



Article

Effects of Drip Irrigation and Top Dressing Nitrogen Fertigation on Maize Grain Yield in Central Poland

Jacek Żarski and Renata Kuśmierk-Tomaszewska *

Department of Agrometeorology, Plant Irrigation and Horticulture, Faculty of Agriculture and Biotechnology, Bydgoszcz University of Science and Technology, 6 Bernardyńska Str., 85-029 Bydgoszcz, Poland

* Correspondence: rkusmier@pbs.edu.pl; Tel.: +48-523749516

Abstract: Maize is a plant of a global cultivation range and great economic importance, which is mainly due to its high yield potential and versatile use as food, fodder, and energy source. To evaluate the effects of drip irrigation and nitrogen fertigation on maize growth in light soil in the climate conditions of Central Poland, a field experiment was carried out in 2015–2017, as a dependent split-plot design with four replications. Two factors were used: I. drip irrigation (W0—no irrigation, W1—optimal irrigation, ensuring 100% coverage of the water needs of maize during the period of increased water needs), II—method of top dressing application of two doses of nitrogen $2 \times 40 \text{ kg} \cdot \text{ha}^{-1}$ (T—traditional application as broadcasted urea, F—fertigation with the use of a 6% aqueous solution of urea). The results presented in the paper concerning the absolute, relative and unitary average increases in corn grain yields under the influence of drip irrigation indicated the potential for increasing significantly the productivity of corn under the condition of optimizing the water factor. The average yield increase was $2.35 \text{ t} \cdot \text{ha}^{-1}$, varying depending on rainfall pattern: in the dry season it was 4.79, and in the wet season $1.03\text{--}1.22 \text{ t} \cdot \text{ha}^{-1}$. The application of top-dressing nitrogen fertigation resulted in a significant increase in the yield of maize grain in relation to the traditional method of nitrogen fertilization. Drip irrigation and fertigation are treatments that, ensuring the stability of maize yield over the years, contribute to an increase in plant yield by approximately 25% on average, and over 80% in the dry seasons.

Keywords: drip irrigation; nitrogen fertigation; production effects of maize; irrigation water productivity



Citation: Żarski, J.;

Kuśmierk-Tomaszewska, R. Effects of Drip Irrigation and Top Dressing Nitrogen Fertigation on Maize Grain Yield in Central Poland. *Agronomy* **2023**, *13*, 360. <https://doi.org/10.3390/agronomy13020360>

Academic Editor: Domenico Ronga

Received: 29 December 2022

Revised: 20 January 2023

Accepted: 21 January 2023

Published: 26 January 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Maize is a plant of a global cultivation range and great economic importance, which is mainly due to its high yield potential and versatile use as food, fodder, and energy source. According to data gathered by FAOSTAT [1], in 2020 maize was cultivated on 202 million hectares, and its world production was rated at 1162.4 million tons. Compared to 2001, the cultivation areas of maize increased by 47% while the harvest by as much as 89%. Similar trends in the growth of this crop were recorded in Europe, where the cultivation area increased from 13.5 to 19.4 million ha and a 63% increase in production was recorded. In Poland, the central area of the European continent, the maize cultivation area in 2012–2020 amounted to approx. 620,000 ha and it was twice as high as in 2004–2011. According to the CAPRI model, a further increase in yields is expected due to the introduction of new maize cultivars adapted to changing climatic conditions as well as agrotechnical progress [2].

Irrigation plays an important role in maize cultivation, primarily in arid and semi-arid climate zones, since it is the basic yield-affecting factor under the conditions of constant or periodic lack of rainfall, conditioning the optimum growth, development, and satisfying yielding of the crop. In such climatic conditions, food production without irrigation would not be possible. According to data from AQUASTAT [3], the world area of irrigated maize is 31.5 million hectares, accounting for 15.6% of the global total cultivated area. The largest areas of irrigated maize are located in China (13 million ha), the USA (4.8 million ha), and

India (2.2 million ha). In Europe, maize is irrigated on 2.4 million hectares, mainly in France, Italy, and Spain.

The scientific research on maize irrigation mainly concerns the economic management in conditions of declining irrigation water resources. These studies are aimed at maximizing specific water consumption. In particular, the effects of introducing economical irrigation, based on incomplete coverage of the water needs of plants, are being studied [4–15].

A considerable number of papers have been devoted to the topic of improving innovative water and energy-saving technologies as compared to surface and sprinkler irrigation systems [16–18]. Such technology is drip irrigation, which enables fertigation, i.e., an innovative way of providing plants with water and nutrients, especially nitrogen. The combined use of irrigation and nitrogen fertilization through fertigation is now becoming a common practice in modern agriculture due to its advantages over conventional methods. The advantages of fertigation include the accurate timing and application of fertilizer (nitrogen) which contributes to a reduction of environmental pollution [19].

In Poland, the irrigation of crops is an interventional procedure used to supplement periodic shortages of atmospheric precipitation in relation to the water requirements of the crops. On average, these shortages are medium level and concern especially sandy soils with low water retention, located in the central, lowland part of the country [20–22]. The problem, however, is the highly variable amount of precipitation from year to year, which leads to repeated but irregular atmospheric, agricultural and hydrological droughts. These phenomena occur with an average frequency of about 30% of the years [23–25]. Under such conditions, maize cultivation in central Poland is at high risk of yield reduction due to water deficits. According to our previous research, regional yield losses in dry years average 13%, with a maximum of 27% [26].

Despite the limitations resulting primarily from economic conditions [27] and the lack of an adequate number of water sources characterized by a sufficient amount of water, irrigation of maize in central Poland is a solution being considered for the future. The main factors that will accelerate the introduction of irrigation in this area include, firstly, the provision of higher, more stable and better quality crop yields, secondly, the need to increase the innovativeness and competitiveness of increasingly developing farms, and finally, the projected climate change [22]. According to the theory of global warming, the frequency of droughts in moderate latitudes will increase [28,29]. Some studies indicate that these changes are already taking place. Tendencies for increased droughts during the summer have been observed, especially in central Poland, where water is a limiting factor for crop yields [30].

Introducing irrigations to maize production on a larger scale in central Poland, including maize for grain, should be preceded by field experiments that would assess its effectiveness. Such studies have already been carried out in the vicinity of the city of Bydgoszcz, the capital of Kujavia, and the southern part of the Pomerania region [31], but such trials should be continued due to the abundance of new cultivars, and remarkable biological and agrotechnical progress in maize cultivation.

The main objective of the undertaken research was to evaluate the response of maize grown for grain to drip irrigation as an innovative, water-saving, and energy-saving irrigation technology. The aim of the study was also to evaluate the response of maize to fertigation and the interaction of drip irrigation and fertigation in shaping the yield of the crop. In Poland, fertigation is used mainly in fruit and vegetable production [32–34]. So far, only one case study has been conducted in maize cultivation with fertigation treatment, however, the expected significant differentiation of most of the maize features under the influence of the use of drip nitrogen fertigation was not found on sandy soil [35].

2. Materials and Methods

2.1. Experimental Site

The field experiment with drip irrigation and fertigation in maize was carried out in 2015–2017 at the Agricultural Experimental Station of the Bydgoszcz University of Science and Technology located in the agricultural area of the Mochełek settlement in the region of Kujawsko-Pomorskie in Poland (Figure 1). The experimental field is situated about 20 km from the center of the city of Bydgoszcz, on the south-eastern edge of the Krajeńska Upland ($\varphi = 53^{\circ}13' \text{ N}$, $\lambda = 17^{\circ}51' \text{ E}$, $h = 98.5 \text{ m a.s.l.}$).

