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Effect of Subsurface Drip Fertigation with Nitrogen on the Yield of Asparagus Grown for the Green Spears on a Light Soil in Central Poland

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Abstract: During the growing period of many agricultural and horticultural plants, the use of fertigation usually increases the yield; however, the response to this treatment may depend on the cultivar. The effect of subsurface drip fertigation with nitrogen on the yield of three asparagus (*Asparagus officinalis*) cultivars grown for green spears in light soil was studied. The multi-year (2011–2017) field experiment was carried out on sandy soil and was arranged in a split-plot design with four replications. The first factor was the method of fertilization with nitrogen: (1) control—spreading nitrogen fertilization without irrigation and (2) subsurface drip fertigation with nitrogen. The second factor was the genotype (a cultivar) of asparagus—the following cultivars were tested: Ramada, Rapsody and Ravel. Generally, subsurface drip fertigation with nitrogen increases the marketable yield of green spears and the number of spears produced by a single plant, as well single-spear weight. 'Ramada' achieved the best results with all yield parameters. A significant correlation coefficient between the sum of rainfall and irrigation rates and yield parameters of tested cultivars was also found. The studies showed a varied response of the tested asparagus cultivars to the fertigation treatment.

Keywords: *Asparagus officinalis*; evapotranspiration; irrigation needs; irrigation water use efficiency; rainfall deficit; water requirements

1. Introduction

Asparagus (*Asparagus officinalis* L.) is one of the world's top 20 vegetable crops [1]. China is a leading producer of asparagus in the world with 57,000 t, which ranks them as the leader in productivity with approximately 84% of the world's production, which is mostly dedicated to domestic consumption. In Europe, asparagus is grown on 66,500 hectares and is one of the most popular vegetables being consumed, either fresh or processed. In Europe the leading producer is Germany with 25 thousand ha and a production of 130,881 t [2,3].

Asparagus is a perennial vegetable species; therefore, choosing the most advantageous cultivars for cultivation is a very important factor in yield. Thanks to intensive breeding

work carried out in many countries around the world, new cultivars of asparagus are quickly emerging [4]. Production of asparagus in Poland is increasing according to estimates from year to year. This applies primarily to green asparagus, which has a greater share in the total amount of asparagus produced in our country. The establishment of new plantations outside traditional cultivation regions has also been observed, e.g., in the Masovian, Lublin or Kuyavian-Pomeranian provinces [5].

New cultivars of asparagus are in general very fertile, with relatively high soil and water requirements, especially German ones [4,6]. This is why, to obtain maximum marketable yields of a given asparagus cultivar, creating optimal growth and developmental conditions during the growing season is recommended. Optimal asparagus production possibilities can be achieved by applying organic and mineral fertilization adapted to species' nutritional needs and ensuring optimal humidity with the usage of irrigation to compensate for deficiency in rainfall. The use of inorganic fertilizers is probably the most common practice that is used around the world to increase the productivity of most crops. As in most crops, the most important nutrients for asparagus growth are nitrogen (N), phosphorus (P) and potassium (K) [7]. As a result, the specific method of cultivation, i.e., harvesting of spears in early spring, the height and quality of asparagus sprouts depend on the number of ingredients stored in asparagus' rootstocks during the vegetation period of the previous year [4,6,8].

The asparagus plantations in Poland are mostly located on very light soils, which are characterized by very low water-holding capacity. Asparagus is considered a drought-tolerant plant; however, it responds to irrigation with increases in the yield of spears, spear number and size [9]. It was noted that the drip irrigation applied during the post-harvest period (from June to August) significantly increased the marketable yield of asparagus in the next growing season [10]. Yield response does not vary with delivery systems, but a subsurface drip uses less water than overhead irrigation [11]. The subsurface irrigation method seems to perform better than the drip irrigation one because the yield and the irrigation water use efficiency are higher [12].

In this paper the main aim of the study was to assess the effect of subsurface drip fertigation with nitrogen on the possibilities of cultivation of chosen asparagus cultivars for green spears in light soil conditions.

2. Materials and Methods

2.1. Plant Material and Scheme of the Experiment

The field experiment was carried out in the years 2011–2017 at Kruszyn Krajenski near Bydgoszcz on sandy soil (Typic Hapludolls). The water reserve to 1 m depth of soil at field capacity was 87 mm and the available water 67 mm.

The results of soil analysis before the establishment of experiments were the following. The soil was characterized by a well-developed arable-humus level with an average value of humus and nutrients. This was probably the result of many years of fertilization with manure [10]. The pH of the soil was slightly acidic to neutral (pH in H_2O was 5.5). The average humus content in the 0–60 cm layer was 1.35%, while the content of selected nutrients was as follows: P—52.5 mg $\times$ 100 g^{-1}, K—71.25 mg $\times$ 100 g^{-1}, Mg—5.9 mg $\times$ 100 g^{-1}.

