Article

Response of Chosen American *Asparagus officinalis* L. Cultivars to Drip Irrigation on the Sandy Soil in Central Europe: Growth, Yield, and Water Productivity

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Abstract: The aim of this study was to verify the response of 13 American asparagus cultivars cultivated for green spear on surface postharvest drip irrigation. Irrigation, used to compensate for periodic deficiencies in precipitation, allows for high- and good-quality crops for many species. The field experiment was carried out in 2006–2008 on a very light sandy soil in central Europe (Poland). Irrigation treatments were applied using the tensiometer indications. Water requirements of asparagus were calculated on the base of reference evapotranspiration and crop coefficients. The following evaluations were made: Height, diameter, and number of summer stalks, as well marketable yield, weight, and number of consumption green spears. Drip irrigation applied for 2 years (2006–2007) in the postharvest period had a positive effect on all studied traits in both summer stalks and green spears in 2007–2008. A significant increase in the height, number, and diameter of summer stalks, as well an increase in the marketable yield, weight, and number of green spears was observed for most of the cultivars. In general, postharvest drip irrigation of asparagus cultivated in very light sandy soil significantly contributes to the increase in productivity of American cultivars of this species.

Keywords: *Asparagus officinalis* L.; cultivars; spears yield; sandy soil; water requirements; IWUE

1. Introduction

Asparagus is a perennial vegetable species. Therefore, choosing the most advantageous cultivars for cultivation is a very important factor in yielding. Thanks to intensive

breeding work carried out in many countries around the world, new cultivars of asparagus are quickly emerging. New cultivars of asparagus are usually very fertile, with relatively high soil and water requirements [1,2]. Therefore, to obtain maximum marketable yields of a given asparagus cultivar, it is recommended to create optimal growth and development conditions during the growing season. Maximum asparagus production possibilities can be achieved by applying organic and mineral fertilization adapted to species nutritional needs and ensuring optimal humidity, with the use of irrigation supplementing deficiency in precipitation. Due to the specific method of cultivation, i.e., harvesting of spears in early spring, the height and quality of asparagus sprouts depend on the amount of ingredients stored in asparagus rootstocks during the growing season of the previous year [1–3].

In recent years in Poland, asparagus (*Asparagus officinalis* L.) has been observed as a vegetable gaining increasing economic significance. On the one hand, this phenomenon is related to the increase in exports of asparagus spears to European Union countries (mainly Germany), and on the other hand, with an increase in demand for this valuable vegetable among domestic consumers, changing their eating habits noticeably. Basic “heavy” species of vegetables, primarily root vegetables such as potatoes, carrots, parsley or red beet, are replaced with low-caloric species with high biological and flavor values [1,2].

Asparagus is a plant grown primarily in light soils with low water content, i.e., limited retention capacity [1,4]. On the one hand, due to a deep-reaching and well-developed root system, asparagus is relatively resistant to water deficiency in soil [5–7]. On the other hand, asparagus, as a light soil plant, reacts very positively to irrigation treatments, which are used in the postharvest period, usually from June to August, in the climatic and soil conditions of Central Europe. Postharvest irrigation significantly increases the yield of asparagus spears in the following year [3,4,8–16].

One of the elements of sustainable plant production, which has the task of protecting the soil and plant raw materials, is melioration treatments, among which drip irrigation is of great importance in commercial crops. The aim of the study was to verify the response of 13 chosen American asparagus cultivars grown for green spear production to surface drip irrigation on sandy soil in the region of central Europe (Poland).

2. Materials and Methods

2.1. Plant Material and Location of the Experiment

The field experiment was carried out in the years 2006–2008 at Kruszyn Krajski near Bydgoszcz (central Poland) on a sandy soil (Figure 1).

The soil was classified to Typic Hapludolls. The clay content in the topsoil was 7% and, in the subsoil, the clay content ranged from 3% to 5%. The average organic matter content was 1.19%. The water reserve to 1 m depth of soil at field capacity was 87 mm and the available water was 68 mm. The field experiment was conducted in a randomized block design of a 2-factorial “split-plot” system with 4 replications. The first factor was irrigation used in 2 variants: O–non-irrigated plots (control) and D–drip-irrigated plots. The second factor was 13 American’s cultivars asparagus (*Asparagus officinalis* L.) including Jersey Giant, Jersey Knight, Jersey Supreme, Jersey Deluxe, Jersey King, Atlas, Grande, Apollo, Purple Passion, UC 157, NJ 953, UC 115, and JWC 1. The asparagus crowns were planted 10th of April 2003.

Terms of single irrigation treatments of asparagus were determined on the basis of tensiometer indications according to Horticultural Institut in Geisenheim (Germany) [17]. During the irrigation season, the soil water potential was not less than -50 kPa. The surface drip irrigation of asparagus plants performed done using 16 mm diameter linear drip line T-Tape, with a 20 cm distance between the emitters. The flow rate was $5 \text{ l m}^{-1} \text{ h}^{-1}$.

Figure 1. Location of the Bydgoszcz region—within the Kuyavian-Pomeranian Province—in Poland and in Europe.