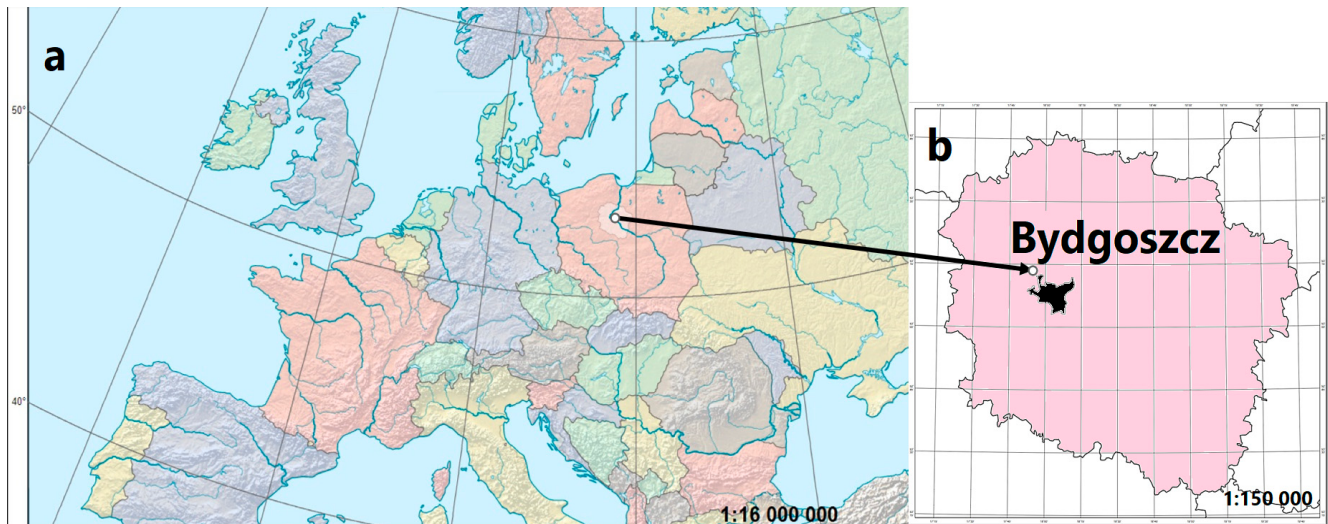


Figure 1. Location of the region of Kujawsko-Pomorskie in Europe (a) and the region of Bydgoszcz; (b) where the field experiment was carried out.

2.2. Experimental Design

The field experiment was carried out on sandy soil, formed from fluvioglacial sands, which is included in the IVa soil valuation class and a very good rye complex of valuation on agricultural suitability. It is light soil on compact subsoil (slightly loamy sand on shallow medium loam). The content of silt and clay fraction is 18% in the layer 0–50 cm and 46% in the layer 51–100 cm. The water content in one meter of the soil layer is 215 mm, at the field water capacity [20].

The experiment was carried out in a dependent split-plot design with four replications. The plot area for harvesting maize was 12 m^2 . Two factors were applied: I. drip irrigation (W_0 —no irrigation, W_1 —optimal irrigation, ensuring 100% coverage of the water needs of maize during the period of increased water needs), II—method of top dressing application of two doses of nitrogen $2 \times 40 \text{ kg} \cdot \text{ha}^{-1}$ (T—traditional application as broadcasted urea, F—fertigation with the use of a 6% aqueous solution of urea).

The cultivar of maize used in the experiment was ‘Smolan’ which is a medium-early maturing variety, trilinear type, and FAO 230. It is characterized by universal use but is mainly intended for grain cultivation. This cultivar has medium soil requirements and is characterized by good disease resistance. The crop was grown as a monoculture. In all seasons, proper agricultural techniques were used, including careful tillage, pre-sowing nitrogen fertilization in the dose of $100 \text{ kg N} \cdot \text{ha}^{-1}$, phosphorus-potassium fertilization in the doses corresponding to the soil’s abundance of these components, early sowing date, and chemical plant protection treatments, which included preventing the occurrence of weeds and pests. Seeds were sown into the ground on 4 May 2015, 28 April 2016, and 29 April 2017, at a row spacing of 75 cm and seed spacing of 20–22 cm which resulted in a density of about 8 plants per 1 m^2 . The harvest was carried out on the following dates: 27 October 2015 and 2016, and 6 November 2017. The treatments of the top dressing with

nitrogen were carried out in the third 10-day period of June (first dose) and the first 10-day period of July (second dose).

2.3. Irrigation Scheduling vs. Weather Conditions

An innovative surface drip system technology was used for maize irrigation. The drip lines were arranged between rows and the spacing between emitters embedded in the pipe wall was 200 mm. Water output of about 1 L per hour was obtained from 1 m of drip line at the pressure of 1 hPa. The source of water for irrigation was the commune water intake located at the edge of the field.

Irrigation dates were determined using continued monitoring of the moisture content of the soil layer penetrated by plants' root systems by balancing the store of readily available water (RAW) based on meteorological parameters, and it was supported by direct measurements of soil moisture with the Fieldscout TDR 300 Soil Moisture Meter by Spectrum Technologies, Inc. The coverage of maize's water needs resulted from maintaining soil moisture in the range of RAW in the root zone of plants. This range was determined by the balance method used, according to which RAW ranges from 0 to the effective useful retention is 35 mm of the field experimental soil where maize was grown.

Top dressing fertilization was static. For fertigation with nitrogen, the water-powered, non-electric chemical injector by Dosatron was used. The plants were optimally irrigated, ensuring a reserve of readily available water in the soil layer with controlled moisture content during the entire period of high water needs of plants. The number of single irrigation doses and the total seasonal dose depended on the course of the weather, including air temperature (Table 1), but mainly on the amount and distribution of precipitation (Table 2). In the dry season of 2015, as much as 225 mm was applied in 9 doses in the period from 10 June to 21 August. In the other two moist seasons, a total of just 45 mm was applied on 19 and 25 August 2016 (2 doses) and only 20 mm at once on 22 June 2017. Comparing the weather in the whole research period of 2015–2017 to the climatic conditions for the area, it can be concluded that in terms of thermal, they were close to the long-term averages. However, the precipitation totals from April to September were 14% higher than the long-term climate norm.

Table 1. Average monthly air temperature in Mochelek in the years of research against the long-term averages (°C).

Year	Apr.	May	June	July	Aug.	Sept.	Apr.–Sept.
1981–2010	7.9	13.3	16.1	18.6	17.9	13.1	14.5
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	14.9
2017	6.8	13.4	16.8	17.7	17.7	13.1	14.2

Table 2. Monthly totals of atmospheric precipitation in Mochelek in the years of research against the long-term averages (mm).

Year	Apr.	May	June	July	Aug.	Sept.	Apr.–Sept.
1981–2010	27.0	49.3	52.8	69.8	62.6	46.0	307.6
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	19.4	386.7
2017	40.8	56.3	54.3	118.9	126.1	78.4	474.8

The influence of the factors on grain yield, its quality, and some elements of its structure was investigated. The protein content in the grain was determined with the colorimetric method. Statistical calculations were performed using the ANALWAR-5.1.FR package.

3. Results

3.1. The Balance of Water Readily Available to Plants

Drip irrigation ensured the access of plants to readily available water (RAW) throughout the period of high maize water needs from 11 June to 31 August (Figures 2–4). Without irrigation, in the conditions of rainfed plots, the water supply was depleting. The pace of water depletion in soil depended on the amount and distribution of rainfall. In the dry growing season of 2015, as many as 55 days were recorded with an allowable depletion in the soil layer with controlled moisture in the period from 11 June to 31 August (Figure 2). In the wet growing season of 2016, RAW water depletion occurred for only a few days in late August (Figure 3). In turn, in the wettest growing season of 2017, readily available water depletion appeared for 9 days in the third 10-day period of June and the first 10-day period of July (Figure 4).

