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Seeding Pattern Impact at Crop Density Establishment and Grain Yield of Maize

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Abstract: Maize is the most represented grain crop on the world's arable land. It is mostly grown using standard sowing at an inter-row distance of 70 cm. However, growing in two rows (double-row sowing) is increasingly common today. The aim of this research was to determine the influence of different spatial distributions of the same population of maize plants on the yield of maize grains in a larger range of the FAO maize hybrid maturing group. The experiment lasted 5 years and was set up at two locations in Jakšić (Požeško-Slavonia County) and Lužani (Brodsko-Posavina County). Maize sowing with standard sowing was carried out with a PSK OLT seed drill with an inter-row spacing of 70 cm, while double-row sowing was carried out with a MaterMacc Twin Row-2 seed drill in two rows spaced 22 cm apart in a zigzag arrangement and 48 cm apart between adjacent sowing furrows. In the experiment, a total of three types of maize hybrids were used: H1-Kashmir (FAO 390 maturing group), H2-Kapitolis (FAO 400 maturing group) and H3-Konfites (FAO 450 maturing group). With standard maize sowing, an average set of plants was achieved: 71,946 plants ha^{-1} (Kashmir), 71,714 plants ha^{-1} (Kapitolis) and 72,205 plants ha^{-1} (Konfites), while the double-row sowing achieved a set of plants of 72,166 plants ha^{-1}, 72,104 plants ha^{-1} and 72,576 plants ha^{-1}. The two-row sowing of the hybrid Kapitolis and Konfites recorded a statistically significant higher set of maize plants. The yield of maize grains in all three types of the hybrid was statistically and significantly higher by 943 kg ha^{-1} using two-row sowing, and the highest yield was achieved by the Kashmir hybrid (13,406 kg ha^{-1}).

Keywords: maize; seeding pattern; twin-row; single-row; grain yield

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Citation: Banaj, A.; Banaj, Đ.; Stipešević, B.; Nemet, F. Seeding Pattern Impact at Crop Density Establishment and Grain Yield of Maize. *Crops* **2023**, *3*, 1–10. https://doi.org/10.3390/crops3010001

Received: 3 November 2022
Revised: 9 December 2022
Accepted: 22 December 2022
Published: 3 January 2023

1. Introduction

Maize is grown all over the world in significant areas and, along with winter wheat and rice, is the most dominant cultivated crop [1]. Although maize recently recorded a slight decrease in production in areas in the Republic of Croatia, it still occupies the most important place in fields [2]. Maize in Europe is predominantly cultivated as a row crop with an inter-row distance of 70 cm and is referred to by most scientists as standard sowing. However, there is a small but increasing share of maize area being sown in an alternative plant spacing, i.e., sown in double rows, popularly called twin-row sowing. The large popularity of maize twin-row sowing in the USA is attributed to higher yields in comparison with standard sowing. Higher yields and better early development of maize in twin-row spacing is most likely the consequence of more even vegetational space for each plant in the crop stand. Namely, under the assumption that the targeted crop stand is 65,000 plants per ha, and the inter-row distance is 70 cm, we get the in-row distance of 22 cm between plants. The vegetational space is rectangular here, with the ratio of length/width = 70 cm/22 cm = 3.18. In twin-row sowing, central lines of double rows are still 70 cm apart, but the distance between rows in a pair is 22 cm. In order to keep the crop stand density at 65,000 plants per ha, the in-row distance is set to 43.69 cm. Therefore, the closest distance between neighboring plants is 49 cm. The distance between neighboring rows of different double rows is 70 cm − 22 cm = 48 cm. In this way the vegetational space becomes much more even, with a length/width ratio closer to 1. By enlarging the distance between the closest plants, each plant suffers less competition from its neighbor, thus enabling better growth, development and grain yield. The importance of light is discussed in the paper by Gao et al. (2010) who say that light (solar radiation) is an important resource for crop growth and development [3]. In maize production, one of the important growth stages is the period of silking, where abiotic stresses, namely, higher temperatures and drought stress can decimate grain yield. Authors Himani et al. (2022) stated that heat stress can cause a reduction in the photosynthesis of the maize plant which results in inhibited growth and development, kernel abortion, poor anthesis and silking that lead to a reduced number of seeds with stabilized weight that ultimately gives a low yield [4].