The field experiment was conducted in a randomized blocks method of a two-factorial "split-plot" system with four replications. The first factor was fertigation with nitrogen used in two variants: (1) non-irrigated plots with spreading nitrogen fertilization (control) and (2) subsurface drip-fertigated plots with nitrogen; the second factor followed the German protocol for cultivars of asparagus (*Asparagus officinalis* L.): Ramada, Rapsody and Ravel.

The asparagus plants were grown for green spears. The plot area for harvest was 12.6 m^2 (20 pcs $\times$ 35 cm $\times$ 180 cm). The standard growing techniques and NPK doses as recommended for asparagus were applied [13]. The fertilization consisted of 120 N, 100 P and 150 K kg ha^{-1}. The phosphorus and potassium fertilization were performed preplant in the spring. Doses of potassium (potash salt) and phosphorus (superphoshate)

fertilizations were dependent on the abundance of these nutrients in the soil. The nitrogen fertilization (ammonium nitrate) was supplied at three single rates: 50 kg ha^{-1} for the first two and 20 kg ha^{-1} for the third during the growing season.

The fertigation was carried out using a proportional fertilizer dispenser 'Dosatron'. The drip irrigation and drip fertigation were carried out using the 'EURO DRIP' line. Water from the subsurface well for irrigation was used. Terms of single irrigation treatments of asparagus were performed based on tensiometer indications according to Horticultural Institut in Geisenheim (Germany) [14]. In the irrigation season the soil water potential was not less than −50 kPa. The subsurface drip irrigation and fertigation of asparagus plants was carried out with the use of drip line EURO DRIP. The single-dripper efficiency was 1 L h^{-1}.

The experiment included both years with irrigation of summer stalks (2011–2016) and full harvest of green consuming spears in the years 2012–2017. The following evaluations of yield were made: 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. IWUE (kg ha^{-1} mm^{-1}) shows how effective the use of water is and was calculated for marketable yield of green spears using the following Equation (1):

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

where:

IWUE = irrigation water use efficiency;
y = yield after irrigation;
a = yield without irrigation;
x = seasonal dose of water used in irrigation.

The experimental data for marketable yield, weight and number of green spears have been statistically processed by variation analysis. Mean values were verified with Tukey's test on p = 0.05 level. The method of regression (logarithmic and linear functions) as well as linear correlation at the level p = 0.01 was used to assess the correlation of the chosen yield features using Excel software. The results of water needs of asparagus in the experimental period, considered as crop evapotranspiration (ETp), were statistically processed by determining the following values: mean, normal (median), maximum and minimum, as well as standard deviation and coefficient of variation [15].

2.2. Assessment of Water Needs and Rainfall Deficits

The water needs of asparagus were determined by the method of crop coefficients [16] for the irrigation period of asparagus, which lasts under Polish climatic conditions from 3rd decade of June till end of August (postharvest irrigation). Methods are based on the reference evapotranspiration (ETo) [17]. In that method, the water needs of a crop are identified by the potential evapotranspiration of a given crop.

To take into account the specificity of drip irrigation (limited wetted area of soil) potential crop evapotranspiration was determined using the following Equation (2):

$$\mathrm{ETp} = \mathrm{ETo} \times \mathrm{kc} \times \mathrm{kr}, \quad (2)$$

where:

ETp = crop evapotranspiration (mm);
ETo = reference evapotranspiration (mm);
kc = crop coefficients (the ratio of evapotranspiration measured in conditions of sufficient soil moisture to reference evapotranspiration) [18];
kr = reduction coefficients were determined according to Freeman and Garzoli's formula [19], which based on the percentage of surface coverage of asparagus in the postharvest period [10].

Crop coefficients (kc) for the specified months of the asparagus irrigation period were calculated by the Formula (3):

$$kc = \frac{S}{ETo}, \quad (3)$$

where:

kc = crop coefficient;
S = field water consumption under drip irrigation of asparagus grown on very light soil in the Bydgoszcz region. The field water consumption (S) under optimal soil moisture conditions (at the level of available water content in the soil) is identified as a crop's evapotranspiration. The amount of field water consumption was adopted according to Rolbiecki [10] on the basis of a field experiment carried out in 2002–2007 in Kruszyn Krajeński near Bydgoszcz, under the same soil conditions as the experiment carried out in 2011–2017. ETo was calculated for the same time intervals. The values of kc determined that way were as follows: 0.4 (3rd decade of June), 0.8 (July) and 1.0 (August);
ETo = reference evapotranspiration (mm).

