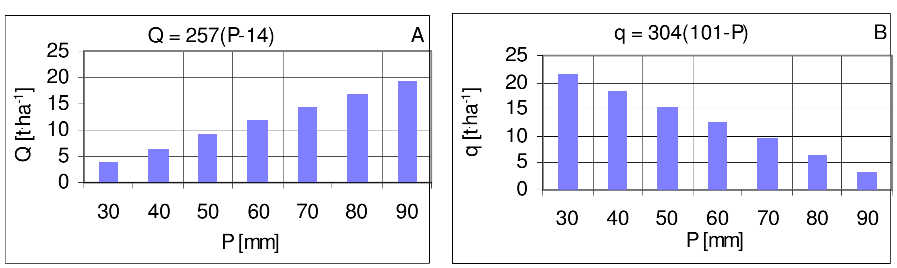


Fig. 2. Relations between rainfall of July and marketable yields of red beet obtained on non-irrigated plots [A] or increases in yields caused by drip irrigation [B]

Rys. 2. Zależności pomiędzy opadem atmosferycznym lipca a plonami handlowymi buraka ćwikłowego na poletkach nienawadnianych [A] bądź przyrostami plonów spowodowanymi nawadnianiem kroplowym [B]

Carrot. Yields of carrot cultivated on non-irrigated plots amounted 0.1 t ha^{-1} in dry and 39.3 t ha^{-1} in wet growing season, respectively (fig. 3). Drip-irrigated carrot yields amounted 37.1 and 50.5 t ha^{-1} in dry and wet years, respectively. Yields on non-irrigated plots were directly proportional to rainfall of July (in the range 29–99 mm) (fig. 4A). Yield increases obtained thanks to drip irrigation were inversely proportional to rainfall in July (fig. 4B).

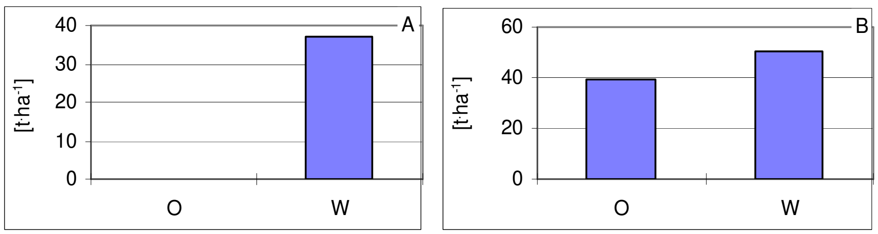


Fig. 3. Effect of drip irrigation on marketable yields of carrot on a sandy soil in dry [A] and wet [B] growing season: O – non-irrigated plants, W – drip-irrigated plants

Rys. 3. Wpływ nawadniania kroplowego na plony handlowe marchwi na glebie piaszczystej w suchym [A] i wilgotnym [B] sezonie wegetacji: O – nienawadniane rośliny, W – kropelkowe nawadnianie roślin

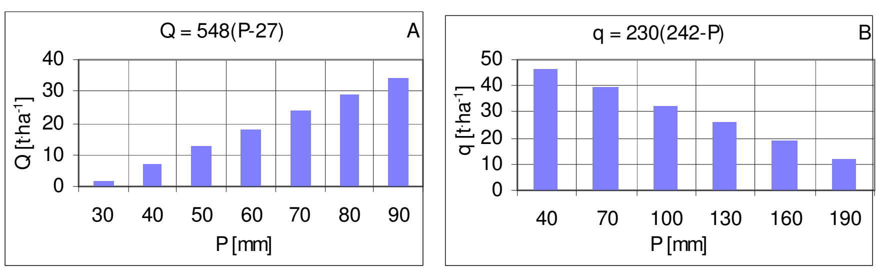


Fig. 4. Relation between rainfall of July and marketable yields of carrot obtained on non-irrigated plots [A] as well as relation between rainfall total in June and July and increases in yields of carrot caused by drip irrigation [B]