Banaj et al. (2018) stated that the Chapalu hybrid (FAO 350) achieved a yield of 14,501 kg ha^{-1} when sown in double rows (74,905 ha^{-1} plants after emergence) or 5.61% more than in standard sowing (73,130 plants ha^{-1} after germination and a grain yield of 13,731 kg ha^{-1}) [5]. The same authors state that in the case of Ferarixx hybrids, sowing in double rows (75,970 ha^{-1} plants after emergence) harvested 14,570 kg ha^{-1} or 7.79% more than in standard sowing (13,516 kg ha^{-1}). In the eastern part of Croatia, authors Banaj et al. (2017a) found a 10.35% higher grain yield of the maize hybrid P0023 and a 10.59% higher grain yield of the maize hybrid P0412 using double-row spacing in comparison with standard sowing [6]. According to the authors Banaj et al. (2017b), the hybrid Kamparis (FAO 380) sown in double rows had a grain yield 10.07% higher than in standard sowing, while the hybrid Balasco (FAO 410) gave a lower yield by 5.6% when compared to standard sowing [7]. Jurković et al. (2018) recorded an increase in yield using the hybrid OS 403 in double rows by 3.56%, and in the hybrid OS 378 by 7.66% above standard sowing [8]. Similar results are recorded by the same authors (Jurković et al., 2017) where the increase in grain yield in the sowing system in double rows with the hybrid P0412 was 5.53% and in the hybrid BC 525, 14.95% more compared to standard sowing [9]. Authors Tadić et al. (2017) confirm that using the system of sowing in double rows, the ZP 488 hybrid achieved a yield increase of 6.48%, and the ZP 560 hybrid only 2.40% higher than standard sowing [10]. According to the research of Banaj et al. (2018b), the hybrid P 9911 from the FAO group 480 sown in double rows achieved an increase in grain yield of 2.44%, and in the set of 85,049 germinated plants ha^{-1}, even 7.09% or 985 kg ha^{-1} more than standard sowing [11]. The same authors Banaj et al. (2019a) found that in double sowing, the FAO group 290 hybrid achieved higher grain yields from 3.77 to 9.66%, the FAO group 380 hybrid from 6.46 to 10.97%, the FAO group hybrid 410 from 3.45 to 9.95% and a hybrid of the FAO group 450 at 11.72% [12]. In 2018, the FAO group 590 hybrid achieved a lower yield by 0.59% when compared to standard sowing by sowing in strips. The author Ogrizović (2015) stated that sowing in double rows showed an increase in yield of 3.26% compared to standard sowing [13]. Blandino et al. (2013) stated that at 66% of the examined locations, there was an increase in grain yield when sowing in double rows by an average of 5.5% [14]. In this case, the increase in yield was from 0.6 t ha^{-1} to 0.9 t ha^{-1} [14]. The majority of European authors cite similar results confirming the existence of a statistically significant increase in maize grain yield when sowing in double rows compared to standard sowing [15,16]. They also did not statistically confirm that the size of the set (plants ha^{-1}) affected the yield in any of the sowing methods. No statistically significant differences in yield were observed in Alabama, Iowa, Missouri and Nebraska [17,18] when applying strip sowing, for the same density of plants, compared to standard sowing at the standard 76 cm row distance [19,20]. Roth et al. (2002), in their research, also did not reveal the existence of statistically significant differences in yield between maize sown by standard sowing and sown in strips [21].

This research was conducted in order to investigate the impact of different spatial distributions of the same population of maize plants on maize yield in a larger range of FAO maturing groups of maize hybrids, and thus to determine the optimal parameters necessary for the application of this technology in wider maize production.