Reference evapotranspiration was determined using the Blaney–Criddle model modified by Żakowicz [20] and expressed in Equation (4):

$$ETo = n \times [p \times (0.437 \times t + 7.6) - 1.5], \quad (4)$$

where:

ETo = reference evapotranspiration (mm);
n = number of days in a month;
p = evaporation coefficients according to Doorenbos and Pruitt [21] for months and latitude determined from tables;
t = monthly mean air temperature (°C).

The precipitation deficiencies (D) were considered according to Ostromęcki's method [22]. The rainfall deficit in the period, including the months July and August, which are critical in terms of the amount of water available to the plants, was calculated as the difference between the water needs of asparagus, expressed as the crop evapotranspiration for a considered month, and the total precipitation in this month. Water deficits were determined using the following Equation (5):

$$D = ETp - P, \quad (5)$$

where:

ETp = crop evapotranspiration (mm);
P = total precipitation at the studied period (mm).

2.3. Meteorological Conditions

For calculations the numerical data from measurements were taken from the meteorological station of the Laboratory of Land Reclamation and Agrometeorology at the Bydgoszcz University of Science and Technology located in Mochełek near Bydgoszcz.

The average air temperature during the growing season (April–September) in the years 2011–2017 was 14.8 °C, i.e., 0.3 °C higher than in the years 1981–2010 (Table 1). The warmest growing season, with a temperature of 15.4 °C, was in 2014. The warmest month of the growing season in the years 2011–2017, with a temperature 18.8 °C (0.2 °C higher than in the years 1981–2010), was July. During the growing season of 2014, the average air temperature in July was as high as 21.5 °C (2.9 °C higher than in the years 1981–2010).

The average sum of precipitation during the growing season in the years 2011–2017 was 353.3 mm and was 45.8 mm higher than in the years 1981–2010 (Table 2). The highest rainfall, amounting to 474.8 mm (167.3 mm higher than in the years 1981–2010), occurred during the growing season in 2017. In each month of the 2017 growing season, the rainfall was higher than it had been in the years 1981–2010. The lowest precipitation in the growing season, amounting to 193.3 mm (114.2 mm lower than it was in the years 1981–2010),

occurred in 2015. The average sums of precipitation were higher in May, June and July in the years 2011–2017 than in the years 1981–2010. The most abundant precipitation during the growing season was noted in 2012 (133.8 mm in June and 115.6 mm in July) and in 2017 (118.9 mm in July and 126.1 mm in August).

Table 1. Air temperature in the years 2011–2017 (°C).

Years	Months of the Growing Season						Mean for April–Sepember
	April	May	June	July	August	September	
2011	10.5	13.4	17.7	17.6	17.7	14.3	15.2
2012	8.4	14.5	15.2	18.8	17.6	13.3	14.6
2013	7.0	14.2	17.4	18.9	18.1	10.7	14.4
2014	9.9	13.3	16.0	21.5	17.2	14.4	15.4
2015	7.5	12.4	15.7	18.5	20.9	13.8	14.8
2016	8.3	14.7	17.7	18.3	16.4	14.3	15.0
2017	6.8	13.4	16.8	17.7	17.7	13.1	14.3
2011–2017	8.3	13.7	16.6	18.8	17.8	13.4	14.8
1981–2010	7.8	13.3	16.1	18.6	17.9	13.1	14.5

Table 2. Precipitation in the years 2011–2017 (mm).

Years	Months of the Growing Season						Mean for April–September
	April	May	June	July	August	Sepember	
2011	0.0	2.0	40.0	137.0	30.7	24.3	234.0
2012	26.5	25.4	133.8	115.6	51.8	25.1	378.2
2013	13.6	91.7	49.3	79.0	56.6	64.1	354.3
2014	40.7	65.7	44.9	55.4	57.3	25.9	289.9
2015	15.6	21.6	33.0	50.4	20.3	52.4	193.3
2016	28.7	51.4	98.1	133.8	55.3	8.1	375.4
2017	40.8	56.3	54.3	118.9	126.1	78.4	474.8
2011–2017	23.7	44.9	64.8	98.6	56.9	39.7	353.3
1981–2010	27.0	49.3	52.8	69.8	62.6	46.0	307.5

2.4. Water Needs of Asparagus, Water Deficits (Irrigation Needs) and Irrigation Water Doses

The water needs of asparagus, expressed as a potential evapotranspiration and calculated by the method of plant coefficients, in the period from 21 June to 31 August in the years 2011–2017, amounted to 243 mm (Table 3). In the individual growing seasons, the value of water needs ranged from 236 mm (in 2011) to 257 mm (in 2015). The water needs of asparagus plants were higher in August than in July. On average, in the years 2011–2017 the water needs amounted to 109 mm in July and 117 mm in August.