Rys. 4. Zależność pomiędzy opadem atmosferycznym w lipcu a plonami handlowymi marchwi na poletkach nienawadnianych [A] oraz zależność pomiędzy sumą opadów czerwca i lipca a przyrostami plonów marchwi spowodowanymi nawadnianiem kroplowym [B]

Snap bean. There was no marketable yields of pods of this vegetable grown without supplemental irrigation in the vegetation period characterized by very low rainfall (fig. 5). Marketable yields harvested from non-irrigated plots in a year characterized by sufficient rainfall amounted more than 6,5 t ha^{-1}. Figure 6A shows the directly proportional relationship between rainfall of June-July (in the range 44–184 mm) and yields of snap bean from control plots. Increases in marketable yield of pods caused by drip irrigation were inversely proportional to rainfall sum from June 1 to July 31 (fig. 6B).

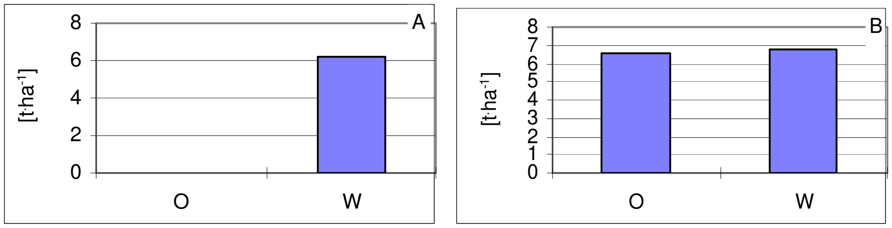


Fig. 5. Effect of drip irrigation on marketable yields of snap bean on a sandy soil in dry [A] and wet [B] growing season: O – non-irrigated plants, W – drip-irrigated plants

Rys. 5. Wpływ nawadniania kroplowego na plony handlowe fasoli szparagowej na glebie piaszczystej w suchym [A] i wilgotnym [B] sezonie wegetacji: O – nienawadniane rośliny, W – kropelkowe nawadnianie roślin

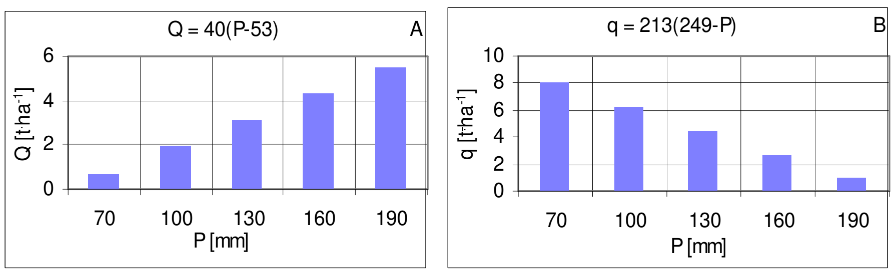


Fig. 6. Relations between rainfall total in June and July and marketable yields of snap bean obtained on non-irrigated plots [A] or increases in yields of snap bean caused by drip irrigation [B]

Rys. 6. Zależności pomiędzy sumą opadów czerwca i lipca a plonami handlowymi fasoli szparagowej na poletkach nienawadnianych [A] bądź przyrostami plonów fasoli szparagowej spowodowanymi nawadnianiem kroplowym [B]

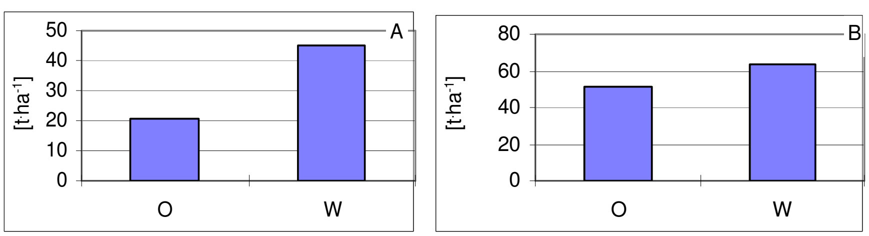
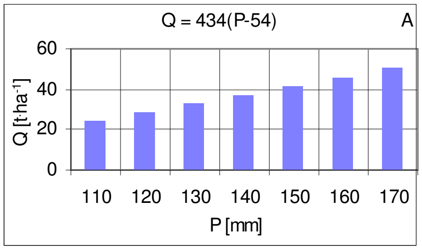