2. Material and Methods

2.1. Analysis of the Chemical Properties of Soil

The conducted research into the chemical properties of soil included the following properties: pH value, humus content and the total content of phosphorus and potassium.

Before the pH reaction determination procedure, a soil sample was dried and sieved through a 2 mm sieve. The prepared soil sample was weighed into amounts of 10 g and placed into two plastic cups. One sample was poured into one beaker containing 25 mL of distilled water (current acidity), and the other into another beaker with 25 mL of 1 M potassium chloride (substitution acidity). Both samples were mixed using glass rods and left to stand for 10 min. While the samples were standing, the pH meter was calibrated using appropriate buffer solutions (e.g., pH 4 and 7, or pH 7 and 9), depending on the origin of the sample. In order to check the accuracy of the measurement before the procedure of determining the pH reaction of the soil samples, the pH reaction of the reference material was conducted. The measurement of the pH reaction of the soil samples was performed by immersing the glass electrode of the pH meter in the soil suspension, and for an accurate measurement procedure, it takes about 1 min for the value to stabilize [22].

A 0.5 g dry soil sample was placed into a 150 mL laboratory beaker and then 5 mL of dissolved potassium dichromate and 7.5 mL of concentrated sulfuric acid were added. The sample was carefully homogenized and then placed in an oven at 135 °C for half an hour. Subsequently, the samples were rapidly cooled in a water bath, transferred to a 100 mL volumetric flask and filled to the mark with deionized water. The sample was left overnight in the volumetric flask. The next day, the sample was decanted into a 15 mL beaker and centrifuged for 10 min at 2000 rpm. The concentration of organic carbon was measured using a spectrophotometer [23].

A 10 g air-dried soil sample was placed into a plastic bottle and 100 mL of diluted AL-solution was added. The soil sample thus prepared was shaken with a rotary shaker for 2 h. After the shaking procedure was completed, the soil suspension was filtered into Erlenmeyer flasks with volumes of 250 mL. To prepare the basic standard, it was necessary to weigh 0.1917 g of KH_2PO_4 and 0.0534 g of KCl and transfer them to a 1000 mL volumetric flask. The weighed salts were dissolved into a small amount of AL-solution and then diluted up to the desired standard concentration. A series of working standards were prepared by pipetting 10, 20, 30, 40, 50 and 80 mL of the basic standard into 200 mL volumetric flasks which were filled up to the mark with AL-solution. The standards prepared in this way represent the amount of 10, 20, 30, 40, 50 and 80 mg P_2O_5/100 g of soil and the same amount of K_2O. After the working standards were completed, 10 mL of soil extract was pipetted into a 100 mL measuring flask. To prepare the standards, 10 mL of working standards 0, 10, 20, 30, 40, 50 and 80 mg P_2O_5/100 g of soil were added to seven measuring flasks of 100 mL each. Following this, 9 mL of 4 M H_2SO_4 was added to each measured flask with the standard or soil extract using an automatic dispenser and filled to half with distilled water and then heated in a water bath for 15 min.

During heating, 10 mL of 1.44% ammonium molybdate and 2 mL of 2.5% ascorbic acid were added to the flasks by automatic dispensers. After this procedure, the flasks were kept in a water bath for another 30 mins to develop a complex blue color. Flasks with samples and standards were cooled and then topped up to the 100 mL mark with distilled water. The concentration of P_2O_5/100 in the series of standards and samples were read by the spectrophotometric method at a wavelength of 680 nm. The preparation of soil samples for the measurement of readily available potassium is the same as for the determination of readily available phosphorus. The only difference is that readily available phosphorus was measured directly from the soil extract on the ICP OES and expressed in mg K_2O/100 g of soil [24].