The highest rainfall deficit (168 mm) occurred in the 2015 growing season (Table 4). Large rainfall deficits were also noted in 2013 and 2014, and they amounted to 121 mm and 118 mm, respectively. The lowest rainfall deficit occurred in 2017.

In the research published by Rolbiecki, et al. [23] the water needs of asparagus are the highest in the last two months of the irrigation season, i.e., July and August (from 3.2 mm to 4.4 mm, daily). In the research on asparagus water needs in various regions of Poland, reported by Rolbiecki et al. [24], it was calculated that the irrigation requirements of asparagus plants are on average 228 mm in the period from 1 July to 31 August in the central-northwest region of Poland, which also covers the area considered in the present study. In the previous study [10], water requirements of asparagus under drip irrigation ranged from 205 mm to 272 mm in the individual years. Under Germany's climatic conditions, the results of experiment carried out by Paschold et al. [25] indicate that the water needs of asparagus plants from 20 June to 1 September range between 150 mm and 241 mm, whereas Hartmann [26] in prior studies estimated that depending on precipitation conditions, the water requirements of asparagus range between 179 mm and 240 mm. Pardo et al. [27]

estimated seasonal water consumption of asparagus under lysimeter conditions ranges from 274 mm to 294 mm.

Table 3. Water needs (mm) of asparagus plants during the irrigation period under drip irrigation conditions in the years 2011–2017.

Years and Statistical Characteristics	Irrigation Period				
	21–31 June	**July**	**August**	**21–31 Junuary–August**	**Junuary–August**
2011	18	104	115	236	218
2012	16	109	116	241	225
2013	17	110	117	245	227
2014	16	120	112	248	232
2015	16	108	132	257	241
2016	18	108	111	238	220
2017	17	104	116	237	220
Statistical Characteristics of Asparagus Water Needs					
Minimum (mm)	16	104	111	236	218
Maximum (mm)	18	120	132	257	241
Mean (mm)	17	109	117	243	226
Median (mm)	17	108	116	241	225
Standard Deviation	0.73	5.11	6.57	7.06	7.46
Variation Coefficient (%)	4.3	4.7	5.6	2.9	3.3

Table 4. Rainfall deficit (mm) in asparagus cultivation during the irrigation period in 2011–2017.

Years	Irrigation Period			
	21–31 June	**July**	**August**	**21–31 Junuary–August**
2011	-	4	86	90
2012	-	15	73	88
2013	-	68	53	121
2014	7	67	44	118
2015	-	43	125	168
2016	-	-	70	70
2017	-	-	18	18

Seasonal irrigation doses (the sum of single water doses throughout the irrigation season) used in the cultivation of asparagus plants were appropriate for the existing rainfall deficits (Figure 1). The largest amount of water was supplied to asparagus plants by means of a drip irrigation system in 2015. Seasonal water doses in the 2015 irrigation period were 177 mm. Seasonal water doses in 2013, 2014 and 2016 were also high, ranging from 100 mm to 154 mm.

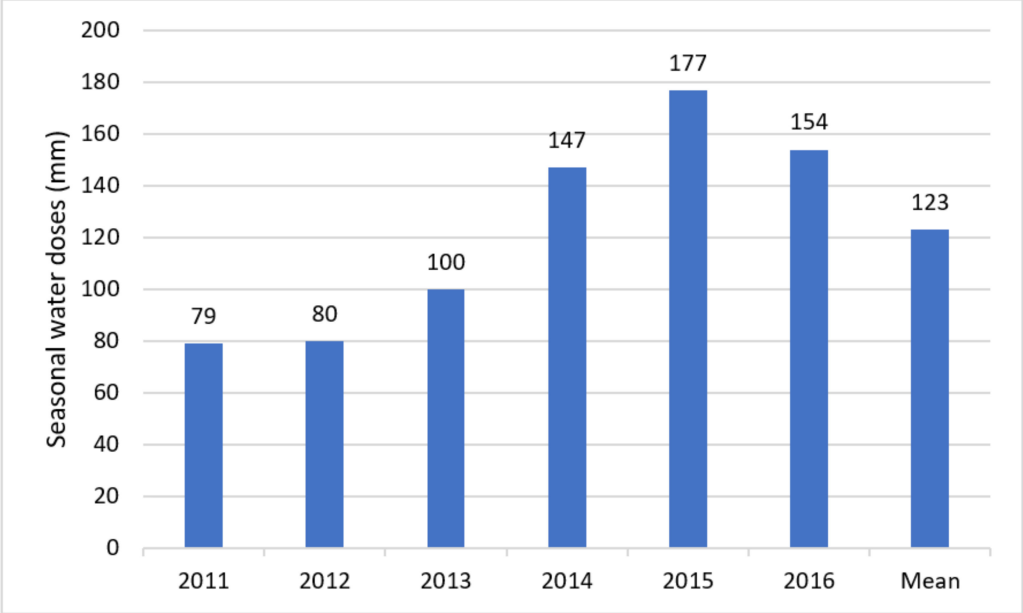

Figure 1. Seasonal water doses (mm) for asparagus plants in the years 2011–2016.