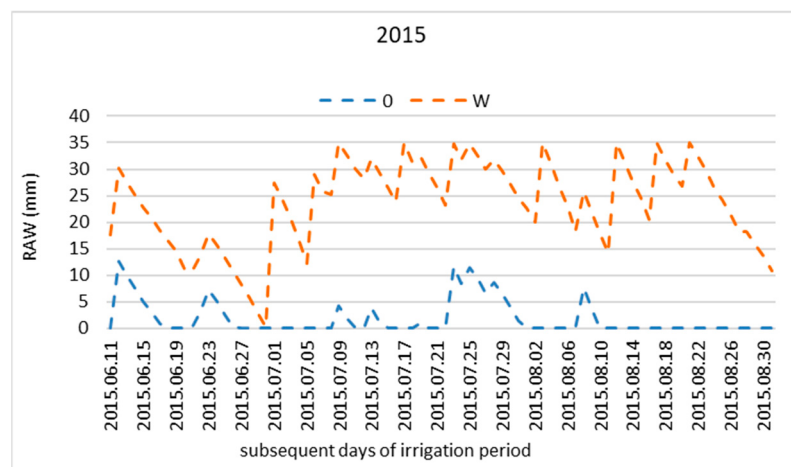


Figure 2. The balance of water readily available to plants in the soil layer with controlled moisture in the period from 11 June to 31 August 2015 (dry season) (0–rainfed, W–irrigation).

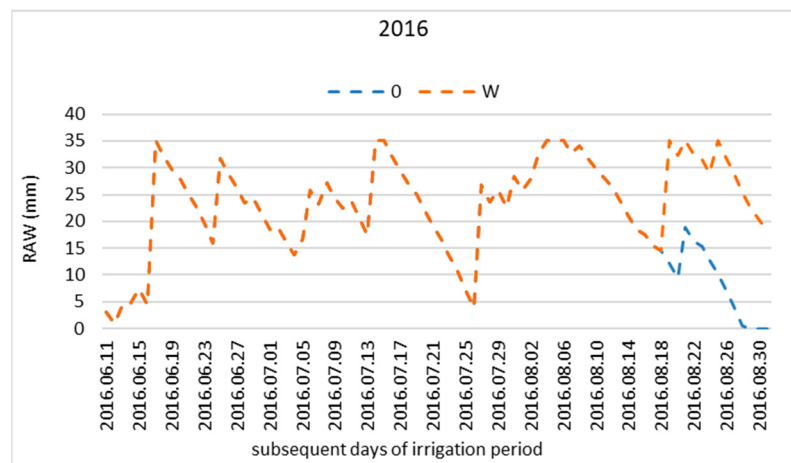


Figure 3. The balance of water readily available to plants in the soil layer with controlled moisture in the period from 11 June to 31 August 2016 (wet season) (0–rainfed, W–irrigation).

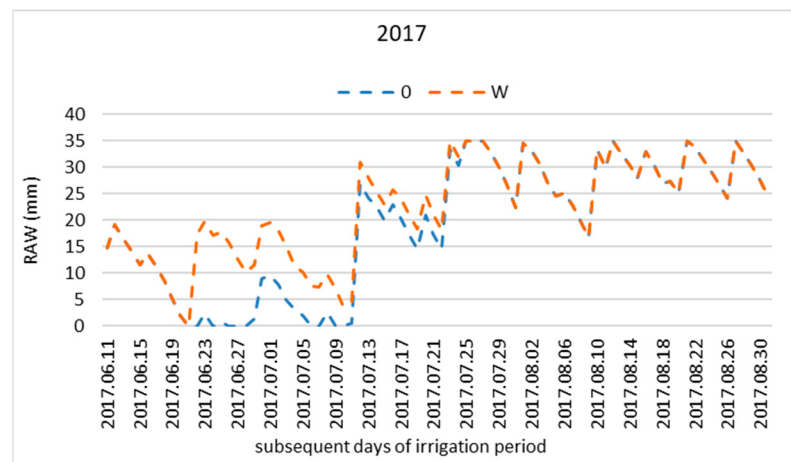


Figure 4. The balance of water readily available to plants in the soil layer with controlled moisture in the period from 11 June to 31 August 2017 (wet season) (0—rainfed, W—irrigation).

3.2. Evaluation of the Production Effects of Irrigation and Fertilization in Maize

The obtained production effects were derived from the irrigation needs of the crop (Table 3). In the dry season of 2015, a significant increase of $4.79 \text{ t} \cdot \text{ha}^{-1}$ (77%) in the yield of grain dry matter was achieved. In contrast, in the wet seasons of 2016 and 2017, this was 1.22 (9%) and $1.03 \text{ t} \cdot \text{ha}^{-1}$ (9%), respectively. The average efficiency of production under irrigation, which should be the basis for considerations regarding the advisability of maize irrigation in the climatic conditions of Central Poland, was 2.35 t of grain dry matter per ha (23%), and the efficiency of 1 mm of irrigated water amounted to $24.3 \text{ kg} \cdot \text{ha}^{-1}$. Irrigation helped stabilize grain yields, which were higher under irrigated conditions in the wet seasons of 2016 and 2017 compared to the dry of 2015.

Table 3. Differentiation of dry matter yield of maize grain under the influence of experimental factors ($\text{t} \cdot \text{ha}^{-1}$).

Variants		2015	2016	2017	Mean
W ₀	T	6.23	12.46	11.49	10.06
	F	6.18	12.45	11.50	10.04
	Mean	6.20	12.46	11.50	10.05
W ₁	T	10.66	13.42	12.15	12.08
	F	11.32	13.95	12.92	12.73
	Mean	10.99	13.68	12.53	12.40
N	T	8.44	12.94	11.82	11.07
	F	8.75	13.20	12.21	11.39
	Mean	8.59	13.07	12.01	11.23
W ₁ –W ₀	$\text{t} \cdot \text{ha}^{-1}$	4.79	1.22	1.03	2.35
	%	77	9	9	23
F–T	$\text{t} \cdot \text{ha}^{-1}$	0.31	0.26	0.39	0.32
	%	4	2	3	3
LSD 0.05	W	0.38	ns	0.42	**
	N	ns	ns	ns	*
	I (N × W)	ns	ns	ns	*

W₀—non-irrigated, W₁—irrigated, W—water factor, N—nitrogen application, T—broadcasted nitrogen fertilizer, F—nitrogen fertilization, W × N—interaction between factors, ns—non-significant, *— $p \geq 0.05$, **— $p \geq 0.01$.

The application of drip nitrogen fertilization, compared to the traditional method of fertilization, resulted in an average significant increase in dry matter yield of grain by $0.32 \text{ t} \cdot \text{ha}^{-1}$ (3%), while under irrigation conditions by $0.65 \text{ t} \cdot \text{ha}^{-1}$ (5%). Fertilization was

ineffective in the rainfed maize plots. The effect of fertilization and its interaction with irrigation was significant throughout the three-year research period.

3.3. Water Needs of Maize

Significant dependency of maize grain dry matter yield on water conditions in the period of active vegetation (June–September) is presented in Figure 5. The dependency is a quadratic function. As can be seen from the formula shown in Figure 5, the maximum grain yield was gained at the level of the total amount of atmospheric precipitation and irrigation doses of 320 mm. This sum can be considered an approximation of the amount of water needed by maize grown for grain during the active vegetation season, which covers the period from early June to late September.

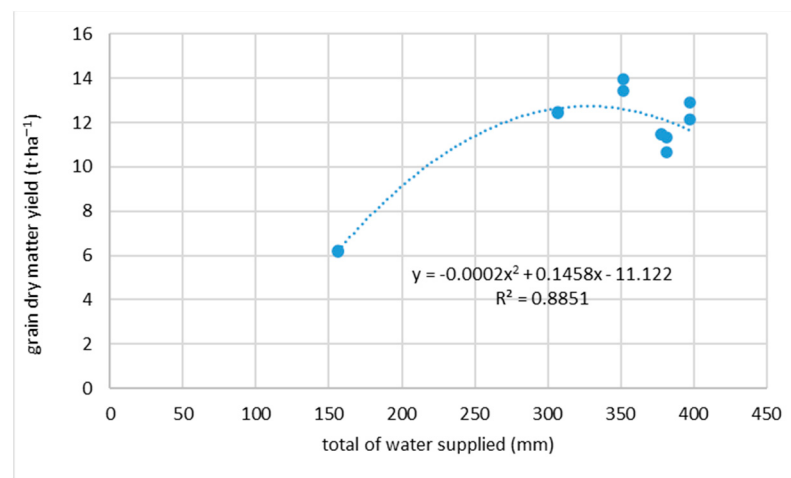


Figure 5. Dependence of dry matter yields of maize grain on water availability conditions during the period of active vegetation (June–Sept. 2015–2017).