2.2. Experimental Setup

The experiment was conducted at two sites in Croatia: J: near Jakšić (Poželko-Slavonia County) and L: near Lužani (Brodsko-Posavina County) with distinctive soil types. At the Jakšić site, the predominant soil type is pseudogley, whereas at the Lužani site, the soil type humigley is predominant.

On both trial sites, the previous crop was winter wheat with standard soil tillage applied consisting of shallow disk harrowing after the winter wheat harvest, followed by moldboard ploughing before winter, shallow to medium disk harrowing after winter and seedbed preparation before seeding. Fertilization was uniform during the whole time of the experiment: there were applications of 350 kg NPK 7:20:30 ha^{-1} before moldboard ploughing, 100 kg of urea (46% N) ha^{-1} before spring disk harrowing, and 200 kg of KAN (27% N) ha^{-1} with post-emergence herbicide application. Crop protection was also uniform each year, consisting of one application of 0.44 l ha^{-1} of Adengo (*Thiencarbazone-methyl* 39 g + *Isoxaflutole* 99 g). Seeding time was always during the second half of April, in order to avoid possible late spring frost.

Three hybrids were used: H1-Kashmir (the FAO 390 maturity group), H2-Kapitolis (the FAO 400 maturity group) and H3-Konfites (the FAO 450 maturity group).

Seeding patterns were: standard seeding pattern for maize (ST) and twin-row seeding pattern for maize (TR).

When sowing using the ST treatment, which is at the same time a control treatment, being the standard practice for maize seeding in standard rows with a row spacing of 70 cm, a pneumatic seed drill PSK OLT Osijek was used with a fixed 70 cm distance between neighboring rows. When sowing using the twin-row pattern, the MaterMacc Twin Row-2 seed drill was used, with two rows 22 cm apart in zigzag pattern and 48 cm distance between neighboring seeding furrows. Both seed drills were set up for seeding densities of 75,000 seeds per hectare, which represents the recommended seeding density for the given hybrids in these agro-environmental conditions.

Experimental design at both trial sites (J and L) in each year was split-plot in 4 repetitions, with hybrid being the main treatment and seeding pattern being the sub-treatment. The basic experimental plot was 56 m^2 (width 2.8 m and length 20 m). Crop density was recorded by counting all plants in the middle two rows or two twin rows from each basic experimental plot and recalculated to a per hectare basis. The harvest was performed by hand-picking maize ears from the two middle rows from the ST treatment and the two middle twin rows from the TR treatment over a 14.3 m length. The collected ears were mechanically shelled, and the grain was weighed using a technical digital scale. Grain moisture was determined using Dickey John GAC 2100 grain moisture apparatus. Grain yield was recalculated to a standard moisture of 14%.

2.3. Weather Conditions

During the experiment (Table 1), the average mean monthly air temperature (°C) at both trial sites in the maize vegetation (April–October) was higher than 17 °C. At the J trial site, in 2018, the highest average monthly average air temperature was 18.46 °C, and in 2016, the lowest temperature recorded was at only 16.67 °C. In five consecutive vegetation years of maize cultivation at the J trial site, the highest precipitation recorded was at 598.00 mm in 2020. The lowest precipitation recorded was in 2018 at 470.8 mm and in 2017 at 486.4 mm.

Table 1. Mean air temperature (°C) and total monthly precipitation (mm) at the trial site Jakšić (meteorological station Požega) and Lužani (meteorological station Slavonski Brod) [25].