3. Results and Discussion

In comparison with the control, drip irrigation combined with fertilization, i.e., fertigation, on average for the three tested cultivars and six years of harvest (2012–2017), significantly increased the marketable yield of asparagus green spears from 5.69 t ha^{-1} to 8.79 t ha^{-1} (Table 5). The yield increase obtained by fertigation, in relation to the control—non-irrigated plots with spreading nitrogen fertilization—amounted to 3.1 t ha^{-1}, i.e. 54%.

Table 5. The marketable yield (t ha^{-1}) of green spears of asparagus.

Treatments	Cultivars	Years of the Study						Mean
		2012	2013	2014	2015	2016	2017	
Control	Ramada	5.10	5.49	6.33	6.96	6.88	6.75	6.25
	Rapsody	4.30	4.92	4.61	4.94	5.21	5.15	4.85
	Ravel	5.40	5.24	5.76	6.26	6.55	6.55	5.96
Fertigation	Ramada	7.20	8.19	8.97	9.33	9.24	9.21	8.69
	Rapsody	6.90	7.77	8.69	9.01	9.66	8.90	8.48
	Ravel	7.80	8.64	9.22	9.74	10.21	9.58	9.19
Control		4.93	5.21	5.56	6.05	6.21	6.15	5.69
Fertigation		7.30	8.20	8.96	9.36	9.70	9.23	8.79
Ramada		6.15	6.84	7.65	8.14	8.06	7.98	7.47
Rapsody		5.60	6.34	6.65	6.97	7.43	7.02	6.66
Ravel		6.60	6.94	7.49	8.00	8.38	8.06	7.57
$LSD_{0.05}$ for Control		0.951	0.208	0.412	0.534	0.745	0.459	0.551
$LSD_{0.05}$ for Fertigation		0.632	0.585	0.625	0.758	0.862	0.711	0.695

The significant influence of the studied asparagus cultivars on the marketable yield of green spears was also noticed. Cultivars Ramada and Ravel, irrespective of irrigation and fertilization treatments, in the years 2012–2017, had significantly better yields (averages of 7.47 t ha^{-1} and 7.57 t ha^{-1}, respectively) than the cultivar Rapsody (6.66 t ha^{-1}).

Among the three studied asparagus cultivars, the highest marketable yield of green spears was collected from 'Ravel' grown under the conditions of drip irrigation combined with fertigation. The marketable yield of this cultivar, on average for the years 2012–2017, amounted to 9.19 t ha^{-1}.

The results shown in this study are consistent with the results of experiments conducted by other authors. Hartmann [26,28,29], under German climatic conditions, thanks to drip irrigation, obtained a yield increase of 50% in his trials on sandy soil and 25% on loamy sand. Rolbiecki et al. [23], in an experiment carried out at the same soil and climatic conditions but with American asparagus cultivars, obtained, on average, lower yields compared to the German ones. In the Netherlands, Mulder and Lavrijsen [30], in an asparagus cultivar trial under sprinkler irrigation conditions, obtained the highest yields for 'Gijnlim', which amounted to 4.5 t ha^{-1} in the first harvest year and 12.8 t ha^{-1} in the second year. Brainerd et al. [11] in the same years of harvest (2012–2017) under the conditions of Western Michigan (USA) received the cumulative yields (on average for two cultivars: Jersey Supreme and Guelph Millenium) of 31.56 t ha^{-1} and 32.22 t ha^{-1}, respectively, for unirrigated and subsurface drip-irrigated plots. The cumulative yields obtained in our own experiment were higher, amounting to 37.5 t ha^{-1} for cv. Ramada in non-irrigated plots and 53 t ha^{-1} for the cv. Ravel in subsurface drip-irrigated plots.

In an experiment on microirrigation and nitrogen fertilization with other German cultivars of asparagus carried out in the same soil and climatic conditions [8] the irrigation treatments significantly reduced the number of nitrates in asparagus spears. There were significant differences among the cultivars tested. 'Vulkan' presented a much lower tendency to accumulate nitrates than 'Ramos'.

An example of significant linear correlation between the sum of rainfall and irrigation doses in the period of July–August and the marketable yield of 'Ramada' cultivar is shown at Figure 2. The high regression coefficient (r = 0.8079) shows the high influence of supplemental irrigation on the yield of green spears shaping.