3.4. The Effect of Drip Irrigation and Nitrogen Fertilization on the Yield Structure and Its Quality

Of the factors used in the experiment, drip irrigation had a greater impact on the diversity of selected elements of the yield structure and grain quality. Irrigated plants had a significantly higher share of cob yield in whole-plant yield, their grain had a higher dry matter content at harvest, and the weight of one thousand grains was higher compared to non-irrigated plants. Maize fertilized with nitrogen compared to plants fertilized traditionally had a greater share of cob yield in the yield of whole plants. The method of nitrogen dosing through the drip system did not significantly differentiate the other elements of the maize yield structure. The significance of the interaction of irrigation and fertilization in shaping those features was also not demonstrated (Table 4). It is worth noting that none of the applied factors differentiated the protein content of the grain, which amounted to 10.0–10.1% of dry matter. Therefore, the resulting variation in protein yield was the result of variation in grain dry matter yield among the variants (Figure 6). Protein yield was higher by 3.82 t·ha^{−1} (28.7%), as a result of drip irrigation, which supplemented the deficiencies of rainfall during the period of plants' vegetation, while it increased by 0.98 t·ha^{−1} (6.7%) under the effect of the additional dose of nitrogen applied as top dressing fertilization.

Table 4. Effect of drip irrigation and nitrogen fertigation on selected elements of yield structure and grain quality (average values of 2015–2017) 1—share of cob yield in total crop yield, 2—share of grain yield in cob yield, 3—dry matter content in grain at harvest, 4—thousand-grain weight, 5—protein content in grain.

Variants		Elements of the Yield Structure				
		1	2	3	4	5
Irrigation	N Fertigation	%	%	%	g	%
W ₀	T	48.9	76.0	67.5	320	10.0
W ₀	F	49.8	74.7	67.1	320	10.1
W ₁	T	49.6	72.4	68.8	340	10.1
W ₁	F	50.6	73.2	68.8	343	10.0
	W ₀	49.3	75.3	67.3	320	10.0
	W ₁	50.1	72.8	68.8	342	10.0
	T	49.3	74.0	68.2	330	10.1
	F	50.2	73.9	68.0	332	10.0
	Mean	49.7	73.9	68.1	331	10.0
LSD 0.05		W	*	ns	*	ns
		N	*	ns	ns	ns
		W × N	ns	ns	ns	ns

W₀—non-irrigated, W₁—irrigated, W—water factor, N—nitrogen application, T—broadcasted nitrogen fertilizer, F—nitrogen fertigation, W × N—interaction between factors, ns—non-significant, *— $p \geq 0.05$, **— $p \geq 0.01$.

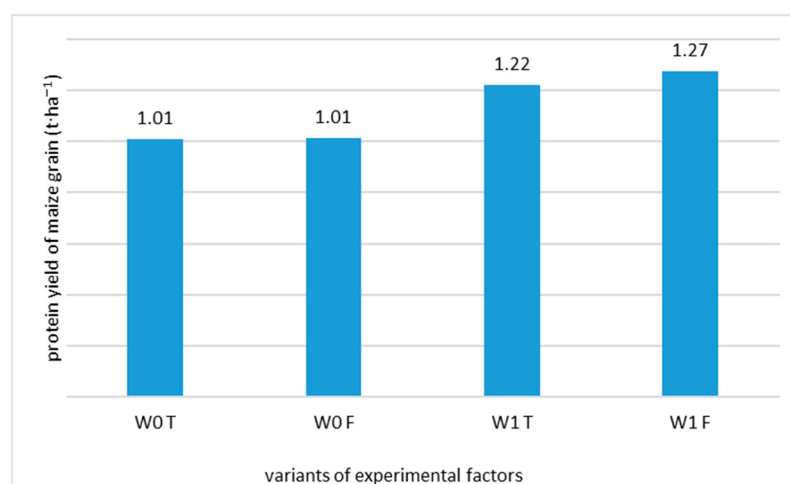


Figure 6. The effect of drip irrigation and nitrogen fertigation on the protein yield of maize cv. ‘Smolan’ (the average of 2015–2017).

4. Discussion

Maize is a plant particularly predestined for cultivation under irrigation conditions, as evidenced by the results of domestic [20,35–41] and foreign research [42–46]. In climatic zones where water is the primary yield-forming factor in crop production, modern studies are focused on the impact of the so-called deficit irrigation on the yield and quality of maize grain. Therefore, many studies in the literature are devoted to this approach to irrigation [47–50]. Under the climatic conditions of Central Poland, maize irrigation is supplementary to unevenly distributed or too-low precipitation totals [51]. Żarski and Dudek [41] report that in Central Poland, where precipitation deficits are characterized by the highest frequency of occurrence, compared to other regions of the country, medium and high irrigation needs of grain maize grown on light soil occur in as many as 71.4% of years, of which in 25.7% of years these needs are defined as large, requiring the use of more than 4 doses of water (amounted to a total of 125 mm). Other research results [21] state that maize cultivation in the region of Kujawsko-Pomorskie is carried out in conditions

of rainfall deficiency, which during the period of increased water needs of maize range from -91 to -124 mm, (depending on the location). This confirms the thesis that the main reasons for the high variability of corn grain yields from year to year in Central Poland are water shortages during the growing season of this crop [21]. Additionally, numerous authors mention soil conditions, especially the water properties, which determine the production effects of grain maize cultivation under irrigation [52–55]. Results of research by Źarski et al. [52] indicate that the yield of dry matter maize grain depended significantly on crop soil conditions. Drip irrigation applied to maize grown on heavy loamy sand with medium loam subsoil resulted in an average increase in dry matter yield by 2.77 t ha^{-1} , while on very light soil the average yield was 7.37 t ha^{-1} and it was slightly lower than the yield of irrigated plants cultivated on medium soil (8.33 t ha^{-1}). The positive effect of maize irrigation with the drip system on very light soil is also confirmed by the study by Grzelak and Źarski [38], in which the authors obtained an increase in the yield of dry matter of grain of two maize cultivars at the level of 4.22 – 5.31 t ha^{-1} , compared to the yield of plants from non-irrigated plots. The importance of the soil type in shaping the production effects of irrigation and nitrogen fertigation in the climatic conditions of the Asian continent is emphasized in their research by Wu et al. [56], according to which the optimization of water conditions in maize cultivation through the use of drip irrigation system increased grain yield by 28% on sandy soils and 12% on clay soils, compared to the yield obtained from rainfed plots. In turn, the use of nitrogen fertigation under irrigation conditions resulted in an increase in grain yield by 41% on sandy soil and 17% on clay soil, compared to the non-irrigated control group.

