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The Impact of Crop Year and Crop Density on the Production of Sunflower in Site-Specific Precision Farming in Hungary

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Abstract: Sunflower is considered a plant with extraordinary adaptability. However, the conditions of growing sunflower function as a limiting factor in its production. The hybrids used in production tolerate weather variability to a different level and utilise the nutrient and water resources of the soil, while the yield is also affected by the number of plants per hectare. In this study, the authors attempted to observe the environmental effects influencing sunflower cultivation, the heterogeneous productivity zones of the given production site and the correlation of the number of seeding plants used under various farm practices. The average rainfall of 2021 and the dry weather of 2022 created suitable conditions for examining the yearly weather effect. In the selected experimental areas, three distinguishable zones were defined in terms of productivity. In each productivity zone, three crop density steps were used in four replicates. Based on the performed comparative tests, the rainy year of 2021 resulted higher yield than the drier year of 2022 in the average- and high productivity zones, while in the low-productivity zone, higher yields were harvested under the drier conditions of 2022 than in the rainy year of 2021. In 2021, with the improvement in productivity, the obtained yield was also higher. However, in 2022, this clarity could not be demonstrated. In the zones with low productivity, identical yield results were observed in both weather conditions. Based on the examination of the obtained results, it was shown that the effect of weather conditions and the given number of plants have a smaller influence on the yield results of low-productivity zones, while these factors have a greater influence on the yields of high-productivity zones.

Keywords: crop density; crop year effect; productivity zone; sunflower

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1. Introduction

Climate change is one of the world's biggest challenges and one of the most complex problems on a global scale [1]. As a result of anthropogenic impact, average temperature rose by 0.99 °C in the first two decades of the century (2001–2020). In addition, based on forecasts, the temperature rise is expected to reach or exceed 1.5 °C by 2050. This accelerated temperature increase causes drought, floods and erratic precipitation amounts and their temporal distributions as well as heat waves and extreme weather conditions worldwide [2,3]. Of the natural disasters caused by weather and climate change, the damage caused by drought is prominent, and alternation of drought periods is frequently researched [4–9]. The effect of drought is felt in the functioning of social, economic and environmental systems [10]. In addition, it significantly influences the effectiveness of anthropogenic production areas, including the agricultural, forestry and water management sectors, while also affecting areas such as energy production and healthcare [11]. As a direct effect, drought reduces crop production results [12], thus indirectly affecting food prices.

Consequently, extreme price fluctuations are experienced in the agricultural sector [13]. Similar to other Central European countries, Hungary is affected by the effects of climate change and drought [14,15]. Drought was common throughout Hungarian history, which significantly reduced the number of crops, increased the number of dead animals and caused famines [16]. The frequency of drought periods also increased continuously over time [16]. On average, Hungary is hit by a moderate drought every two years and by a severe drought every three years [17]. According to forecasts, this tendency will continue throughout the century [14,18].

As a result of these circumstances, the main aim of today's tillage research is the development of cultivation systems and procedures that promote adaptation to changed environmental conditions and are suitable for preventing or mitigating crop losses due to extreme water balance disturbances [19]. Cultivation technology interventions result in water and energy saving, and their more economical use potentially gives farmers the opportunity to maintain the effectiveness of farming even in the face of reduced yields [20].

The quality of the performed agrotechnical operations is important: water supply should be made available to sunflower to the highest possible extent [21].

Higher number of plants consumes more water. Hybrids utilise soil water resources with different levels of efficiency, which is also greatly influenced by the number of plants, i.e., crop density [22]. The optimal number of seedlings is also an area- and hybrid-specific property. However, the productivity of the soil, the heterogeneity of the given area, the expected yield, the possibilities of the used seed drill as well as the adaptability of the given hybrid are also modifying factors [23]. The appearance of satellite remote sensing and positioning, sensor measurement, geospatial data analysis and processing software as well as the possibility of their use established the foundations of precision crop production [24,25].

Due to the technological developments of site-specific crop production, GIS applications and cultivation tools have become available to producers. The use of these tools can significantly increase the efficiency of farming [26]. While there is increasing interest in differentiated nutrient application, site-specific controlled sowing [27] is less used, even though the basis of its usability and efficiency is the realisation of greater benefits through cost reduction.

Hungary is suitable for sunflower production based on the amount of sunlight and heat, as well as the length of the growing season. As a result of simultaneous testing in different climate zones, it was established that the crop yield is significantly affected, while the oil content is only slightly influenced by the environment–hybrid interaction [28].