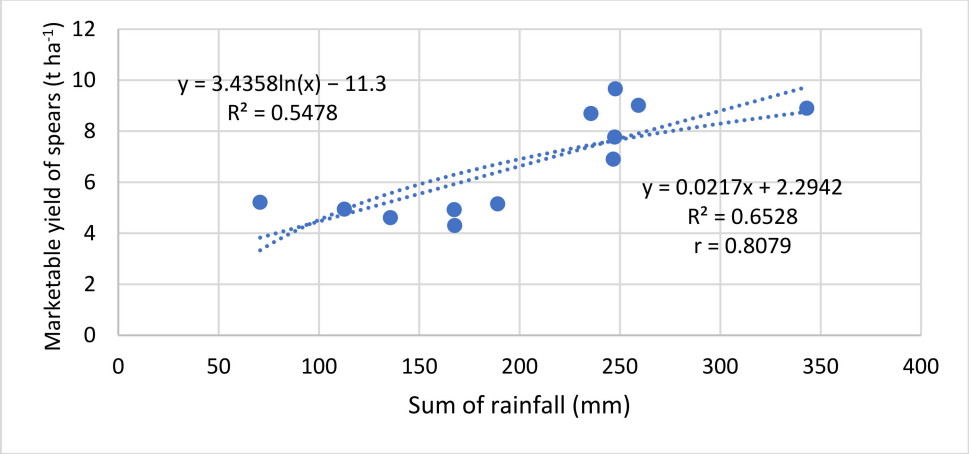

Figure 2. Relationships between the sum of rainfall and irrigation rates in July–August and marketable yield of green spears of 'Rapsody'.

Drip irrigation, combined with fertigation, on average for the three tested cultivars and six years of harvest, significantly increased the number of green spears of asparagus harvested from one plant from 7.81 pieces to 10.99 pieces (Table 6). In relation to the control plots, the average in the years 2012–2017 for the number of green spears per one plant collected from fertigated plots increased by 3.18 pcs, i.e., 41%.

The influence of the studied asparagus cultivars on the number of green spears harvested from one plant was also significant. Regardless of irrigation and fertilization, in the years 2012–2017 the average number of green spears collected from one plant of the 'Ravel' cultivar (10.78 pcs per plant) was significantly higher than those collected from the 'Ramada' (8.64 pcs per plant) and Rapsody (8.78 pcs per plant) cultivars.

Among the tested asparagus cultivars, 'Ravel' grown under drip irrigation combined with fertigation conditions in the years 2012–2017 formed the highest number of green spears per plant (12.68 pcs per plant).

Rolbiecki et al. [23] reported that green spears' number per plant increased due to drip irrigation, on average for the studied cultivars and two years of research, by 2.98 pcs (46%). Hartmann [29], Paschold et al. [31], Rolbiecki and Rolbiecki [6] and Rolbiecki [10] also obtained an increase in the number of asparagus spears caused by drip irrigation.

Table 6. The average number of spears (pcs per plant) harvested from one asparagus plant.

Treatments	Cultivars	Years of the Study						Mean
		2012	2013	2014	2015	2016	2017	
Control	Ramada	6.40	7.00	7.21	7.64	7.92	7.91	7.35
	Rapsody	6.30	6.78	7.29	7.80	7.41	7.58	7.19
	Ravel	8.60	8.62	8.80	9.05	9.01	9.24	8.89
Fertigation	Ramada	8.20	9.80	10.04	10.55	10.57	10.49	9.94
	Rapsody	8.40	10.06	10.67	10.98	10.98	10.95	10.34
	Ravel	11.40	12.55	12.84	13.04	13.21	13.01	12.68
Control		7.10	7.46	7.77	8.16	8.11	8.24	7.81
Fertigation		9.33	10.80	11.18	11.52	11.59	11.48	10.99
Ramada		7.30	8.40	8.62	9.09	9.24	8.85	8.64
Rapsody		7.35	8.42	8.98	9.39	9.19	9.26	8.76
Ravel		10.00	10.58	10.82	11.04	11.11	11.12	10.78
$LSD_{0.05}$ for Control		0.754	0.185	0.215	0.422	0.311	0.412	0.381
$LSD_{0.05}$ for Fertigation		1.121	0.651	0.541	0.581	0.621	0.431	0.657

Figure 3 shows the significant linear correlation between the sum of rainfall and irrigation doses in the period of July–August and number of green spears per plant of 'Ravel'. The regression coefficient (r = 0.8404) shows the significant influence of irrigation on the number of green spears of asparagus per plant.