The standard growing techniques as recommended for asparagus under Polish conditions according to Knaflewski [1] were applied. The asparagus was cultivated for green spears. The plot area for harvest was 15.12 m² (24 pcs × 35 cm × 180 cm). Green spears were daily collected for 9 (2007) or 10 weeks (2008) depending on the year of harvest. The observation included both summer stalks in the years 2006–2007 and green consuming spears in the years 2007–2008. The following evaluations were made: Height (cm), number, and diameter (mm) of summer stalks, as well as marketable yield (t·ha^{−1}), weight (g), and number of green spears. The irrigation water use efficiency (IWUE) was also calculated, which is the quotient of the increase in yield obtained during irrigation and the seasonal dose of water used during irrigation. Irrigation water use efficiency (kg·ha^{−1}·mm^{−1}), which presents the effectiveness of water use, was calculated for a marketable yield of green spears using the following Equation (1):

$$IWUE = \frac{(y - a)}{x}, \quad (1)$$

where

y = yield after irrigation (kg),

a = yield without irrigation (kg),

x = seasonal dose of water used in irrigation (mm).

The experimental data height, number, and diameter of summer stalks, as well marketable yield, weight, and number of green spears were statistically processed by variation analysis. Mean values were verified with Tukey's test at a 5% level.

2.2. Assessment of Water and Irrigation Needs

Reference evapotranspiration (ET_o) was determined using Hargreaves' model [18] modified by Droogers and Allen [19] and expressed in Equation (2):

$$ET_o = HC \times Ra \times (T_{max} - T_{min})^{HE} \times \left(\frac{T_{max} + T_{min}}{2} + HT \right), \text{ (mm)} \quad (2)$$

where

HC = empirical Hargreaves coefficient = 0.0025,

Ra = extraterrestrial radiation (mm day⁻¹),

T_{max} = maximum air temperature (°C),

T_{min} = minimum air temperature (°C),

HE = Hargreaves exponent = 0.5,

HT = Hargreaves temperature coefficient = 16.8.

Potential evapotranspiration (ET_p) was determined by the method of crop coefficients [20] using crop coefficients for asparagus as determined by Hargreaves' model modified by Droogers and Allen [14]. To take into account the specificity of drip irrigation (limited wetted area of soil), Equation (3) was applied [21]:

$$ET_p = ET_o \times kc \times kr, \text{ (mm)} \quad (3)$$

where

ET_o = reference evapotranspiration (mm),

kc = crop coefficients,

kr = reduction coefficients.

Reduction coefficients were determined according to Freeman and Garzoli's formula [22] based on the percentage of surface coverage of asparagus in the postharvest period [14]. The results are presented in Table 1.

Table 1. Values of the correction factor k_r according to Freeman and Garzoli.

Area Covering [%]	Values of Factor k_r
10	0.10
20	0.20
30	0.30
40	0.40
50	0.75
60	0.80
70	0.85
80	0.90
90	0.95
100	1

Drought index (D) according to Stenz [23] is expressed in Equation (4):

$$D = \frac{ET_o}{P}, \quad (4)$$

where

ET_o = reference evapotranspiration (mm),

P = precipitation in a given period (mm).

To describe the precipitation conditions during the experiment, the worldwide recommended Standardized Precipitation Index (SPI) was used [24]. Equation (5) was used to calculate SPI:

$$SPI = \frac{f(P) - \mu}{\sigma}, \quad (5)$$

where

$f(P)$ = transformed totals of precipitation in a given period,
 μ = mean value of the normalized historical precipitation series,
 σ = mean standard deviation of the normalized historical precipitation series.

2.3. Meteorological Conditions

Precipitation conditions in individual decades of the growing and irrigation seasons for asparagus were described according to the season classification, based on the Standardized Precipitation Index, as presented in Table 2.

Table 2. Classification of the period as dependent on Standardized Precipitation Index values [24].

Period	Standardized Precipitation Index
Extreme drought	≤ -2.00
Severe drought	from -1.99 to -1.50
Moderate drought	from -1.49 to -1.00
Normal	from -0.99 to 0.99
Moderate wet	from 1.00 to 1.49
Severe wet	from 1.50 to 1.99
Extreme wet	≥ 2.00

Numerical data from measurements taken in the meteorological station of the then Department (now the Laboratory) of Land Reclamation and Agrometeorology at the University of Science and Technology located in Mochelek near Bydgoszcz were used in the calculations.

Average air temperature values during the growing season (April–September) in the research years (2006–2007) were higher than in the long-term (1971–2000) by $0.8\text{ }^{\circ}\text{C}$ and $0.5\text{ }^{\circ}\text{C}$, respectively (Table 3). In the first year of the study, high air temperature values were found in July ($22.4\text{ }^{\circ}\text{C}$), with the value exceeding the long-term mean by as much as $4.2\text{ }^{\circ}\text{C}$. In the second year of the study, high air temperature values were found in June ($18.2\text{ }^{\circ}\text{C}$, i.e., $1.9\text{ }^{\circ}\text{C}$ above the long-term mean).

Table 3. Air temperature ($^{\circ}\text{C}$) in the 2006–2007 vegetation season.