Fig. 7. Effect of drip irrigation on marketable yields of squash (‘Bambino’) on a sandy soil in dry [A] and wet [B] growing season: O – non-irrigated plants, W – drip-irrigated plants

Rys. 7. Wpływ nawadniania kroplowego na plony handlowe dyni odmiany ‘Bambino’ na glebie piaszczystej w suchym [A] i wilgotnym [B] sezonie wegetacji: O – nienawadniane rośliny, W – kropelkowe nawadnianie roślin

Squash. Marketable yields of squash fruits harvested from non-irrigated plots amounted 20.4 t ha^{-1} in a dry year, whereas in a wet year they were higher than 50 t ha^{-1} (fig. 7). Also higher were squash yields obtained on drip-irrigated plots in a wet year (63.8 t ha^{-1}) as compared to those in a dry year (44.9 t ha^{-1}). Figure 8 shows linear rela-



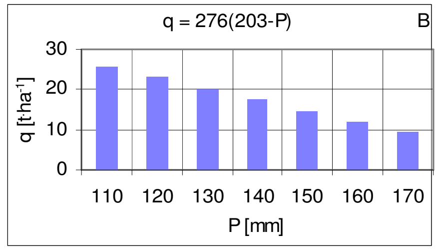
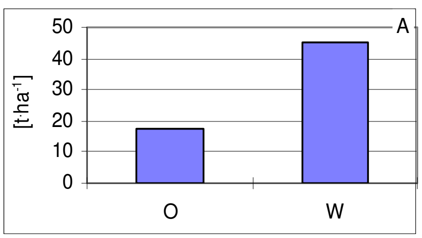


Fig. 8. Relations between rainfall total in July and August and marketable yields of squash ('Bambino') obtained on non-irrigated plots [A] or increases in yields of squash ('Bambino') caused by drip irrigation [B]

Rys. 8. Zależności pomiędzy sumą opadów lipca i sierpnia a plonami handlowymi dyni ('Bambino') na poletkach nienawadnianych [A] bądź przyrostami plonów dyni ('Bambino') spowodowanymi nawadnianiem kroplowym [B]



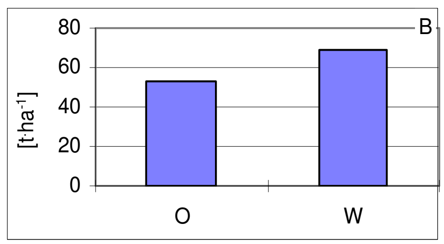
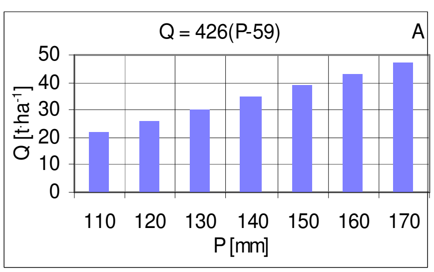


Fig. 9. Effect of drip irrigation on marketable yields of zucchini on a sandy soil in dry [A] and wet [B] growing season: O – non-irrigated plants, W – drip-irrigated plants

Rys. 9. Wpływ nawadniania kroplowego na plony handlowe cukinii na glebie piaszczystej w suchym [A] i wilgotnym [B] sezonie wegetacji: O – nienawadniane rośliny, W – kropelkowe nawadnianie roślin