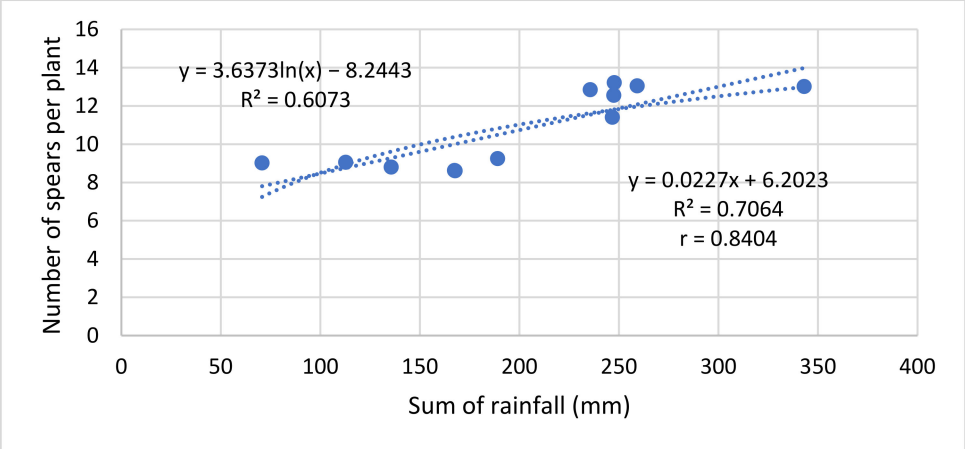

Figure 3. Relationships between the sum of rainfall and irrigation rates in July–August and number of spears per plant of 'Ravel'.

Drip irrigation combined with fertigation, on average for the three tested cultivars and six years of harvest, significantly increased the weight of one green asparagus spear from 41.13 g to 49.36 g (Table 7). In relation to the control plots, the weight gain of the asparagus green spears obtained by fertigation treatment, on average for cultivars and years, amounted to 8.23 g, i.e., 20%.

Table 7. The average weight (g) of single green spears of asparagus.

Treatments	Cultivars	Years of the Study						Mean
		2012	2013	2014	2015	2016	2017	
Control	Ramada	34.20	43.10	42.11	43.55	43.15	45.33	41.90
	Rapsody	33.10	40.80	41.18	42.66	43.40	43.41	40.75
	Ravel	36.60	39.95	40.65	41.58	42.85	42.75	40.73
Fertigation	Ramada	43.20	52.68	53.58	54.62	58.61	55.60	53.04
	Rapsody	42.50	48.65	49.75	50.44	50.85	50.85	48.84
	Ravel	41.30	43.42	44.92	45.65	56.82	45.12	46.20
Control		34.63	41.28	41.31	41.60	43.13	43.83	41.13
Fertigation		42.33	48.25	49.42	50.24	55.43	50.52	49.36
Ramada		38.7	47.89	47.84	49.08	50.88	50.46	47.47
Rapsody		37.8	44.72	45.46	46.55	47.12	47.13	44.79
Ravel		38.95	41.68	42.78	43.61	49.83	43.93	43.46
$LSD_{0.05}$ for Control		0.958	2.609	2.509	2.853	2.753	2.883	2.427
$LSD_{0.05}$ for Fertigation		5.221	4.375	3.475	3.681	3.885	2.961	3.933

The studied asparagus cultivars also differed significantly in terms of the weight of single green spears. In the years 2012–2017 'Ramada', regardless of irrigation and fertilization treatments, produced the highest weight of single green spears (47.47 g). Moreover, the weight of single green spears of 'Ramada' was significantly higher than the weight of single green spears of 'Ravel'.

In the cultivation of asparagus under the conditions of drip irrigation combined with fertigation, 'Ramada' had the highest weight of single green spears. The average weight of single green spears of 'Ramada' grown on the fertigated plots in the years 2012–2017 was 53.04 g.

In the research published by Rolbiecki et al. [23] drip irrigation, used after the harvest in the growing season preceding the asparagus harvest, significantly increased the mean spear weight from 35.33 g to 40.35 g, on average, for the 13 cultivars tested. In a previous study by Rolbiecki [10] the average weight of a single asparagus spear for the German cultivar Ramos was lower for both unirrigated and drip-irrigated plots, amounting to 29 g and 33 g, respectively. The weight of spear of the Gijnlim cultivar in the experiments carried out by Mulder and Lavrijsen [30] under irrigation conditions was approx. 40 g. Paschold et al. [32] obtained values similar to those of the previous study [10], at the level of 35 g. Sterrett et al. [33], in the fifth year of cultivation, received the average spear weight of about 25 g.

The significant linear correlation coefficient between the sum of rainfall and irrigation doses in the period of July–August and number of spears per plant of 'Ramada' is also presented at Figure 4.

Irrigation water use efficiency (IWUE), through the drip fertigation system, on average for the three tested cultivars and six years of harvest, was 23 kg ha^{-1} mm^{-1} (Figure 5). Among the tested cultivars, the highest IWUE was noted in the case of 'Rapsody' (27 kg ha^{-1} mm^{-1}) and the lowest for 'Ramada' (18 kg ha^{-1} mm^{-1}).