The yield and oil content of sunflower are significantly affected by temperature and the amount of precipitation during the growing season [29]. The plant height of sunflower is mostly determined by both soil and air temperature. Higher soil temperature results in increased plant height [30]. During the cultivation period of sunflower, the lack of water resulting from evaporation conditions is a bottleneck for the development of large crops. When sunflower was grown under water-deficient conditions, leaf initiation and leaf unfolding were significantly reduced. However, the development of flower parts and the beginning of flowering did not change, despite the decreased number of leaves, which supports the proper adaptability of sunflower. Favourable growing years for sunflowers are characterised by rainier weather and higher-than-average temperature [31].

Of the factors that determine the yield of sunflower, N and P supply, precipitation and temperature changes during the vegetation period and the genetic potential of the given hybrid stand out [32].

In addition to productivity, quality is also important (oil content, oleic acid content, thousand-grain weight). In addition, from a crop safety aspect, favourable pathological characteristics are also a determining factor for variety selection. In recent crop years, it has been proven that Hungary's climate has become increasingly drier and drier, i.e., drought tolerance is also an important feature of sunflower [33].

In the future, better results can be achieved with hybrids with favourable pathological characteristics and related chemical control. Differences in yield between sunflower hybrids are caused by potential productivity and different yield reliability [34].

Different ecological conditions, soil type, fertility and water management, as well as the characteristics of the grown hybrids, determine the size of the production area and the number of plants per hectare, i.e., plant density. Many researchers have conducted studies and expressed their opinions regarding this important agrotechnical factor as it affects yield. Despite extensive studies, contradictory results were obtained regarding the relationship between plant density and yield. The effect of plant density on crop yield and infection mainly depends on the environmental conditions of the experiment site, as well as on the tested hybrid. By means of increasing plant density, there is a decrease in head diameter, the number of seeds per head, yield per head and the thousand-grain weight [35].

Of the various production technology elements, the number of plants per area unit has an immense importance. By increasing plant density, although not linearly, the oil content of the harvested grain increases to a certain limit, which is necessary to establish within the given production characteristics [30].

According to other research, by increasing plant density, plant height also increases, but the head diameter decreases. As the plant density decreases, the diameter of the head, the number of seeds on the head as well as the oil content increase [36]. When examining the reaction of the number of plants regarding sunflower hybrids, the oil content was directly proportional to the plant density at 57,000 plants ha^{-1} and 80,000 plants ha^{-1} [37].

In this study, the authors attempted to investigate the environmental effects affecting the effectiveness of sunflower production, the heterogenous productivity zones of the given production site and the correlation of the number of sown plants used under operating conditions.

2. Materials and Methods

2.1. The Open Field Sowing Experiment

In 2021 and 2022, a sunflower sowing experiment was carried out with site-specific crop density in two fields with the same soil outside of Egerfarmos (Heves County, Hungary), by sowing significantly different amounts of seeds within the given zones. During the experiment, the effect of crop year, the characteristics of the production site, the soil properties of the individual zones, the characteristics of the applied sowing technique (nominal and germinated number of seedlings, the uniformity of plant spacing, the ratio of double and missing seeding) and the quantity and quality of yield were examined.

The number-controlled sowing experiments were set up in two high-plasticity meadow soil type areas: in 2021 in the field C14 and in 2022 in the field C10 (Table 1).

Table 1. Soil properties of experimental sites.

Zone ID.		C14 low	C14 Average	C14 High	C10 low	C10 Average	C10 High
Soil Type		High-Plasticity Meadow					
Parameter	Unit	Measured Values					
pH (KCl)		6.06	5.87	6.1	5.41	6.7	6.62
Arany's plasticity index		42	>60	>60	59	>60	>60
Total salt	m/m%	0.09	0.13	0.12	0.14	0.16	0.14
$CaCO_3$	m/m%	0	0	0	0	0.9	0.1
Organic matter	m/m%	3.01	2.66	2.68	3.32	4.31	3.18
(NO_2^-+NO_3^-)-N (KCl)	mg kg^{-1}	25.3	12.7	16.3	27.7	39.8	42.4
P_2O_2 (AL)	mg kg^{-1}	1060	258	209	150	461	73.3
K_2O (AL)	mg kg^{-1}	1230	484	445	849	1060	622