Year	10-Day Period	Month						Mean
		Apr	May	June	July	Aug	Sept	
2006	1	5.3	12.9	11.8	22.7	17.6	15.2	15.1
	2	7.3	13.1	18.9	21.8	17.4	15.7	
	3	8.7	11.4	19.7	22.7	15.0	14.6	
	Mean	7.1	12.5	16.8	22.4	16.6	15.2	
2007	1	5.9	9.3	18.8	15.7	18.6	12.6	14.8
	2	9.3	12.7	19.5	21.1	18.6	11.3	
	3	10.2	19.0	16.2	17.3	16.4	13.2	
	Mean	8.5	13.8	18.2	18.0	17.8	12.4	
Mean for 2006–2007		7.8	13.1	17.5	20.2	17.2	13.8	14.9
Mean for 1971–2000		7.6	13.1	16.3	18.0	17.7	13.1	14.3
Difference (+/–)		+0.2	0.0	+1.3	+2.2	−0.5	+0.7	+0.6

Total precipitation of the growing season in the research years, in relation to the long-term mean, was higher by 54 mm (i.e., by 19%) (Table 4). Higher precipitation totals were recorded in the year 2007 (367 mm, i.e., 131% of the long-term mean). Particularly heavy rainfall occurred in June and July 2007, amounting to 103 mm and 112 mm, respectively, which constituted 172% or 167% of the long-term mean. In the first year of the study, the highest rainfall was recorded in August (115 mm, i.e., 225% of the long-term mean).

Table 4. Rainfalls (mm) in the 2006–2007 vegetation season.

Year	10-Day Period	Month						Mean
		Apr	May	June	July	Aug	Sept	
2006	1	0	10	7	0	75	37	317
	2	0	20	15	26	23	0	
	3	45	34	0	5	17	4	
	Mean	45	64	22	31	115	42	
2007	1	5	21	43	79	3	18	367
	2	0	23	24	4	11	5	
	3	3	5	36	29	46	13	
	Mean	8	49	103	112	60	36	
Mean for 2006–2007		26	56	62	71	87	39	342
Mean for 1971–2000		25	43	60	67	51	42	288
Difference (+/–)		+1	+13	+2	+4	+36	–3	+54

Air temperature during the harvest of asparagus spears (from the third decade of April to the third decade of June) is a very important element of asparagus cultivation [1,14].

2.4. Irrigation Needs

Irrigation was carried out after the harvest period, during the summer months, as recommended [25]. In 2006, irrigation began on July 4 and ended on August 31. The irrigation season lasted 59 days. During the time, 10 single doses were used, amounting to 92 mm. In 2007, the irrigation season was shorter and lasted 37 days (from 15 July to 20 August). A total of 54 mm water was used in 6 doses.

The values of Stenz index, presented in Table 5, indicate the irrigation needs of asparagus cultivars in July and August of the years 2006 and 2007.

Table 5. Values of the Stenz index for the 2006–2007 irrigation period.

Year	Month	
	July	August
2006	6.2	0.9
2007	1.2	2.1

The values of the Standardized Precipitation Index, summarized in Table 6, reflect the actual precipitation conditions occurring in individual decades of the irrigation season. The first decade of July in 2006 was extremely dry, while the second decade of July in 2007 was moderately dry.

Table 6. Values of the Stenz index for the 2006–2007 irrigation period.

Month	10-Days Period	Year	
		2006	2007
July	1	–2.17	2.00
	2	0.08	–1.49
	3	–0.63	0.68
August	1	1.95	–0.69
	2	0.69	0.06
	3	0.31	1.17

The smallest daily water needs under drip irrigation (below 1 mm) were found in the third decade of June when summer stalks were just beginning to grow (Figure 2). However, irrigation needs were much higher in the next 2 months of the irrigation season (from 3.2 mm to 4.4 mm). Depending on weather conditions (particularly temperature), asparagus irrigation needs variation in individual years. For comparison, in 9 years of trials with European cultivars (Gijnlim, Ramos, Vulkan) conducted in central Poland (region of Bydgoszcz), the average daily value of field water consumption at drip irrigated plots in June, July, and August, was 1.7 mm, 3.5 mm, and 4.4 mm, respectively [14]. In the lysimeter studies by Paschold, et al. [12] daily water consumption under drip irrigation was, on average, 1.6 mm in June, 2 mm in July, and 3 mm in August.

Figure 2. Daily values of the potential evapotranspiration (mm) of the asparagus plants under drip irrigation conditions in particular months of the irrigation period.

The total water needs of asparagus in the postharvest period were higher in the first year of the study (258 mm) than in the second year of the study (241 mm) (Figure 3). For comparison, in the Rolbiecki study [14], the water needs of asparagus plants under drip irrigation ranged from 205 mm to 272 mm in individual years. The results of tests carried out by Paschold and Kunzelmann [26] in Germany's climatic conditions indicated that the water needs of asparagus plants from June 20 to September 1 ranged between 150–241 mm. Moreover, in prior studies carried out in Germany, Hartmann [8] estimated that, depending on precipitation conditions, the water needs of asparagus plants ranged between 179 mm and 240 mm. In turn, Pardo et al. [27] recorded the seasonal water consumption of asparagus under lysimeter conditions ranging from 274 mm to 294 mm. In the latest research on asparagus water needs in various regions of Poland reported by Rolbiecki et al. [28], the irrigation needs of asparagus plants were found to be, on average, 228 mm in the period from July 1 to August 31 in the central-north-west region of Poland, which also covers the area considered in the present study.