Different IWUEs in the cultivation of various asparagus cultivars have been confirmed by the results of previous trials curried out in the central Poland (region of Bydgoszcz) with different cultivars of asparagus [6,10,23] and vegetable species [23,34] or berry plants [35–38]. The weather conditions are also important for the productivity of agricultural plants in this region [39,40].

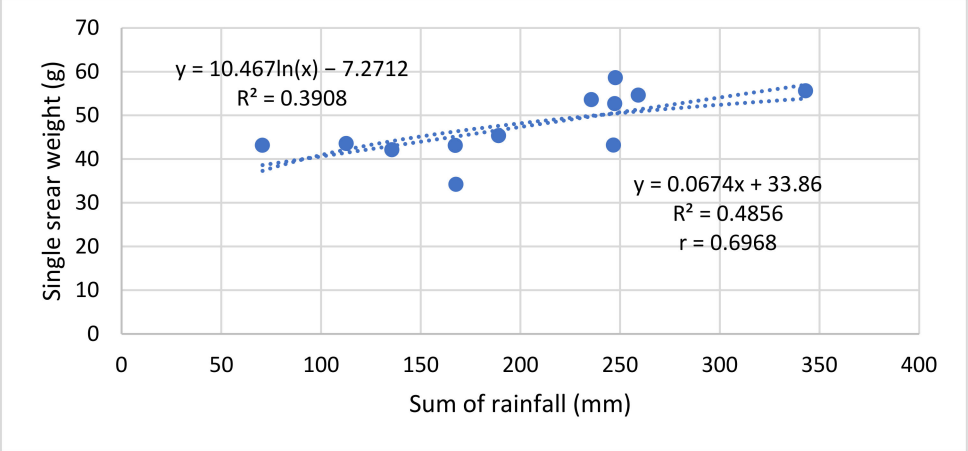

Figure 4. Relationship between sum of rainfall and irrigation rates in July–August and single-spear weight of 'Ramada'.

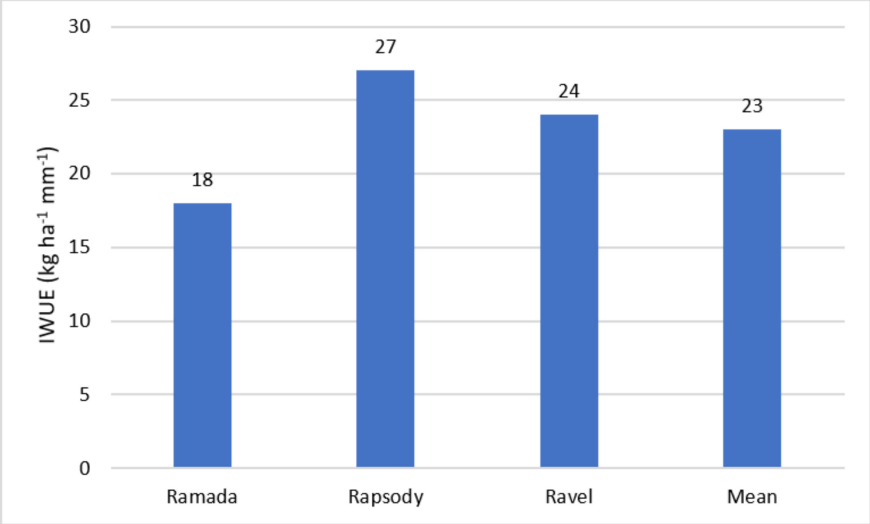

Figure 5. Irrigation water use efficiency (kg ha^{-1} mm^{-1}) as dependent on cultivar, mean for harvest periods 2012–2017.

4. Conclusions

The subsurface drip fertigation with nitrogen significantly influenced the investigated features of the asparagus cultivars tested. Yields obtained from subsurface drip-fertigated plots were significantly higher than those from control plots. Among the cultivars tested at the control plots 'Ramada' achieved the best results with all yield parameters. In the drip-fertigated plots the highest yield and number of spears from a single plant were observed for the Ravel cultivar. The highest weight of a single spear was found for the Ramada cultivar. The studies also showed a significant linear correlation between the sum of rainfall and irrigation rates and yield parameters such as: marketable yield of green spears, number of spears collected from a single plant and weight of a single spear. The investigated cultivars were characterized by different IWUEs. The highest IWUE was noted in the case of 'Rapsody', and the lowest was determined for 'Ramada'.

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B.J., A.A. and F.P.-F.; supervision, R.R., S.R. and B.J.; project administration, R.R. and S.R.; funding acquisition, R.R. All authors have read and agreed to the published version of the manuscript.

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