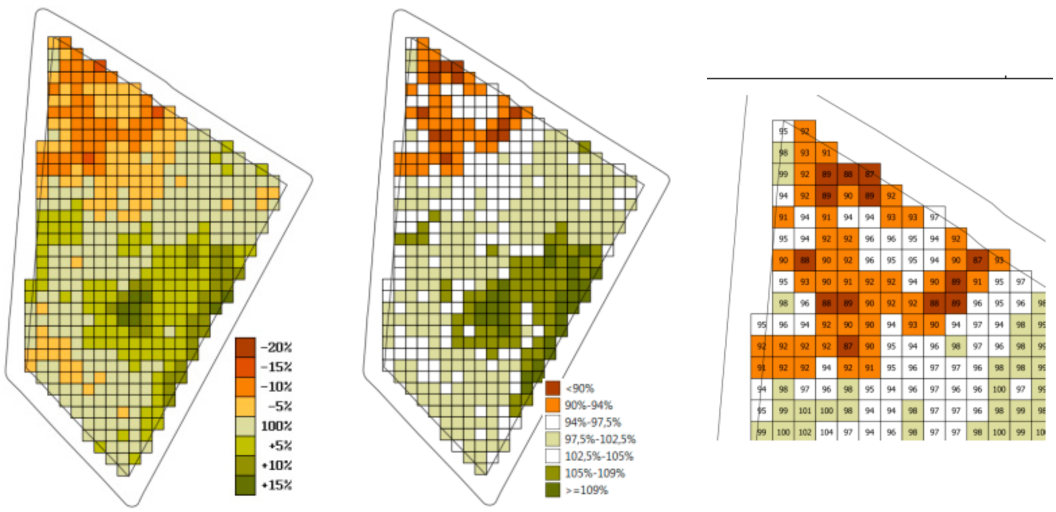
The productivity zones were created using the data of the images taken by the Sentinel-2 satellite in the period between 2017 and 2020 and the yield and height data at the harvest recorded by the harvester's computer (John Deere Greenstar™ 3 Display) between 2017 and 2020.

The mapping of the productivity zones of the areas included in the study and the measurement of their area were conducted with aerial photographs providing 10 × 10 m resolution of ground surface detail, which were taken on several occasions during the examined years. Plant mapping was carried out using the usual image analysis chain based on statistical classification pre-processing, a Maximum Likelihood decision and an accuracy test.

In order to monitor crop development and to estimate yield, in addition to the satellite imagery, the height and yield data measured by the harvesters—available on a yearly basis—were used. Time curves were obtained for the plants from the data of the high-resolution satellite images, from which yield was calculated, but the yield data were also measured by the harvester providing reference data, which were corrected for the average data of the given field.

The results of the data collection were integrated into a geospatial information system for further use.

When determining productivity, a yield level was determined as expected from the productivity of the area (4 t ha^{-1}), which was assigned to the different zones of the area based on the prepared productivity map and modified in a positive or negative direction due to its nature. A pixel with an average productivity is evaluated as 100% (Figure 1), and pixels with homogeneous productivity form zones. The 1.5 ha area required for the sowing experiment was also considered when creating each zone.



(**a**) (**b**) (**c**)

Figure 1. The productivity map of area C14. (**a**) Pixel valuation relative to 100%; (**b**) pixel values based on the productivity classification method; (**c**) the exact pixel values of northern part of the field.

It was considered that the three productivity categories (low, average, high) should have been separated from each other as much as possible. This process was conducted differently from what is used in practice, which often involves combining zones or making zone boundaries more regular, since the goal is to show the existing differences.

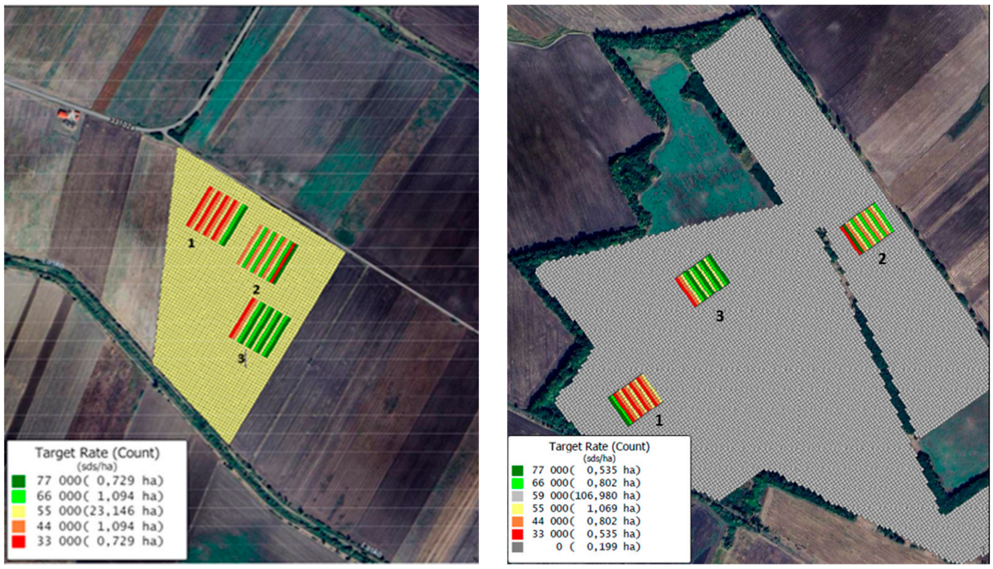
The productivity zones were created and classified as follows:

- Low-productivity zone: the average of pixel vales was between 87% and 94%;
- Average-productivity zone: the average of pixel values was between 97.6% and 102.5%;
- High-productivity zone: the average of pixel values was between 105.1% and 113%.

The seed number changes of the experimental sowing were performed automatically by the tractor's on-board computer based on a pre-written sowing plan.

The experimental sowing was planned in conformity with the productivity zone categories as follows: According to the seed manufacturer's recommendations, the nominal seeding rate of the SY Bacardi CLP sunflower hybrid is 55–58,000 seeds ha^{-1}. Consequently, the proven number was considered to be 55,000 seeds ha^{-1} as the standard seeding number in the experiment. Outside the area of the sowing experiment, 55,000 seeds ha^{-1} were sown in 2021, and 59,000 seeds ha^{-1} in 2022, considering the results obtained in 2021 during the farm's crop production practice. With regard to the feasibility aspects of the experiment, three seed number steps were used in each productivity zone with four repetitions, each repetition being twelve rows (9 m) wide (Figure 2).

1. In the low-productivity zone, we applied the standard nominal number of seeds ha^{-1} (55,000), and the number of seeds was reduced by 20% (44,000) and 40% (33,000).
2. In the average-productivity zone, the standard nominal number of seeds (55,000) was used, and the number of seeds increased by 20% (66,000) and reduced by 20% (44,000).
3. In the high-productivity zone, the standard nominal number of seeds (55,000) was used, and the number of seeds increased by 20% (66,000) and 40% (77,000).



(**a**) (**b**)

Figure 2. Sowing plan in experimental fields (**a**) C14 and (**b**) C10 based on productivity zones: (1) low-productivity zone; (2) average-productivity zone; (3) high-productivity zone.

Additionally, in the case of all three productivity zones, one strip was sown with a nominal seed number that is not included in the given zone, but it is in one of the other two. Thus, 66,000 and 77,000 seeds were sown in the low-productivity zone, while 33,000 and 44,000 seeds were sown in the high-productivity zone in one repetition. The aim was to see if any unexpected information pops up concerning which experiments are noticeable on the shown figures but are not considered in this recent research.

The experimental sowing took place on 27.04.2021 in field C14 and on 23.04.2022 in field C10.

In the case of both experimental sites—in accordance with the characteristics of the given year—the soil as well as fertiliser and pesticide management were the same in the whole area, i.e., only the number of sown seeds changed due to the experimental strip with the given nominal seed number (Table 2).

Within the area of the established productivity zones, the area of the experimental sowings was physically marked (signal stakes) and the EOV coordinates of the corner points were also recorded (TopCon GMS-2). At the beginning and the end of the 100 m length of the experimental sowing, a 3 m wide area in the direction perpendicular to the sowing was left unsown, and the 3 rows before the first row and after the last row of the experiment were left unsown for the entire length of the experiment, thereby forming an unsown frame around the experiment to facilitate harvesting and the identification of the area.

Table 2. Crop management of experimental areas.