Figure 3. Cumulative potential evapotranspiration (mm) of the asparagus plants under drip irrigation conditions in particular months of the irrigation period.

3. Results and Discussion

3.1. Height, Number, and Diameter of Asparagus Summer Stalks

Drip irrigation, used after the green spears harvest in the growing season preceding the next asparagus harvest, significantly increased the height of asparagus summer stalks for the studied cultivars and years, on average, from 152 cm to 172 cm (Table 7). Stalk height due to drip irrigation increased, on average, by 20 cm (13%). The highest increase in stalk height (above 180 cm) under drip irrigation, on average, for 2 years of research, was obtained for the cultivars Apollo (196 cm), Grande (185 cm), Atlas (182 cm), Jersey King, and Purple Passion (181 cm). The best response to drip irrigation, with reference to this characteristic, was noted in Atlas cultivar. Drip irrigation increased the height of its summer stalks by 40 cm (i.e., by 28%). Some researchers have also shown a significant impact of irrigation on the height of summer stalks in the year preceding the harvest. For example, in the third and fourth year of cultivation, Drost and Wilcox-Lee [29], Hartmann [8,9], Pardo et al. [27], Paschold et al. [12], and Sterrett et al. [30] obtained an average increase in summer stalk height of 14 cm in comparison to non-irrigated control variants.

Table 7. Height of the asparagus summer stalks (cm) as dependent on cultivar and irrigation.

Cultivar	Control (Without Irrigation)			Drip Irrigation			Increase of the Height of Summer Stalks		
	2006	2007	Mean	2006	2007	Mean	2006	2007	Mean
Jersey Giant	133	139	136	164	168	166	31	29	30
Jersey Knight	158	161	159	166	175	170	8	14	11
Jersey Supreme	149	151	150	165	169	167	16	18	17
Jersey Deluxe	151	155	153	161	180	170	10	25	17
Jersey King	156	162	159	179	183	181	23	21	22
Atlas	139	145	142	179	185	182	40	40	40
Grande	160	165	162	181	190	185	21	25	23
Apollo	169	172	170	192	201	196	23	29	26
Purple Passion	150	155	152	178	185	181	28	30	29
UC 157	141	146	143	166	176	171	25	30	27
NJ 953	155	161	158	158	170	164	3	9	6
UC 115	159	162	160	159	171	165	0	9	4
JWC 1	122	149	135	130	157	143	8	8	8
Mean	149	156	152	165	178	172	18	22	20

2006: LSD_{0.05} for: Irrigation = 6.343; Cultivars = 16.591; Interaction: Cultivars/Irrigation = 25.831; Irrigation/Cultivars = 13.599. 2007: LSD_{0.05} for: Irrigation = 7.225; Cultivars = 14.739; Interaction: Cultivars/Irrigation = 22.341; Irrigation/Cultivars = 12.664. 2006–2007: LSD_{0.05} for: Irrigation = 2.663; Cultivars = 11.936; Interaction: Cultivars/Irrigation = 16.879; Irrigation/Cultivars = 9.603.

Postharvest drip irrigation, applied in the growing season preceding the next asparagus harvest, significantly increased the number of asparagus summer stalks per plant for the studied cultivars and years, on average, from 7.9 to 11.1 (Table 8). Stalk number per plant due to drip irrigation increased, on average, by 3.2 pcs (40%). The highest increase in stalk number per plant (12 and more) under drip irrigation, on average, for 2 years of research, was observed for Jersey King (13.3), Apollo (12.6), Jersey Supreme, Atlas, and UC 157 (12) cultivars. The best response to drip irrigation, with reference to this characteristic, was noted in UC 157 and Grande. Drip irrigation increased the number of stalks per plant of these cultivars by 5.0 and 5.1 pcs (i.e., by 72%), respectively. The positive impact of drip irrigation on the increase in the number of summer stalks was also presented for Germany's weather conditions, which are similar to Polish weather conditions, by Hartmann [9], Hartmann et al. [10], and Paschold et al. [12]. Drost [31] reported that under dry climatic conditions, lowering sandy soil moisture below -50 kPa reduced the number and height of stalks in comparison to drip-irrigated variants. Sterrett et al. [30] obtained an increase in stalk number due to irrigation, on average, of four stalks per plant, and Battilani [32] obtained an increase of one stalk per plant. The diverse response of asparagus cultivars to drip irrigation has been confirmed, i.e., by the results of Dutch [33] and Polish [14] studies.

Table 8. Number of the asparagus summer stalks (pcs) as dependent on cultivar and irrigation.