The results of our study presented in this paper confirmed that the use of irrigation in maize cultivation under the climatic conditions of Central Poland is an intervention measure that supplements emerging precipitation deficiencies, but is not a primary yield-forming factor [20,22,57]. Irrigation needs depend on the amount and distribution of atmospheric precipitation, which in Central Poland is characterized by very high variability in the individual years. In our experiment, high irrigation needs occurred only in the growing season of 2015 while in the remaining seasons' irrigation was used occasionally because the water needs of plants were covered by natural rainfall. The absolute, relative and unitary average increases in maize grain yields obtained in the conducted research under the influence of drip irrigation indicate the potential for increasing the productivity of the crop when the water factor is optimized. In the three-year period of 2015–2017, which was more beneficial in terms of rainfall conditions compared to the reference period 1981–2010, the average increase in yield of 2.35 t of grain dry matter per ha (23%) and the unitary efficiency of 1 mm of irrigated water of 24.3 kg ha^{-1} was obtained. The efficiency of 1 mm of water supplied by drip irrigation in maize grown for grain on very light soil in Central Poland ranged from 25.2 kg ha^{-1} [52] to 29.3 kg ha^{-1} [35]. In the growing season, with the greatest shortages of precipitation, during the period of the plants' highest needs of water, this indicator reached the level of 33.4 kg ha^{-1} . Therefore, it can be assumed, based on the analysis of models of dependence of irrigated yield increase on rainfall conditions [20], that the average production effects of drip irrigation in maize cultivation in the region of Bydgoszcz will be higher than those obtained in our research.

Our results are consistent with the results of Źarski and Dudek [41], who report that in years of high irrigation needs, the predicted increases in grain yields due to irrigation amount to at least 3.60 t ha^{-1} . Dudek et al. [31] found that the water supplementation resulted in an increase in grain dry matter yield, from 5.62 to 8.53 t ha^{-1} on average, or 2.91 t ha^{-1} (52%). Yield increments varied depending on weather conditions in individual growing seasons from 0.46 to 8.47 t ha^{-1} . Production effects of maize irrigation on very light soil were also reported by Źarski et al. [35]. The authors indicate that the yield of dry matter of maize grain depended on the course of weather conditions. The yield obtained from plots, without irrigation, did not exceed 1.0 t ha^{-1} in any of the years of the study, while the irrigation treatment resulted in an average yield of 6.55 t ha^{-1} , ranging from 5.42 to 8.62 t ha^{-1} , depending on the growing season and the level of nitrogen fertilization.

The authors indicate that nitrogen fertigation resulted in a 6% increase in grain yield, but this result was not statistically significant. Lamm et al. [16] and Papadopoulos [58], found that using the drip fertigation system, the nitrogen uptake from the liquid form of fertilizer exceeded 80% compared to conventional soil nitrogen fertilization, where the efficiency of nitrogen use rarely exceeded 50%, even with a good watering schedule.

The results of our research allow us to conclude that the applied drip irrigation significantly shaped selected yield indicators, such as the total yield of the fresh mass of plants and the yield of the fresh mass of grain and cobs in most growing seasons. There are few reports in the domestic and foreign literature on the effect of drip irrigation on these indicators and the quality of maize grain yield. Research results that confirm the beneficial effect of supplementary irrigation on the yield quality and some yield structure elements of maize cultivated in Central Poland are available [37,40]. Also, in the semi-arid climate of west-central Nebraska drip irrigation of maize significantly increased the share of cob weight in total yield, on average by about 8% [12]. In the studies of Dudek et al. [31] drip irrigation had a positive effect on the improvement of grain quality by 19.4 g, an average increase of 3.1% of the share of cobs in the total yield of plants and an increase of 10.3% of the share of grain per cob. Research results by Źarski et al. [52] indicate that selected indicators of the yield structure of plants cultivated under irrigation were also influenced by the type of soil. The authors report that the irrigation treatment caused a 16% increase in the share of cobs in the yield of plants cultivated on very light soil, while a slight decrease (0.6%) in this indicator was recorded on medium soil.

Dudek and Źarski [37] obtained a significant increase in the thousand-grain weight under the influence of drip irrigation, averaging 14.7 g, as well as Źarski et al. [52], obtained improvements in grain size of 36.8 and 85.9 g, respectively, due to the application of the treatment on light and very light soil. The use of the innovative method of applying nitrogen in liquid form as fertigation, compared to the traditional broadcasting method, in research conducted by Źarski et al. [35] resulted in a significant increase in the weight of 1000 grains from fertigated plants but did not bring the expected differentiation of other yield structure elements. According to a study by Blandino et al. [59] on irrigation and nitrogen fertigation of maize grown for grain in the Mediterranean area, fertigation did not affect the number of fully developed cobs and grain but caused a significant increase (by 6%) in the weight of a thousand grains compared to the control group. The authors found no interaction between fertigation and drip irrigation. In contrast, Ibrahim et al. [7], using the deficit irrigation method and nitrogen fertigation in maize cultivation on light soil, found that there was an interaction between the experimental factors that significantly increased the maize grain yield, but did not cause changes in the weight of one thousand grains. Analyzing selected elements of the yield structure in each year of the study, the authors noted that the interaction, or lack thereof, between drip irrigation and nitrogen fertigation, could be related to the different course of weather conditions in each season of plant vegetation. On the other hand, Bibe et al. [60], based on their research, found that the interaction effect resulting from different levels of drip irrigation and nitrogen fertigation was insignificant for all maize growth and yield characteristics. In the studies of Dudek et al. [31], irrigation caused a slight (0.1%) decrease in the total protein content in maize grain, while Źarski et al. [52] reported that this treatment slightly (by 0.1%) improved the concentration of this component in the grain of plants grown on medium soil, but decreased it (by 1.7%) on very light soil. Kresovic et al. [50] found that full coverage of the water needs of maize resulted in a decrease in protein concentration in the grain, and the highest content of this component was found in the grain of plants, whose water needs were covered in 75%. Ertek and Kara [61] reached similar conclusions. In contrast, Aydinsakir [62] came to the opposite conclusion when growing maize in an ecological system, which confirmed the highest protein content in grain of plants from irrigated facilities, where their water needs were fully covered. The positive effect of nitrogen fertigation on the protein content in maize grain was confirmed by Źarski et al. [35]. In the field experiment conducted by the authors, doubling the dose of nitrogen contributed to the increased concentration of this

component in dry matter of grains in the fertigated plants, compared to those fertilized by the traditional method. The results obtained by the authors indicate the possibility of using nitrogen fertigation in place of traditional fertilization to reduce expenditures and activities related to the need for additional passages of agricultural machines. Recent studies on the impact of fertigation on yielding and shaping the quality of maize grain have a dynamic character, which means they are focused on the ongoing control of macronutrient resources in the soil [63–70]. In these studies, the following factors are differentiated: treatment frequency, the size of fertilizer doses and doses of supplemented water, plant development stages, and the rate of fertilizer release. Coordination of such studies requires the use of statistical models and the monitoring of macronutrient levels in soil and plant tissues. This means that new varieties of plants introduced into cultivation, as well as anticipated changes in climatic and hydrological conditions; require continuous expansion of this research topic.

According to Rzekanowski et al. [57], the unitary efficiency of irrigation is greater on poor soils characterized by low water holding capacity, while on soils with a high water holding capacity, the efficiency is less. The results presented in this paper indicate that the production effects in maize cultivation depend on the coverage of the water needs of plants in the period of the greatest water demand, but as stated by Źarski et al. [71] in the occurrence of agricultural drought in the earlier development phases, the losses are not compensated for, even if the optimal amount of rainfall occurs in the critical period. In light of the obtained results, drip irrigation in maize cultivation on light soil should be considered as a measure to improve the stability of crop yields in the following years, but not as a treatment that would ensure profitability and return on investment. On the other hand, the method of nitrogen application in our research significantly improved grain yield in most growing seasons but did not significantly differentiate the structure and qualitative features of the yield. The significance of the interaction of irrigation and fertigation in shaping these features was also not demonstrated. According to Źarski [72], despite the positive effects of nitrogen fertigation of horticultural plants, the use of this technology in the cultivation of maize for grain is expensive in our country and is currently difficult to implement on a practical scale.