Operation	Tool	Input	Doze
discing	John Deere 9620RX (Deere and Company, Moline, IL, USA), Vaderstad Carrier 1225 (Vaderstad AB, Vaderstad, Sweden)		
subsoiling	John Deere 9620RX (Deere and Company, Moline, IL, USA) Maschio Artiglio (Maschio Gaspardo, Campodarsego, Italy)		
spraying	Agrifac Condor 4000 (Agrifac Maschinery B.V., Steenwijk, Netherlands)	glyphosate 480 gr/L	3l ha^{-1}
seedbed preparation	John Deere 9620RX (Deere and Company, Moline, IL, USA) Vaderstad NZ Agressive 10000 (Vaderstad AB, Vaderstad, Sweden)		
rolling	John Deere 6195R (Deere and Company, Moline, IL, USA) Vaderstad Rexius 1230 (Vaderstad AB, Vaderstad, Sweden)		
spraying	Agrifac Condor 4000 (Agrifac Maschinery B.V., Steenwijk, Netherlands)	glyphosate 480 gr/L	2l ha^{-1}
drilling	John Deere 8335R (Deere and Company, Moline, IL, USA) Horsch Maestro 12.75 SW (Horsch Maschinen Gmbh, Schwandorf, Germany) applied with Precision Planting Sowing Unit (Precision Planting, Tremont, IL, USA)	SY Bacardi CLP	according to sowing plan
		cypermethrin 8g/kg	10 kg ha^{-1}
		urea N47%	30 kg ha^{-1}
spraying	Agrifac Condor 4000 (Agrifac Maschinery B.V., Steenwijk, Netherlands)	dimethenamid-P 212.5 g/L, pendimethalin 250 g/L	4l ha^{-1}
fertilising	John Deere 6195R (Deere and Company, Moline, IL, USA) Amazone ZA TS (AMAZONEN-Werke H. Dreyer GmbH & Co. KG, Hasbergen, Germany)	monoammonium phosphate N12-P52%	50 kg ha^{-1}
spraying	Agrifac Condor 4000 (Agrifac Maschinery B.V., Steenwijk, Netherlands)	imazamox 25 g/L	2l ha^{-1}
fertilising	John Deere 6195R (Deere and Company, Moline, IL, USA) Amazone ZA TS (AMAZONEN-Werke H. Dreyer GmbH & Co. KG, Hasbergen, Germany)	ammonium sulphate N21-S24%	50 kg ha^{-1}
fertilising	John Deere 6195R (Deere and Company, Moline, IL, USA) Amazone ZA TS (AMAZONEN-Werke H. Dreyer GmbH & Co. KG, Hasbergen, Germany)	urea N47%	200 kg ha^{-1}
inter-row cultivation	John Deere 8335R (Deere and Company, Moline, IL, USA) Orthman 8315 (Unverferth Manufacturing Co., Kalida, OH, USA)		
spraying	Agrifac Condor 4000 (Agrifac Maschinery B.V., Steenwijk, The Netherlands)	deltamethrin 50 g/L	0.15l ha^{-1}
		fluopiram 125 g/L, protiokonazol 125 g/L	0.8l ha^{-1}
		foliar B 150 gr/L, Mo 7.5 gr/L	1.5l ha^{-1}
		foliar Zn 700 gr/L	1l ha^{-1}
		foliar $MgSO_4$ MgO 160 g/kg, SO_3 325 g/kg	5 kg ha^{-1}
spraying	Agrifac Condor 4000 (Agrifac Maschinery B.V., Steenwijk, The Netherlands)	boskalid 200 g/L, dimixistrobin 200 g/L	0.5l ha^{-1}
		foliar B 150 g/L, Mo 7.5 g/L	0.7l ha^{-1}
		foliar Zn 700 g/L	0.5l ha^{-1}
		foliar $MgSO_4$ MgO 160 g/kg, SO_3 325 g/kg	5 kg ha^{-1}
harvest	John Deere S690 (Deere and Company, Moline, IL, USA)		

Plant density was monitored after inter-row cultivation, for field C14 between 11 and 13 June 2021 and for field C10 between 8 and 10 June 2022. Six rows were randomly selected from the twelve rows of each differentiated number of cut strips. Within the 100 m long area of the experimental sowing, a 10 m long sample area was designated at an arbitrary point per row, in which the number of plants found in the rows and the distance between the plants were recorded. From the obtained data, it became possible to calculate the number of plants that sprouted per hectare.

2.2. Weather Monitoring

The weather conditions of the examined period were suitable for analysing the crop year effect. Weather data (Table 3) were collected using our own meteorological station (Sencrop Raincrop) installed on the site, located at the same place in both years, 1 km away from the test areas.

Table 3. Monthly average temperature and monthly precipitation data during the experimental years.

Month	Monthly Total Rain (mm)		Rain Diff. (mm)	Monthly Avg. Temp. (°C)		Temp. Diff. (°C)	No. of Days over 5 mm of Rain	
	2021	**2022**		**2021**	**2022**		**2021**	**2022**
January	26.8	4.5	−22.3	0.05	−0.32	−0.37	0	0
February	47.8	8.6	−39.2	1.57	4.11	2.54	3	0
March	10.3	32.0	21.7	5.3	5.4	0.10	1	1
April	59.3	40.1	−19.2	8.47	9.56	1.09	5	3
May	73.7	11.4	−62.3	14.21	17.58	3.37	4	0
June	41.4	26.9	−14.5	22.66	22.98	0.32	1	2
July	49.5	20.1	−29.4	24.32	24.06	−0.26	4	1
August	65.7	81.6	15.9	20.71	24.48	3.77	6	3
September	11.7	51.3	39.6	17.37	15.76	−1.61	1	3
October	17.5	6.4	−11.1	10.05	12.31	2.26	1	0
November	62.0	38.2	−23.8	4.95	6.17	1.22	4	2
December	45.5	81.5	36.0	0.82	1.97	1.15	1	4
Σ	511.2	402.6	−108.6	10.87	12.01	1.13	31	19

Meteorological data were transmitted in real time and collected in an online application (Sencrop App), recorded and made available for the study in a Microsoft Excel format.