Cultivar	Control (Without Irrigation)			Drip Irrigation			Increase of the Number of Summer Stalks		
	2006	2007	Mean	2006	2007	Mean	2006	2007	Mean
Jersey Giant	8.1	7.6	7.8	10.6	10.2	10.4	2.5	2.6	2.5
Jersey Knight	6.7	7.0	6.8	10.5	10.7	10.6	3.8	3.7	3.7
Jersey Supreme	8.0	8.2	8.1	12.1	11.9	12.0	4.1	3.7	3.9
Jersey Deluxe	8.5	7.9	8.2	9.7	10.0	9.8	1.2	2.1	1.6
Jersey King	10.5	10.3	10.4	13.2	13.5	13.3	2.7	3.2	2.9
Atlas	9.2	8.8	9.0	12.1	12.0	12.0	2.9	3.2	3.0
Grande	6.8	7.1	6.9	12.0	11.9	11.9	5.2	4.8	5.0
Apollo	8.7	9.1	8.9	12.3	12.9	12.6	3.6	3.8	3.7
Purple Passion	8.3	7.9	8.1	8.8	9.1	8.9	0.5	1.2	0.8
UC 157	7.1	6.8	6.9	11.8	12.2	12.0	4.7	5.4	5.0
NJ 953	8.5	8.1	8.3	10.7	11.2	10.9	2.2	3.1	2.6
UC 115	6.8	7.3	7.0	10.6	11.5	11.0	3.8	4.2	4.0
JWC 1	7.2	6.9	7.0	9.1	9.0	9.0	1.9	2.1	2.0
Mean	8.0	7.9	7.9	11.0	11.2	11.1	3.0	3.3	3.2

2006: LSD_{0.05} for: Irrigation = 0.870; Cultivars = 2.190; Interaction: Cultivars/Irrigation = 3.655; Irrigation/Cultivars = 2.413. 2007: LSD_{0.05} for: Irrigation = 0.987; Cultivars = 1.839; Interaction: Cultivars/Irrigation = 3.196; Irrigation/Cultivars = 2.417. 2006–2007: LSD_{0.05} for: Irrigation = 1.160; Cultivars = 0.719; Interaction: Cultivars/Irrigation = 1.017; Irrigation/Cultivars = 0.578.

Drip irrigation, used after the harvest in the growing season preceding the next asparagus harvest, significantly increased the diameter of asparagus summer stalks for the studied cultivars and years, on average, from 11.2 mm to 12.6 mm (Table 9). Stalk diameter due to drip irrigation increased, on average, by 1.3 mm (12%). The highest increase in stalk diameter under drip irrigation, on average, for 2 years of research, was observed for Apollo (15.3 mm) and Grande (14.6 mm) cultivars. The best response to drip irrigation, with reference to this characteristic, was also noted in Apollo and Grande. Drip irrigation increased the diameter of their summer stalks by 3.6 mm and 3.2 mm, respectively (i.e., by 31% and 29%). Researchers such as, i.e., Sterrett et al. [30], Contador [34], Rubio [35], and Battilani [32], also observed a significant impact of drip irrigation on stalk diameter. As numerous authors have stated, irrigation significantly affects the growth of summer stalks and, consequently, the yield of asparagus spears in the next year [4,36–41]. Based on the results of a cultivar trial in 2003 (carried out as part of the third IACT) in which 31 asparagus cultivars were compared, Rolbiecki and Rolbiecki [2] found a significant impact of drip irrigation on the formation of summer stalks and marketable yield in the first harvest season. The impact of irrigation was manifested by the increased accumulation of carbohydrates in

asparagus rootstocks of the plants growing in optimal humidity conditions, used in spring of the next harvest year [30,31,42–48].

Table 9. Diameter of the asparagus summer stalks (mm) as dependent on cultivar and irrigation.

Cultivar	Control (Without Irrigation)			Drip Irrigation			Increase of the Diameter of Summer Stalks		
	2006	2007	Mean	2006	2007	Mean	2006	2007	Mean
Jersey Giant	10.6	10.3	10.4	10.8	11.2	11.0	0.2	0.9	0.5
Jersey Knight	12.6	12.3	12.4	12.0	13.5	12.7	−0.6	1.2	0.3
Jersey Supreme	10.0	9.1	9.5	11.9	12.2	12.0	1.9	3.1	2.5
Jersey Deluxe	11.6	11.2	11.4	11.4	12.3	11.8	−0.2	1.1	0.4
Jersey King	13.2	12.4	12.8	13.0	13.6	13.3	−0.2	1.2	0.5
Atlas	14.0	11.2	12.6	11.0	13.8	12.4	−3.0	2.6	−0.2
Grande	11.4	11.4	11.4	14.5	14.8	14.6	3.1	3.4	3.2
Apollo	11.8	11.5	11.6	15.0	15.6	15.3	3.2	4.1	3.6
Purple Passion	12.3	11.7	12.0	10.4	13.5	11.9	−1.9	1.8	0.0
UC 157	11.8	11.6	11.7	10.4	12.9	11.6	−1.4	1.3	0.0
NJ 953	10.5	10.1	10.3	13.2	13.7	13.4	2.7	3.6	3.1
UC 115	9.5	9.8	9.6	11.3	11.9	11.6	1.8	2.1	1.9
JWC 1	10.0	10.2	10.1	10.8	12.6	11.7	0.8	2.4	1.6
Mean	11.5	11.0	11.2	12.0	13.2	12.6	0.5	2.2	1.3

2006: LSD_{0.05} for: Irrigation = ns; Cultivars = 3.293; Interaction: Cultivars/Irrigation = 4.657; Irrigation/Cultivars = 2.677. 2007: LSD_{0.05} for: Irrigation = 0.143; Cultivars = 1.532; Interaction: Cultivars/Irrigation = 3.221; Irrigation/Cultivars = 2.774. 2006–2007: LSD_{0.05} for: Irrigation = 0.499; Cultivars = 2.234; Interaction: Cultivars/Irrigation = 3.159; Irrigation/Cultivars = 1.797.