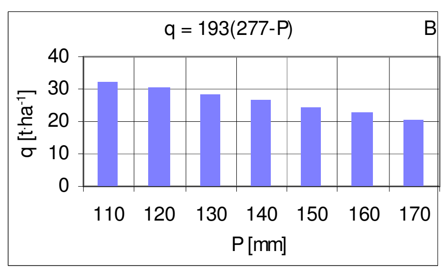


Fig. 10. Relations between rainfall total in July and August and marketable yields of zucchini ('Astra') obtained on non-irrigated plots [A] or increases in yields of zucchini ('Astra') caused by drip irrigation [B]

Rys. 10. Zależności pomiędzy sumą opadów lipca i sierpnia a plonami handlowymi cukinii ('Astra') na poletkach nienawadnianych [A] bądź przyrostami plonów cukinii ('Astra') spowodowanymi nawadnianiem kroplowym [B] tionships between rainfall of July–August (in the range 103–173 mm) and yields on non-irrigated plots (directly proportional) or increases in yields due to irrigation (inversely proportional).

Zucchini. Zucchini crop yielded 17,3 t ha^{-1} on plots without irrigation in a dry year and 52.6 t ha^{-1} in a wet one (fig. 9). Under conditions of irrigation, this vegetable yielded 44.9 and 68.9 t ha^{-1} in dry and wet growing seasons, respectively. Linear relationships between sum of rainfall in July–August (range 103–173 mm) and yields on non-irrigated plots or yield increasings due to irrigation were shown on figure 10.

The analysis of the obtained results proved that the use of irrigation under conditions of sandy soils in region of Bydgoszcz was effective which confirmed previous opinions and reports of other authors [Kee et al. 1994, Niedziela et al. 1994, Kaniszewski and Knaflewski 1997]. According to the mentioned above papers, supplemental irrigation is beneficial in most years since rainfall is rarely uniformly distributed, even in years with above-average precipitation. Therefore, supplemental irrigation is necessary every year for successful vegetable crop production. Water is simple but necessary requirement for plant growth. Nothing will substitute for timely application of water.

CONCLUSIONS

The results obtained and the data analyses show that the higher was rainfall during the critical periods in growing season, the higher were yields of vegetables cultivated in a sandy soil without irrigation. On the other hand, the lower was rainfall during vegetation, the higher were increases in marketable yield of all the tested vegetable crops owing to drip irrigation.

The results indicated the decisive role of water on the outcome of yield of vegetable crops grown on a soil characterized by limited water holding capacity. The use of drip irrigation in vegetable growing under sandy soil conditions reduced distinctly the uncertainty in yields of these crops due to climatic – especially rainfall – variability. The experiments proved that vegetable production on loose sandy soils was only possible with the use of drip irrigation.

Using the equations elaborated it is possible to determine critical periods for individual vegetable species, optimal rainfall during these periods as well as increases of yields caused by supplementary drip irrigation covering rainfall deficits. According to the elaborated dependences, the approximated estimation of average needs of drip irrigation and average production effects of drip irrigation in particular rainfall regions is also possible.

REFERENCES

Borna Z. (ed.), 1982. Szczegółowa uprawa warzyw. PWRiL, Warszawa, 681.

Drupka S., 1976. Techniczna i rolnicza eksploatacja deszczowni. PWN, Warszawa, 310.

Dzieżyc J., 1988. Rolnictwo w warunkach nawadniania. PWN, Warszawa, 415.

Grabarczyk S., 1977. Nowy przewód i dozator do nawadniania kroplowego. Zesz. Nauk. ATR w Bydgoszczy 49, Rolnictwo 4, 13–19.

Grabarczyk S., 1987. Efekty, potrzeby i możliwości nawodnień deszczownianych w różnych regionach kraju. Zesz. Probl. Post. Nauk Roln. 314, 46–64.

Grabarczyk S., Dudek S., Rzekanowski C., Żarski J., 1997. Effects of irrigation of plants in central Poland with special emphasis on very light soils. Proceedings of Poland – Israel Conference on „Water requirements and irrigation effects of plants cultivated in arid and semiarid climates". Tel Aviv, 2, 139–147.