The weather of 2021 was average rainy and average warm, while 2022 brought poor rainfall, drought and significantly warmer weather. In 2021, the amount of precipitation was 108.6 mm higher, and the average yearly temperature was 1.13 °C cooler than in 2022. The amount of precipitation during the vegetation periods (between April and September) was 301.3 mm in 2021 and 231.4 mm in 2022, while the number of days with more than 5 mm of the precipitation was 21 and 12, respectively.

2.3. Yield Monitoring

The parts of both fields of the sowing experiment outside the experimental plots were previously harvested and the stubble removed. The experimental sowing of the area marked C14 was harvested on 28 September 2021, and the experimental plots of the area marked C10 were harvested on 7 September 2022. The 100 m long plots of the sowing experiment were cut and harvested separately for each plot, and the quantities of cut sunflowers were emptied onto the transport vehicle and measured per plot with a mobile weighing unit (Avery Weight-Tronix Model 640). We took samples from the drained sunflower samples at five points, and approx. 1 kg weighted average sample was formed for the laboratory tests and was taken to the laboratory, where the moisture and oil contents of the average samples were examined. The thousand-grain weight was measured by the authors, by weighing two hundred grains taken twice from the average sample, converted to one thousand grains.

The moisture and oil contents were measured in the Laboratory of the Agricultural Instrument Center of the University of Debrecen. The test samples were prepared according to the standard MSZ EN ISO 664:2008 [38], the moisture was determined according to the standard MSZ EN ISO 665:2020 [39], and the oil content was determined according to the standard MSZ EN IS 659:2009 [40].

The yield data were calculated using the amount of the experimental site converted to 1ha and corrected for 8% moisture content.

2.4. Statistical Analysis

Data preparation included the calculation of plant density as the number of plants per hectare, based on plant spacing (n = 16,536), and deviation of plant density based on the absolute value of difference between calculated and nominal density, excluding double and missing seeding. Double seeding was determined if plant spacing was 5 cm or lower; and missing seeding was determined if measured plant spacing was more than 1.5 times higher than the supposed plant spacing calculated on the basis of nominal density regardless of what caused the missing plant.

The model of the open-field survey included the following explanatory variables: 'year' (nominal variable; 2021 or 2022), 'zone' (ordinal variable; low, average or high) and 'nominal density class' (ordinal variable; low, average or high). All variables were tested by Multivariate Analysis of Variance (MANOVA) in the case of grain moisture [%], grain oil content [% in dry weight], thousand-grain weight [g], yield [kg ha^{-1}], deviation of crop density [plants per hectare], double seeding [%] and missing seeding [%] during open-field experiments.

In significant cases, explanatory variables were evaluated by a two-sample *t*-test for the 'year' variable or by a Tukey HSD comparison for the 'zone' and 'nominal density class' variables. The entire statistical analysis was performed in SPSS (IBM, version 27.0.1).

3. Results

Most of the tested yield and seeding variables were significantly affected by all of year, zone and nominal density factors in this research (Tables 4 and 5).

Table 4. Effect of explanatory variables on measured yield in a sunflower experiment (Mezőszemere, Hungary, 2021–2022).

Tested Variable	Test Results						
			MANOVA		*t*-test/Tukey Comparison		
	Variable	d.f.	F	*p*-Value	Group	Avg. Value (%)	Sign.*
Seed moisture	Year	1	12,521	<0.001	2021 2022	6.05 5.83	b a
	Zone	2	5928	<0.001	Low Average High	6.16 5.89 5.82	c b a
	Nominal crop density	2	236	<0.001	Low Average High	5.92 5.97 5.92	a b a
Seed oil content	Variable	d.f.	F	*p*-Value	Group	Avg. Value (%)	Sign.*
	Year	1	4500	<0.001	2021 2022	47.61 46.18	b a
	Zone	2	405	<0.001	Low Average High	47.30 46.84 46.61	c b a
	Nominal crop density	2	556	<0.001	Low Average High	47.35 46.66 46.75	c a b