3.2. Marketable Yield, Weight and Number of Asparagus Green Spears

Postharvest drip irrigation treatment of asparagus plants used in the growing season preceding the asparagus harvest significantly increased green spear yields from 4.21 t·ha^{−1} to 6.23 t·ha^{−1} in the next growing season (Table 10). The marketable yield increase in green spears due to drip irrigation for the studied cultivars and 2 years of research was, on average, 2.02 t·ha^{−1} (48%). The highest marketable yield increase under drip irrigation—above 7 t·ha^{−1}, on average, for 2 years of research—was obtained for Apollo, NJ 953, Jersey Deluxe, and Grande cultivars. High marketable yields above 6 t·ha^{−1} were obtained for UC 157, Jersey King, UC 115, Jersey Supreme, and Jersey Giant cultivars. Marketable yields above 5 t·ha^{−1} were obtained for Purple Passion and Jersey Knight. The lowest yields under drip irrigation (above 4 t·ha^{−1}) were collected from JWC 1 and Atlas. The best response to drip irrigation was noted in Jersey Deluxe and Jersey Giant. Drip irrigation increased their marketable yields by 4.37 t·ha^{−1} (157%) and 3.91 t·ha^{−1} (142%), respectively. No significant response to drip irrigation was found in Purple Passion, Jersey King, and Atlas. The response to drip irrigation in other tested cultivars was positive, and the observed marketable yield increases ranged from 1.71 t·ha^{−1} to 2.78 t·ha^{−1} (35–79%). The results obtained are consistent with the results of studies conducted by other scientists. Hartmann [8,9], in weather conditions characteristic for Germany, obtained yield increases of 50% in his trials on sandy soil and 25% on loamy sand due to drip irrigation. Moreover, Paschold et al. [4,11,13], carrying out a cultivar trial using drip irrigation, recorded the highest marketable yields for Gijnlim cultivar. In Poland, Rolbiecki [14] also obtained the highest marketable yields for both control (no irrigation) (6.5 t·ha^{−1}) and drip irrigated plots (10.9 t·ha^{−1}) for Gijnlim. Pinkau and Grutz [49] obtained significantly lower marketable yield increases in spears, on average, of 12.4%, observing the highest yield increases in dry years. Mulder and Lavrijsen [33], in an asparagus cultivar trial under sprinkler irrigation conducted in the Netherlands, obtained the highest yields for Gijnlim, amounting to 4.5 t·ha^{−1} in the first harvest year and 12.8 t·ha^{−1} in the second year. Numerous other authors have also presented a significant impact of irrigation on yield increases in asparagus spears grown in different than Polish climate zones [15,16,29,30,47].

Table 10. Marketable yield of the asparagus green spears ($\text{t}\cdot\text{ha}^{-1}$) as dependent on cultivar and irrigation.

Cultivar	Control (Without Irrigation)			Drip Irrigation			Increase of the Marketable Yield of Green Spears		
	2007	2008	Mean	2007	2008	Mean	2007	2008	Mean
Jersey Giant	2.55	2.95	2.75	6.46	6.87	6.66	3.91	3.92	3.91
Jersey Knight	3.43	3.51	3.47	5.64	5.81	5.72	2.21	2.30	2.25
Jersey Supreme	4.18	4.32	4.25	6.16	6.70	6.43	1.98	2.38	2.18
Jersey Deluxe	2.66	2.91	2.78	6.96	7.34	7.15	4.30	4.43	4.37
Jersey King	6.15	5.80	5.97	6.04	6.50	6.27	−0.11	0.70	0.30
Atlas	4.57	4.41	4.49	4.67	4.92	4.79	0.10	0.51	0.30
Grande	5.42	4.80	5.11	6.91	7.25	7.08	1.49	2.45	1.97
Apollo	5.77	5.40	5.58	7.21	7.84	7.52	1.44	2.44	1.94
Purple Passion	5.75	5.01	5.38	4.96	5.64	5.30	−0.79	0.63	−0.08
UC 157	4.16	3.98	4.07	5.72	6.58	6.15	1.56	2.60	2.08
NJ 953	5.13	4.22	4.67	6.93	7.51	7.22	1.80	3.29	2.55
UC 115	3.11	3.96	3.53	5.75	6.87	6.31	2.64	2.91	2.78
JWC 1	2.51	2.89	2.70	3.91	4.91	4.41	1.40	2.02	1.71
Mean	4.26	4.17	4.21	5.95	6.52	6.23	1.69	2.35	2.02

2007: LSD_{0.05} for: Irrigation = 0.473; Cultivars = 1.572; Interaction: Cultivars/Irrigation = 2.223; Irrigation/Cultivars = 1.274. 2008: LSD_{0.05} for: Irrigation = 0.581; Cultivars = 1.822; Interaction: Cultivars/Irrigation = 2.451; Irrigation/Cultivars = 1.422. 2007–2008: LSD_{0.05} for: Irrigation = 0.211; Cultivars = 0.946; Interaction: Cultivars/Irrigation = 1.337; Irrigation/Cultivars = 0.761.