Kaniszewski S., 1987. Nawadnianie warzyw. PWRiL, Warszawa, 111.

Kaniszewski S., Cieślak-Wojtaszek W., 1994. Vegetable production in Poland. Acta Hort. 371, 21–28.

Kaniszewski S., Knaflewski M., 1997. The results of studies on water requirement and effectiveness of the irrigation of vegetable crops in Poland. Proceedings of Poland – Israel Conference on „Water requirements and irrigation effects of plants cultivated in arid and semiarid climates". Tel Aviv, 2, 103–110.

Kee E., Cook W., Granberry D., Hohlt H., Sanders D., 1994. Drought Advisory for vegetable production. North Carolina Cooperative Extension Service, North Carolina State University, Raleight, North Carolina, (Electr. Publ. Number DRO-13).

Niedziela C. E., Evans R, Sanders D. C., Jester W. R., 1994. Offsetting Druoght for Small-Scale Vegetable Production. North Carolina Cooperative Extension Service, North Carolina State University, Raleight, North Carolina, (Electr. Publ. Number DRO-16).

Rolbiecki S., Rolbiecki R., 1998. Irrigation effects of red beet (*Beta vulgaris* L.) under sandy soils conditions as affected by rainfall during the critical periods. Przegl. Nauk. Wydz. Melioracji i Inżynierii Środowiska SGGW w Warszawie, 15, 87–90.

Rolbiecki S., Żarski J., Grabarczyk S., 2000. Yield-irrigation relationships for field vegetable crops grown in Central Poland. Acta Hort. 537, 2, 867–870.

Żarski J., 1989. Zwyżki plonów ogórków gruntowych i selerów pod wpływem deszczowania a opady atmosferyczne w okresie krytycznym. Zesz. Probl. Post. Nauk Roln. 343, 67–74.

NAWADNIANIE KROPLOWE JAKO CZYNNIK ŁAGODZĄCY SUSZĘ W UPRAWIE WARZYW NA GLEBACH PIASZCZYSTYCH W REGIONIE BYDGOSKIM

Streszczenie. Celem badań było ukazanie możliwości zapobiegania suszy w uprawie warzyw na luźnych glebach piaszczystych w regionie Bydgoszczy poprzez użycie nawadniania kroplowego. Zastosowane w takich warunkach klimatyczno-glebowych nawadnianie kroplowe było podstawowym czynnikiem plonotwórczym, zapewniającym stabilne plony badanych warzyw (marchwi, buraka ćwikłowego, fasoli szparagowej, dyni i cukinii). Wyniki potwierdziły podstawową rolę wody w uzyskiwaniu plonów warzyw na glebie o ograniczonej pojemności wodnej. Doświadczenia dowiodły, że uprawa warzyw na glebach piaszczystych jest możliwa wyłącznie przy zastosowaniu nawadniania uzupełniającego. Stosując opracowane formuły, możliwe jest określenie okresów krytycznych dla poszczególnych gatunków roślin, opadów optymalnych dla tych okresów oraz spodziewanych przyrostów plonów spowodowanych nawadnianiem kroplowym pokrywającym deficyty opadów. Dzięki opracowanym zależnościom szacunkowa ocena przeciętnych potrzeb nawadniania kroplowego i efektów produkcyjnych nawadniania w poszczególnych regionach opadowych również jest możliwa.

Słowa kluczowe: burak ćwikłowy, marchew, fasola szparagowa, dynia, cukinia

Stanisław Rolbiecki, Roman Rolbiecki, Czesław Rzekanowski, Jacek Żarski, Katedra Melioracji i Agrometeorologii, Wydział Rolniczy Akademii Techniczno-Rolniczej w Bydgoszczy, ul. Bernardyńska 6, 85-029 Bydgoszcz, e-mail: rolbs@atr.bydgoszcz.pl