Table 4. *Cont.*

Tested Variable	Test Results					
	Variable	**d.f.**	**F**	***p*-Value**	**Group**	**Avg. Value (g)**	**Sign.***
Thousand-seed weight	Year	1	1,859,382	<0.001	2021 2022	55.82 20.18	b a
	Zone	2	64,264	<0.001	Low Average High	30.53 39.16 41.46	a b c
	Nominal crop density	2	16,982	<0.001	Low Average High	41.15 37.85 35.44	c b a
	Variable	**d.f.**	**F**	***p*-Value**	**Group**	**Avg. Value (kg ha^{-1})**	**Sign.***
Yield	Year	1	309,665	<0.001	2021 2022	4557 2681	b a
	Zone	2	106,832	<0.001	Low Average High	2637 3465 4376	a b c
	Nominal crop density	2	911	<0.001	Low Average High	3519 3599 3675	a b c

* cases with the same letter mean no significant difference on 95% confidence level.

Table 5. Effect of explanatory variables on seeding parameters in sunflower experiment (Mezőszemere, Hungary, 2021–2022).

Tested Variable	Test Results						
			MANOVA		***t*-Test/Tukey Comparison**		
	Variable	**d.f.**	**F**	***p*-Value**	**Group**	**Avg. Value (Plant per Hectare)**	**Sign.***
Deviation of crop density	Year	1	5.30	0.021	2021 2022	12,747 13,407	a b
	Zone	2	257.16	<0.001	Low Average High	8656 12,429 16,714	a b c
	Nominal crop density	2	143.20	<0.001	Low Average High	9852 12,615 15,761	a b c
	Variable	**d.f.**	**F**	***p*-Value**	**Group**	**Avg. Value (%)**	**Sign.***
Double seeding	Year	1	35.41	<0.001	2021 2022	1.35 0.39	b a
	Zone	2	16.34	<0.001	Low Average High	0.23 0.88 1.28	a b b
	Nominal crop density	2	6.81	0.001	Low Average High	0.56 0.73 1.19	a a b
	Variable	**d.f.**	**F**	***p*-Value**	**Group**	**Avg. Value (%)**	**Sign.***
Missing seeding	Year	1	3.46	0.063	2021 2022	10.47 9.12	- -
	Zone	2	8.38	<0.001	Low Average High	9.06 8.96 10.96	a a b
	Nominal crop density	2	8.80	<0.001	Low Average High	8.26 9.85 10.76	a b b

* cases with the same letter mean no significant difference on 95% confidence level.

The first year (2021), with a more even distribution of rainfall, resulted in higher seed moisture, higher seed oil content and specifically higher seed weight and yield level than the drier year of 2022. This relationship is explained by different weather conditions. The effect of crop year on sowing parameters varied as follows: in 2021, the deviation of density was lower and double seeding was higher than in 2022. The proportion of missing plants did not differ significantly between the two years.

The effect of different productivity zones (low, average, high) was also significant during the tested growing seasons. Higher nutrient supply resulted in higher yield and seed weight but lower seed moisture and seed oil content consistently. In the case of seeding parameters, there was significantly less deviation of crop density, less double seeding and less missing plants in the growing zones with lower nutrients. This result is partly related to the lower crop density in the lower-productivity areas. Tukey's post hoc test resulted in significant differences between each productivity zone for deviation in crop density, but double seeding was significantly lower only in low-productivity zones, and no differences were found between average and high zones. In the case of missing seeding, low- and average-productivity zones were not different but high-productivity zones resulted in a higher proportion of missing crops.

The increase in crop density could not result in trend-like differences in seed moisture and oil content. In the observed cases, average crop density resulted in significantly higher seed moisture and significantly lower oil content than other crop density classes. Any significant differences between low- and high-crop density classes were detectable only in the case of seed oil content. In addition, the increase in crop density resulted in significantly lighter seeds but higher yield level consecutively between different crop density classes. The tested sowing parameters also highly correlated to crop density. All these parameters resulted in lower sowing quality (higher value) for higher density.

Knowing the results and considering the sowing technology, it may be worth considering reducing the velocity of sowing by increasing crop density.