Economic analyses based on the current agricultural prices and the expenses of investment and operation of the drip irrigation system used in maize cultivation in Central Poland show that this would be economically ineffective [27]. The treatment would be profitable only with an average multi-year grain yield increments of at least 4.5 t of dry matter of grain per ha. Such production effects of irrigation in the area are obtained only in dry seasons, occurring with a frequency of 30% of years. The lack of profitability of maize irrigation means that in practice it is irrigated very rarely. Drip irrigation can be considered future-oriented, referred to as production reserves. These reserves can be used under the circumstances of changes in the economic conditions of irrigation resulting from the increasing demand for maize grain or climatic conditions. Some predictions relating to the spring-summer season report are, that higher air temperatures would be beneficial for crop production in the countries located in the higher latitudes of Europe, where the length of the growing season is currently a limiting factor, compared to the southern parts [73,74]. Therefore, some crops would probably be moved from hot southern areas to other ones with lower temperatures [75] where production conditions would be enhanced. This means the more northern areas could benefit from temperature increases due to climate change [76], provided the access to irrigation water resources would be available.

5. Conclusions

Maize is a plant of a global cultivation range and great economic importance, which is mainly due to its high yield potential and versatile use as food, fodder, and energy source. The main objective of the undertaken research was to evaluate the response of maize grown for grain to drip irrigation a water-saving and energy-saving irrigation technology. The aim of the study was also to evaluate the response of maize to fertigation and the

interaction of drip irrigation and fertigation in shaping the yield of the crop. In Poland, fertigation is used mainly in fruit and vegetable production. So far, only one case study has been conducted in maize cultivation with fertigation treatment, however, the expected significant differentiation of most of the maize features under the influence of the use of drip nitrogen fertigation was not found on sandy soil. The results presented in the paper concerning the absolute, relative and unitary average increases in corn grain yields under the influence of drip irrigation indicate the potential for increasing the productivity of corn under the condition of optimizing the water factor. Drip irrigation caused a significant increase in the yield of maize grains of the ‘Smolan’ cultivar. The average yield increase was $2.35 \text{ t} \cdot \text{ha}^{-1}$, and varied depending on rainfall pattern: in the dry season it was 4.79, and in the wet season $1.03\text{--}1.22 \text{ t} \cdot \text{ha}^{-1}$. The application of top-dressing nitrogen fertigation resulted in a significant increase in the yield of maize grain compared to the traditional method of nitrogen fertilization. Drip irrigation and fertigation are treatments that, ensuring the stability of maize yield over the years, contribute to an increase in plant yield by approximately 25% on average, and by more than 80% in dry seasons. It can be concluded that the water factor plays a significant role in shaping the height, structure, and quality indicators of maize yield grown for grain in Central Poland.

Author Contributions: Conceptualization, J.Ż. and R.K.-T.; methodology, J.Ż. and R.K.-T.; formal analysis, J.Ż. and R.K.-T.; investigation, J.Ż. and R.K.-T.; resources, J.Ż. and R.K.-T.; writing—original draft preparation, J.Ż. and R.K.-T.; writing—review and editing, J.Ż. and R.K.-T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data available on request from the authors.

Acknowledgments: We would like to thank Stanisław Dudek for his help in taking care of the field experiment.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. FAOSTAT. Food and Agriculture Data. Available online: <https://www.fao.org/faostat> (accessed on 30 September 2022).
2. Syp, A. Projected changes in grain Maize yields in Poland and European Union in 2030. *Roczn. Nauk. Stow. Ekonom. Roln. Agrob.* **2015**, *17*, 373–378. (In Polish)
3. AQUASTAT. Global Information System on Water and Agriculture. Available online: <https://www.fao.org/aquastat> (accessed on 30 September 2022).
4. Bozkurt, S.; Yazar, A.; Mansuroglu, G.S. Effects of different drip irrigation levels on yield and some agronomic characteristics of raised bed planted corn. *Afric. J. Agric. Res.* **2011**, *6*, 5291–5300.
5. Greaves, G.E.; Wang, Y.-M. Yield response, water productivity, and seasonal water production functions for maize under deficit irrigation water management in southern Taiwan. *Plant Prod. Sci.* **2017**, *20*, 353–365. [[CrossRef](#)]
6. He, Z.; Zhang, T.; Liu, X.; Shang, X. Water-yield relationship responses of maize to ridge-furrow planting systems coupled with multiple irrigation levels in China’s Horqin sandy land. *Agronomy* **2018**, *8*, 221. [[CrossRef](#)]
7. Ibrahim, M.M.; El-Baroudy, A.A.; Taha, A.M. Irrigation and fertigation scheduling under drip irrigation for maize crop in sandy soil. *Int. Agrophys.* **2016**, *30*, 47–55. [[CrossRef](#)]
8. Karasu, A.; Kuscu, H.; Oz, M.; Bayram, G. The effect of different irrigation water levels on grain yield, yield components and some quality parameters of silage maize (*Zea mays indentata* Sturt.) in Marmara Region of Turkey. *Not. Bot. Hort. Agrob.* **2015**, *43*, 138–145. [[CrossRef](#)]
9. Ko, J.; Piccinni, G. Corn yield responses under crop evapotranspiration-based irrigation management. *Agric. Water Manage.* **2009**, *96*, 799–808. [[CrossRef](#)]
10. Kuscu, H.; Karasu, A.; Oz, M.; Demir, A.; Turgut, I. Effect of irrigation amounts applied with drip irrigation on maize evapotranspiration, yield, water use efficiency, and net return in a sub-humid climate. *Turk. J. Field Crops* **2013**, *18*, 13–19.
11. Parizi, A.R.C.; Robaina, A.D.; Dos, S.; Gomes, A.C.; Peter, M.X.; Soares, F.C. Corn yield under various simulated irrigation depths. *Eng. Agric. Jaboticabal* **2016**, *36*, 503–514. [[CrossRef](#)]
12. Payero, J.O.; Tarkalson, D.D.; Irmak, S.; Davison, D.; Petersen, J.L. Effect of irrigation amounts applied with subsurface drip irrigation on corn evapotranspiration, yield, water use efficiency, and dry matter production in a semiarid climate. *Agric. Water Manage.* **2008**, *95*, 895–908. [[CrossRef](#)]