Drip irrigation, used after the harvest in the next growing season preceding the asparagus harvest, significantly increased the mean spear weight from 35.33 g to 40.35 g (Table 11). The mean spear weight due to drip irrigation increased for the studied cultivars and 2 years of research, on average, by 5.02 g (14%). The greatest mean spear weight under drip irrigation—above 40 g, on average, for 2 years of research—was obtained for the cultivars Grande (48.79 g), Jersey Knight (43.32 g), Apollo (43.03 g), Purple Passion (42.99 g), Atlas (42.71 g), and UC 115 (41.24 g). The best response to drip irrigation, with reference to this characteristic, was noted in Atlas and UC 115 cultivars. Drip irrigation increased the mean spear weight by 24% and 32%, respectively. For comparison, the spear weight for Gijnlim cultivar in asparagus trials under irrigation conducted by Mulder and Lavrijsen [33] was approximately 40 g. Paschold et al. [13] obtained values at the level of 35 g, and Sterret et al. [30] obtained values at the level of 25 g.

Table 11. Weight of the asparagus green spears (g) as dependent on cultivar and irrigation.

Cultivar	Control (Without Irrigation)			Drip Irrigation			Increase of the Weight of Green Spears		
	2007	2008	Mean	2007	2008	Mean	2007	2008	Mean
Jersey Giant	25.02	26.02	25.52	34.51	36.31	35.41	9.49	10.29	9.89
Jersey Knight	36.77	38.22	37.49	42.33	44.31	43.32	5.56	6.09	5.83
Jersey Supreme	37.63	36.61	37.12	35.95	39.45	37.70	−1.68	2.84	0.58
Jersey Deluxe	32.87	31.81	32.34	35.39	38.40	36.89	2.52	6.59	4.55
Jersey King	42.86	34.76	38.81	35.19	40.19	37.69	−7.67	5.43	−1.12
Atlas	34.80	34.22	34.51	41.70	43.73	42.71	6.90	9.51	8.20
Grande	43.55	42.55	43.05	48.29	49.30	48.79	4.74	6.75	5.74
Apollo	36.95	38.55	37.75	42.05	44.01	43.03	5.10	5.46	5.28
Purple Passion	39.46	39.46	39.46	40.99	44.99	42.99	1.53	5.53	3.53
UC 157	35.97	32.97	34.47	37.49	39.50	38.49	1.52	6.53	4.02
NJ 953	37.52	36.52	37.02	36.78	39.88	38.33	−0.74	3.36	1.31
UC 115	30.23	32.33	31.28	40.24	42.24	41.24	10.01	9.91	9.96
JWC 1	29.95	31.05	30.50	37.44	38.44	37.94	7.44	7.39	7.44
Mean	35.66	35.01	35.33	39.10	41.60	40.35	3.44	6.59	5.02

2007: LSD_{0.05} for: Irrigation = ns; Cultivars = 8.822; Interaction: Cultivars/Irrigation = 11.316; Irrigation/Cultivars = 7.066. 2008: LSD_{0.05} for: Irrigation = 6.343; Cultivars = 6.022; Interaction: Cultivars/Irrigation = 9.416; Irrigation/Cultivars = 6.116. 2007–2008: LSD_{0.05} for: Irrigation = 1.031; Cultivars = 4.622; Interaction: Cultivars/Irrigation = 6.536; Irrigation/Cultivars = 3.718.

Drip irrigation, applied after the harvest in the growing season preceding the next asparagus harvest, significantly increased the number of green spears per plant from 6.50

to 9.49 (Table 12). Green spears number per plant increased due to drip irrigation for the studied cultivars and 2 years of research, on average, by 2.98 pcs (46%). The highest increase in green spears number per plant (10 or more) under drip irrigation conditions, on average, for 2 years of research, was observed for the cultivars Jersey Deluxe (11.10), Jersey King (10.90), Jersey Supreme (10.78), Jersey Giant (10.72), NJ 953 (10.46), and Apollo (10.00). The best response to drip irrigation, with reference to this characteristic, was noted in Jersey Deluxe cultivar. Drip irrigation increased the number of green spears per plant in this cultivar by more than six spears (i.e., by 123%). Hartmann [9], Paschold et al. [11], Rolbiecki and Rolbiecki [2], and Rolbiecki [14] also obtained an increase in the number of asparagus spears due to drip irrigation.

Table 12. Number of the asparagus green spears (pcs) as dependent on cultivar and irrigation.

Cultivar	Control (Without Irrigation)			Drip Irrigation			Increase of the Number of Green Spears		
	2007	2008	Mean	2007	2008	Mean	2007	2008	Mean
Jersey Giant	5.20	6.30	6.25	10.17	11.27	10.72	4.97	4.97	4.97
Jersey Knight	5.44	5.50	5.47	7.64	8.02	7.83	2.20	2.52	2.36
Jersey Supreme	6.60	7.60	7.10	10.27	11.30	10.78	3.67	3.7	3.68
Jersey Deluxe	4.94	5.02	4.98	11.65	10.55	11.10	6.71	5.53	6.12
Jersey King	8.41	8.44	8.42	10.35	11.45	10.90	1.94	3.01	2.47
Atlas	6.49	6.22	6.35	7.53	8.53	8.03	1.04	2.31	1.67
Grande	6.47	6.01	6.24	8.20	8.65	8.42	1.73	2.64	2.18
Apollo	7.10	6.92	7.01	9.69	10.32	10.00	2.59	3.40	2.99
Purple Passion	8.66	9.66	9.16	7.32	10.32	8.82	−1.34	0.66	−0.34
UC 157	6.77	5.61	6.19	9.07	9.84	9.45	2.30	4.23	3.26
NJ 953	7.81	7.01	7.41	10.87	10.05	10.46	3.06	3.04	3.05
UC 115	4.46	5.21	4.83	8.56	9.22	8.89	4.10	4.01	4.05
JWC 1	5.17	6.20	5.68	7.15	8.83	7.99	1.98	2.63	2.30
Mean	6.42	6.59	6.50	9.11	9.87	9.49	2.69	3.28	2.98