4. Discussion

4.1. Nominal and Germinated Seeds

The effect of crop year on sowing parameters was clearly visible: in the average warm and average rainy year of 2021, the deviation of crop density was lower and double seeding was higher than in 2022, when the weather was exceptionally hot and dry. The more favourable soil and seedbed conditions created the opportunity for more even sowing, and the better-quality seedbed favoured emergence. Jonge et al. (1999) [41] and Kushwaha et al. (2001) [42] confirmed that organic matter increases soil water capacity and lessens evaporation from the soil. Ion et al. (2015) [43] showed that increasing the plant population increased the yield under favourable growing conditions and decreased the yield under less favourable growing conditions. Marin et al. (2022) [44] highlighted that plant density must be correlated with the growing conditions of sunflower plants. Thus, the better the growing conditions, the higher the plant density should be, as to put into value the available growing factors.

Önemli (2004) [45] cited earlier studies concluding that soil organic matter, the environment and soil organic matter x environment factors had significant effects on seeding emergence. It was also stated that decreasing soil organic matter content resulted in a decrease in seeding emergence due to the decreases in water content of the soil. As opposed to these findings, the authors of this paper found that in the case of seeding parameters there was significantly less deviation of crop density, less double seeding and less missing plants in the growing zones with lower productivity. This result is partly related to the lower crop density in the low-productivity zones. All of these parameters resulted in poorer quality (higher value) for higher density.

4.2. Quantity and Quality of the Yield

The development of sunflower hybrids with a high genetic potential for seed yield is a key factor. In the authors' recent study, the chosen hybrid was the same in both years and the effect of the different growing zones (low, average, high) on yield and quantitative parameters was significant during the examined growing seasons. The higher nutrient supply resulted in higher yield and seed weight but lower seed moisture and seed oil content consistently.

Jocić (2003) [46] considers seed yield a complex trait with a polygenic basis that is influenced by the production environment. Also, Gunasekera et al. (2006) [47] found the seed yield to be a quantitative trait, the expression of which is the result of the given genotype, the environment and the interaction between them. Novák et al. (2013) [48] found that the grown hybrid had a strong impact on yield and oil content in both years (2010 and 2012). In addition, the sowing date significantly influenced oil content. The results obtained by the study of Mrdja et al. (2012) [49] indicate that, on average, the seed yield of the studied hybrids was influenced by genotype the most. Looking at the season and production sites as factors, differences were observed regarding seed yield, although not statistically significant. The same conclusion was drawn by Villegas et al. (2010) [50], who showed that despite the diversity of environmental conditions, the main differences in yield were due to the used genotypes. However, Marjanović-Jeromela et al. (2011) [51] found that seed yield per plant is highly influenced by environmental factors, which indicates the adaptability of specific genotypes to specific growing seasons.

It is worth considering that Long et al. (2001) [52] showed that sunflower plants in east–west rows yielded on average 12% more oil than plants in north–south rows. The maximum yield was produced in the east–west rows, at four to eight plants m^{-2} and in the case of 75 to 100 cm row spacing.

In the authors' recent research, it was found that average crop density resulted in significantly higher seed moisture and significantly lower oil content than other crop density classes. In addition, the increase in crop density resulted in significantly lighter seeds but higher yield level consecutively between the different crop density classes.

The findings of Mijic et al. (2020) [53] showed that the used hybrid had the greatest influence on the phenotypic expression of the mentioned traits, while the crop density and the crop density x hybrid interaction had a much smaller influence. On average— similarly to the authors' results—the highest grain yield, oil content and oil yield were achieved in the highest crop density.

5. Conclusions

The adaptability of sunflower is well known to be exceptional. However, of the possibilities offered by precision farming technologies, the question arises as to how to make the most of this exceptional ability and how to grow sunflower most economically. The genetic yield potential of the plant is extremely high. For this reason, the question is what weather conditions, soil properties, sowing and cultivation technology solutions farmers can use to best exploit this potential and turn it into profit.

In this research, the authors attempted to examine the germination parameters of sunflower and the quantitative and qualitative yield characteristics in two growing seasons with different weather conditions, on the same soil type, but in separated zones with different productivity levels and with different crop densities depending on the productivity, with the same cultivation technology.

As a result of the performed experiments, weather conditions influenced the success and effectiveness of the sowing technology. With better soil conditions and an optimal seedbed, both the germination percentage and the uniformity of the plant spacing were higher and more accurate. In the average- and high-productivity zones, higher yield was measured in the wetter season, and further growth was achieved in these areas by increasing the number of plants. In zones with low productivity, even the rainy season did not bring a demonstrable increase in yield. In this case, the economic aspects show that a reduction in plant density is appropriate.

Within the average- and high-productivity zones, increasing the number of plants showed a significant increase in yields and seed moisture content, while the thousand-grain weight and seed oil content decreased.

The results of this research also justify conducting further research regarding the row spacing and the orientation of the rows depending on the geographical location of the cultivation environment.

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