13. Van Donk, S.; Davison, D.; Petersen, J. Corn Water Use and Yield for Various Limited Irrigation Treatments. In Proceedings of the ASABE Annual International Meeting, Louisville, KY, USA, 7–10 August 2011; Paper Number: 1111263. West Central Research and Extension Center: North Platte, NE, USA, 2011. Available online: <https://digitalcommons.unl.edu/westcentresext/57> (accessed on 27 November 2022).
14. Van Donk, S.; Petersen, J.; Davison, D. Effect of amount and timing of subsurface drip irrigation on maize yield. *Irrig. Sci.* **2013**, *31*, 599–609. [\[CrossRef\]](#)
15. Norwood, C.A. Water use and yield of limited-irrigated and dryland corn. *Soil Sci. Soc. Am. J.* **2000**, *64*, 365–370. [\[CrossRef\]](#)
16. Lamm, F.R.; Trooien, T.P. Subsurface drip irrigation for corn production: A review of 10 years of research in Kansas. *Irrig. Sci.* **2001**, *22*, 195–200. [\[CrossRef\]](#)
17. Lamm, F.R.; Ayars, J.E.; Nakayama, F.S. *Microirrigation for Crop Production. Design, Operation, and Management*; Elsevier Science: Amsterdam, The Netherlands, 2006; 642p.
18. Peterson, C.A.; Soares, T.; Torbert, E.; Herrera, I.; Scow, K.M.; Gaudin, A.C.M. Drip irrigation effect on soil function, root systems and productivity in organic tomato and corn. In Proceedings of the Organic Agriculture Research Symposium, Pacific Grove, CA, USA, 20 January 2016.
19. Asadi, M.E.; Clemente, R.S.; Das Gupta, A.; Loof, R.; Hansen, G.K. Impacts of fertigation via sprinkler irrigation on nitrate leaching and corn yield in an acid-sulphate soil in Thailand. *Agric. Water Manage.* **2002**, *52*, 197–213. [\[CrossRef\]](#)
20. Żarski, J.; Dudek, S.; Kuśmierk-Tomaszewska, R.; Rolbiecki, R.; Rolbiecki, S. Forecasting effects of plants irrigation based on selected meteorological and agricultural drought indices. *Ann. Set Environ. Protect.* **2013**, *15*, 2185–2203. (In Polish)
21. Żarski, J.; Kuśmierk-Tomaszewska, R.; Dudek, S. Spatial and temporal variability of droughts in the region of Pomorze and Kujawy during the period of high water needs of corn. *Infrastr. Ecol. Rural Areas* **2018**, *II/1*, 407–419.
22. Kuśmierk-Tomaszewska, R.; Żarski, J. The Effects of Plant Irrigation in Poland. In *Management of Water Resources in Poland*, 1st ed.; Zeleňáková, M., Kubiak-Wójcicka, K., Negm, A.M., Eds.; Springer: Cham, Switzerland, 2021; pp. 379–393. [\[CrossRef\]](#)
23. Łabędzki, L. Estimation of local drought frequency in Central Poland using the standardized precipitation index SPI. *Irrig. Drain.* **2007**, *56*, 67–77. [\[CrossRef\]](#)
24. Żarski, J.; Kuśmierk-Tomaszewska, R.; Dudek, S. Trends of changes in climate risk of grain maize cultivation in the Bydgoszcz Region. *Infrastr. Ecol. Rural Areas* **2016**, *III/1*, 725–735. [\[CrossRef\]](#)
25. Kuśmierk-Tomaszewska, R.; Żarski, J. Assessment of meteorological and agricultural droughts occurrence in central Poland in 1961–2020 as an element of the climatic risk to crop production. *Agriculture* **2021**, *11*, 855. [\[CrossRef\]](#)
26. Żarski, J.; Dudek, S.; Kuśmierk-Tomaszewska, R.; Żarski, W. Effects of agricultural droughts in the province of Kujawsko-Pomorskie and possibilities of minimizing their impact. *Infrastr. Ecol. Rural Areas* **2017**, *II/2*, 813–824. [\[CrossRef\]](#)
27. Kledzik, R.; Kropkowski, M.; Dudek, S.; Kuśmierk-Tomaszewska, R.; Żarski, J. Evaluation of economic efficiency of irrigation in maize for grain production in 2005–2016. *Infrastr. Ecol. Rural Areas* **2017**, *II/1*, 587–598. [\[CrossRef\]](#)
28. IPCC 2014. AR5 Synthesis Report—Climate Change. Available online: www.ipcc.ch/report/ar5/syr/ (accessed on 30 September 2022).
29. Kuchar, L.; Iwański, S.; Gasiorek, E.; Diakowska, E. Simulation of hydrothermal conditions for crop production purpose until 2050–2060 and selected climate change scenarios for north central Poland. *Infrastr. Ecol. Rural Areas* **2015**, *II/1*, 319–334. [\[CrossRef\]](#)
30. Wibig, J. Moisture conditions in Poland in view of the spei index. *Water Environ. Rural Areas* **2012**, *12*, 329–340. (In Polish)
31. Dudek, S.; Żarski, J.; Kuśmierk-Tomaszewska, R. Study of maize response on drip irrigation basing on long-term field experiment. *Infrastr. Ecol. Rural Areas* **2009**, *3*, 167–174.
32. Treder, W.; Klamkowski, K.; Krzewińska, D.; Tryngiel-Gač, A. The latest trends in irrigation technology—Research related to irrigation of fruit crops conducted at the research Institute of Pomology and Floriculture in Skierniewice. *Infrastr. Ecol. Rural Areas* **2009**, *6*, 95–107.
33. Kaniszewski, S.; Dyśko, J.; Babik, J. Effect of drip irrigation and nitrogen fertigation on yield of root vegetables. *Infrastr. Ecol. Rural Areas* **2009**, *3*, 43–54.
34. Rolbiecki, R.; Rolbiecki, S.; Piszczek, P. Yields of the three romaine lettuce cultivars on the very light soil under fertigation of nitrogen by drip system. *Infrastr. Ecol. Rural Areas* **2011**, *6*, 205–209.
35. Żarski, J.; Dudek, S.; Grzelak, B.; Kuśmierk-Tomaszewska, R.; Rolbiecki, R.; Rolbiecki, S. Corn yield response to drip irrigation and nitrogen fertigation in the area of excessive water deficits. *Infrastr. Ecol. Rural Areas* **2015**, *II/1*, 279–289.
36. Chmura, K.; Chylinska, E.; Dmowski, Z.; Nowak, L. Role of the water factor in yield formation of chosen field crops. *Infrastr. Ecol. Rural Areas* **2009**, *9*, 33–44.
37. Dudek, S.; Żarski, J. Evaluation of results of irrigation applied to grain maize. *Inż. Roln.* **2005**, *3*, 159–166.
38. Grzelak, B.; Żarski, J. Influence of drip irrigation and nitrogen fertilization on two cultivars corn yielding on very light soil. *Infrastr. Ecol. Rural Areas* **2009**, *6*, 141–149.
39. Podsiadło, C.; Koszański, Z.; Jaroszewska, A.; Kowalewska, R. The effect of drip irrigation on yielding of sweet sorghum and corn on a light soil. *Infrastr. Ecol. Rural Areas* **2013**, *1*, 177–186. (In Polish)
40. Żarski, J.; Dudek, S.; Grzelak, B. Role of water and thermal factors in shaping the corn yield. *Acta Agroph* **2004**, *3*, 189–195. (In Polish)
41. Żarski, J.; Dudek, S. Time variability of selected plants irrigation needs in the region of Bydgoszcz. *Infrastr. Ecol. Rural Areas* **2009**, *3*, 141–149.
42. Zwart, S.; Bastiaanssen, W. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. *Agric. Water Manage.* **2004**, *69*, 115–133. [\[CrossRef\]](#)