2007: LSD_{0.05} for: Irrigation = 0.747; Cultivars = 2.116; Interaction: Cultivars/Irrigation = 2.993; Irrigation/Cultivars = 1.732. 2008: LSD_{0.05} for: Irrigation = 0.824; Cultivars = 1.811; Interaction: Cultivars/Irrigation = 2.459; Irrigation/Cultivars = 1.562. 2007–2008: LSD_{0.05} for: Irrigation = 0.372; Cultivars = 1.666; Interaction: Cultivars/Irrigation = 2.356; Irrigation/Cultivars = 1.340.

3.3. Irrigation Water Use Efficiency

The average value of irrigation water use efficiency (IWUE) for the harvest years and cultivars was 31 kg·ha^{−1}·mm^{−1} (Table 13). Irrigation water use efficiency in the first year of research (2007) was lower (19 kg·ha^{−1}·mm^{−1}) than in the second year of study (2008) (44 kg·ha^{−1}·mm^{−1}). This was due to the fact that, for the irrigation season in 2006, a higher seasonal irrigation norm was used than in 2007. Obviously, asparagus yields harvested at drip irrigated plots in 2007 were the result of irrigation carried out in 2006, and, respectively, postharvest irrigation carried out in 2007 had an impact on asparagus yields harvested in 2008. Jersey Deluxe and Jersey Giant were characterized by the highest IWUE, which, on average, for 2 years of research, was 64 kg·ha^{−1}·mm^{−1} and 57 kg·ha^{−1}·mm^{−1}, respectively. The lowest IWUE (4 kg·ha^{−1}·mm^{−1}–6 kg·ha^{−1}·mm^{−1}) was found in Atlas, Jersey King, and Purple Passion cultivars. The other tested cultivars, on average, for 2 years of research, were described by IWUE as ranging from 26 kg·ha^{−1}·mm^{−1} to 41 kg·ha^{−1}·mm^{−1}. Diverse irrigation water use efficiency in the cultivation of various asparagus cultivars has been confirmed by the results of previous trials conducted in the central Poland (region of Bydgoszcz) with other cultivars of asparagus [2,14] and vegetable species [50,51] or berry plants [52–55].

Table 13. Irrigation water use efficiency ($\text{kg}\cdot\text{ha}^{-1}\cdot\text{mm}^{-1}$) as dependent on cultivar and year studied.

Cultivar	Irrigation Water Use Efficiency		
	2007	2008	Mean
Jersey Giant	42	73	57
Jersey Knight	24	43	33
Jersey Supreme	22	44	33
Jersey Deluxe	47	82	64
Jersey King	-	13	6
Atlas	-	9	4
Grande	16	45	30
Apollo	16	45	30
Purple Passion	-	12	6
UC 157	17	48	32
NJ 953	20	61	40
UC 115	29	54	41
JWC 1	15	37	26
Mean	19	44	31

4. Conclusions

Drip irrigation of 13 cultivars of asparagus, applied for 2 years in the postharvest period (2006–2007), had a positive effect on all studied characteristics in both summer stalks and consumption green spears of this vegetable. On average, in 2006–2007, a significant increase in the height, number, and diameter of summer stalks was visible in 13, 12, and 9 of 13 studied asparagus cultivars, respectively. On average, in 2007–2008, the increase in marketable yield, weight, and number of green spears was significant for 12, 11, and 12 of 13 tested asparagus cultivars, respectively. The highest marketable yield increase of green spears under drip irrigation—above $7 \text{ t}\cdot\text{ha}^{-1}$, on average, for 2 years of research—was obtained for Jersey Deluxe, Grande, Apollo, and NJ 953 cultivars. The best response to drip irrigation was noted in Jersey Deluxe and Jersey Giant. Drip irrigation increased the marketable yields of these cultivars by 157% and 142%, respectively. Jersey Deluxe and Jersey Giant cultivars were characterized by the highest irrigation water use efficiency (calculated for the marketable yield of green spears), which, on average, for 2 years of research, was $64 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{mm}^{-1}$ and $57 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{mm}^{-1}$, respectively. High irrigation water use efficiency, over $30 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{mm}^{-1}$, was observed in the case of 9 of 13 tested cultivars. In summary, postharvest irrigation of asparagus cultivated on a very light sandy soil significantly improved both the summer stalk characteristics, as well as the marketable yield features of consumption green spears of this vegetable species. Drip irrigation of asparagus, applied after the harvest in the growing season preceding the next green spears harvest, makes it possible to significantly increase the productivity of this vegetable, which contributes to the sustainable crop production.

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