43. El-Wahed, M.; Ali, E.A. Effect of irrigation systems, amounts of irrigation water and mulching on corn yield, water use efficiency and net profit. *Agric. Water Manage.* **2013**, *120*, 64–71. [\[CrossRef\]](#)
44. Liu, Y.; Yang, H.S.; Li, J.S.; Li, Y.F.; Yan, H.J. Estimation of irrigation requirements for drip-irrigated maize in a sub-humid climate. *J. Integr. Agric.* **2018**, *17*, 677–692. [\[CrossRef\]](#)
45. Wang, Y.; Li, S.; Cui, Y.; Qin, S.; Guo, H.; Yang, D.; Wang, C. Effect of drip irrigation on soil water balance and water use efficiency of maize in Northwest China. *Water* **2021**, *13*, 217. [\[CrossRef\]](#)
46. Irmak, S.; Mohammed, A.; Kukal, M. Maize response to coupled irrigation and nitrogen fertilization under center pivot, subsurface drip and surface (furrow) irrigation: Growth, development and productivity. *Agric. Water Manage.* **2022**, *263*, 107457. [\[CrossRef\]](#)
47. Da Ge, T.; Sui, F.G.; Nie, S.A.; Sun, N.B.; Xiao, H.A.; Tong, C.L. Differential responses of yield and selected nutritional compositions to drought stress in summer maize grains. *J. Plant Nutr.* **2010**, *33*, 1811. [\[CrossRef\]](#)
48. Thitisaksakul, M.; Jimenez, R.C.; Abias, M.C.; Beckles, D.M. Effects of environmental factors on cereal starch biosynthesis and composition. *J. Cereal Sci.* **2012**, *56*, 67. [\[CrossRef\]](#)
49. Tarighaleslami, M.; Zarghami, R.; Mashhadi, A.B.M.; Oveysi, M. Effects of drought stress and different nitrogen levels on morphological traits of proline in leaf and protein of corn seed (*Zea mays* L.). *Am.-Eurasian J. Agri. Environ. Sci.* **2012**, *12*, 49.
50. Kresović, B.; Gajić, B.; Tapanarova, A.; Dugalić, G. How irrigation water affects the yield and nutritional quality of maize (*Zea mays* L.) in a temperate climate. *Pol. J. Environ. Stud.* **2018**, *27*, 1123–1131. [\[CrossRef\]](#) [\[PubMed\]](#)
51. Żarski, J. The effects of irrigation of cereals in Poland. *Infrastr. Ecol. Rural Areas* **2009**, *3*, 29–42.
52. Żarski, J.; Dudek, S.; Grzelak, B. Comparison of results of corn drip irrigation in two soil types. *Zesz. Probl. Post. Nauk Roln.* **2007**, *519*, 339–345. (In Polish)
53. Alhammad, M.; Al-Shrouf, A. Irrigation of sandy soils, basics and scheduling. In *Crop Production*; Goyal, A., Asif, M., Eds.; IntechOpen: London, UK, 2013. [\[CrossRef\]](#)
54. Kareem, I.; Omran, H.; Hassan, R. Operating a drip irrigation system indifferent types of soil. In *First International Symposium on Urban Development: Koya as a Case Study*; Khoshnaw, F.M., Ed.; Koya University: Koy Sanjaq, Iraq, 2013; pp. 105–116. [\[CrossRef\]](#)
55. Fang, J.; Su, Y. Effects of soils and irrigation volume on maize yield, irrigation water productivity, and nitrogen uptake. *Sci. Rep.* **2019**, *9*, 7740. [\[CrossRef\]](#) [\[PubMed\]](#)
56. Wu, D.; Xu, X.; Chen, Y.; Shao, H.; Sokolowski, E.; Mi, G. Effect of different drip fertigation methods on maize yield, nutrient and water productivity in two-soils in Northeast China. *Agric. Water Manage.* **2019**, *213*, 200–211. [\[CrossRef\]](#)
57. Rzekanowski, C.; Żarski, J.; Rolbiecki, S. Requirements, results and perspectives of plant irrigation on the areas characterized by distinct water deficits. *Post. Nauk Roln.* **2011**, *1*, 51–63. (In Polish)
58. Papadopoulos, I. Use of labelled fertilizers in fertigation research. In *Proceedings of the International Symposium Nuclear Techniques in Soil-Plant Studies for Sustainable Agriculture and Environmental Preservation*, Vienna, Austria, 17–21 October 1994; pp. 399–410.
59. Blandino, M.; Cordero, E.; Vanara, F.; Reyneri, A.; Lagnasco, D. Effect of drip irrigation and fertigation on maize resource-use efficiency, yield and quality. In *Proceedings of the XLVIII Convegno della Società Italiana di Agronomia, Evoluzione e adattamento dei sistemi culturali erbacei, Società Italiana di Agronomia, Perugia, Italy, 18–20 September 2019*. Available online: <https://typeset.io/papers/effect-of-drip-irrigation-and-fertigation-on-maize-resource-48uno9hja> (accessed on 27 October 2022).
60. Bibe, S.; Jadhav, K.; Chavan, A. Response of irrigation and fertigation management on growth and yield of maize. *Int. J. Curr. Microbiol. App. Sci.* **2017**, *6*, 4054–4060. [\[CrossRef\]](#)
61. Ertek, A.; Kara, B. Yield and quality of sweet corn under deficit irrigation. *Agric. Water Manage.* **2013**, *129*, 138–144. [\[CrossRef\]](#)
62. Aydinsakir, K.; Erdal, S.; Buyuktas, D.; Bastug, R.; Tokar, R. The influence or regular deficit irrigation applications on water use, yield, and quality components of two corn (*Zea mays* L.) genotypes. *Agric. Water Manage.* **2013**, *128*, 65–71. [\[CrossRef\]](#)
63. Mahboob, A.; Shoaib, M.; Manzoor, M.; Arshad, M.; Mahboob, I.; Habib, H.U.; Akram, M. Improving yield and quality of maize by different drip-fertigation rates of N, P and K fertilizers. *Soil Environ.* **2020**, *39*, 50–58. [\[CrossRef\]](#)
64. Paolo, E.; Rinaldi, M. Yield response of corn to irrigation and nitrogen fertilization in a Mediterranean environment. *Field Crops Res.* **2008**, *105*, 202–210. [\[CrossRef\]](#)
65. Saracoglu, M.; Oktem, A. The effect of nitrogen application in different doses by fertigation method on grain yield, yield components and quality of corn (*Zea mays* L.). *Appl. Ecol. Environ. Res.* **2021**, *19*, 2017–5031. [\[CrossRef\]](#)
66. Bai, Y.; Zhao, Y. The effect of the rainfall on the nitrogen fertilizer schedule of maize in Jilin. China. *Water Supply* **2022**, *22*, 1492–1502. [\[CrossRef\]](#)
67. Chauhdary, J. Effect of different irrigation and fertigation strategies on corn production under drip irrigation. *Pak. J. Agric. Sci.* **2017**, *54*, 855–863. [\[CrossRef\]](#)
68. Chauhdary, J.; Bakhsh, A.; Engel, B.; Ragab, R. Improving corn production by adopting efficient fertigation practices: Experimental and modeling approach. *Agric. Water Manage.* **2019**, *221*, 449–461. [\[CrossRef\]](#)
69. Guardia, G.; Cangani, M.; Andreu, G.; Sanz-Cobena, A.; García-Marco, S.; Álvarez, J.; Recio-Huetos, J.; Vallejo, A. Effect of inhibitors and fertigation strategies on GHG emissions, NO fluxes and yield in irrigated maize. *Field Crops Res.* **2017**, *204*, 135–145. [\[CrossRef\]](#)
70. Guo, J.; Fan, J.; Xiang, Y.; Zhang, F.; Yan, S.; Zhang, X.; Li, Z. Coupling effects of irrigation amount and nitrogen fertilizer type on grain yield, water productivity and nitrogen use efficiency of drip-irrigated maize. *Agric. Water Manage.* **2022**, *261*, 107389. [\[CrossRef\]](#)

71. Żarski, J.; Rolbiecki, S.; Dudek, S.; Rolbiecki, R.; Rzekanowski, C. Needs and effects of irrigation of plants in the area of Bydgoszcz. In *Water Balances of Agricultural Ecosystems*; Rojek, M., Ed.; AR: Wrocław, Poland, 2004; pp. 187–203. (In Polish)
72. Żarski, J. Needs and effects of irrigation of cereals. In *Irrigation of Plants*; Karczmarczyk, S., Nowak, L., Eds.; PWRiL: Poznań, Poland, 2006; pp. 383–403. (In Polish)
73. Tubiello, F.; Rosenzweig, C.; Goldberg, R.; Jagtap, S.; Jones, J. Effects of climate change on US crop production: Simulation 614 results using two different GCM scenarios. Part I: Wheat, potato, maize, and citrus. *Clim. Res.* **2002**, *20*, 259–270. [[CrossRef](#)]
74. Wiréhn, L. Nordic agriculture under climate change: A systematic review of challenges, opportunities and adaptation strategies for crop production. *Land Use Policy* **2018**, *77*, 63–74. [[CrossRef](#)]
75. Tanasijevic, L.; Todorovic, M.; Pereira, L.S.; Pizzigalli, C.; Lionello, P. Impacts of climate change on olive crop evapo-619 transpiration and irrigation requirements in the Mediterranean region. *Agric. Water Manage.* **2014**, *144*, 54–68. [[CrossRef](#)]
76. Juhola, S.; Klein, N.; Käyhkö, J.; Neset, T.S.S. Climate change transformations in Nordic agriculture? *J. Rural Stud.* **2017**, *51*, 28–36. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.