Months	Monthly Mean Air Temperature (°C)					Monthly Total Precipitation (mm)				
	2016.	**2017.**	**2018.**	**2019.**	**2020.**	**2016.**	**2017.**	**2018.**	**2019.**	**2020.**
Trial site Jakšić (meteorological station Požega)										
IV.	12.9	10.7	15.5	12.0	11.7	47.0	65.4	20.0	72.8	5.9
V.	15.4	16.7	19.0	13.6	15.0	73.1	82.4	64.0	129.0	93.0
VI.	20.2	21.7	20.5	22.6	19.7	113.1	47.3	115.5	151.0	67.7
VII.	21.7	23.2	21.6	22.1	21.4	129.4	47.5	126.1	70.5	91.8
VIII.	19.8	23.5	22.4	22.8	22.2	37.9	27.8	57.2	46.2	125.7
IX.	16.9	15.2	17.0	17.0	17.4	86.4	115.7	78.0	73.7	70.8
X.	9.8	11.2	13.2	12.6	11.8	86.0	100.3	10.0	37.4	143.1
Mean/Sum	16.67	17.46	18.46	17.53	17.03	572.9	486.4	470.8	580.6	598.0
Trial site Lužani (meteorological station Slavonski Brod)										
IV.	12.9	11.3	15.9	12.4	12.3	60.7	71.4	17.7	86.9	13.9
V.	16.0	17.0	19.3	14.0	15.2	46.7	174.6	104.8	148.9	85.6
VI.	21.3	22.2	20.8	23.0	20.0	117.1	46.7	119.8	121.0	46.2
VII.	23.1	23.9	21.9	22.4	22.2	140.6	45.8	122.9	49.9	68.6
VIII.	20.4	23.9	22.9	23.2	23.1	27.7	19.8	25.8	39.7	87.2
IX.	17.2	16.0	16.8	17.2	17.8	67.1	114.2	29.5	67.3	57.3
X.	10.2	11.0	13.6	12.5	12.2	64.2	86.7	10.6	32.6	108.6
Mean/Sum	17.30	17.90	18.74	17.81	17.54	524.1	559.2	431.1	546.3	467.4

Data: Croatian meteorological and hydrological service (2021) and maize vegetation over months IV–X (April–October).

At the L trial site, the average mean monthly air temperature (°C) in the maize vegetation (April–October) in 2016, 2017, 2019 and 2020 was between 17 and 18 °C. In 2018, the highest average monthly average air temperature was 18.74 °C. Slightly lower total monthly precipitation amounts were recorded in the maize growing vegetation for the L trial site in comparison with the J trial site, except in 2018, in which 431.1 mm was recorded. The highest amount of precipitation at the L trial site was determined in 2017 at 559.2 mm, followed by the precipitation values from 2019 (546.3 mm) and 2016 (524.1 mm).

2.4. Statistical Data Processing

The collected results were processed by a statistical tool (SAS Enterprise Guide 7.1). For the ANOVA calculation, split-split-split-plot design was taken into consideration, with the year being the main treatment, the site being the sub-treatment, the hybrid being the sub-sub-treatment and the seeding pattern being the sub-sub-sub-treatment. Means of treatments which were statistically different using ANOVA were compared by the LSD test at $p < 0.05$ probability level.

3. Results and Discussion

3.1. Chemical Properties of Soil

Based on the analysis of the soil properties (Table 2), it can be concluded that the soils at the experimental sites had low humus levels (L = 1.7 and J = 2.59% humus). Considering the P availability, both soils had a good availability (Table 1), while the availability of K was high at the J-site and well-supplied at the L-site (Table 3). By analyzing the value of the K_2O content, the soil at the J experimental site was classified into the group of soils with high availability, and the soil at the L experimental site into the group of well-supplied soils. The soils in the experimental plots J and L were very and slightly acidic, respectively (Table 2).

Table 2. Soil type and some soil properties at the trial sites Jakšić and Lužani.

Trial Site	pH		Humus	AL-P_2O_5 Content	AL-K_2O Content
	H_2O	KCl	(%)	mg/100 g of Soil	mg/100 g of Soil
Jakšić	4.98	4.01	2.59%	23.66	32.62
Lužani	7.73	6.24	1.70%	19.54	21.33

Table 3. Maize plant density (plants ha^{-1}) of three hybrids (H1: Kashmir, H2: Kapitolis and H3: Konfites) at two sites (J: Jakšić and L: Lužani) and two seeding patterns (SR: single row and TR: twin row) during the seasons 2016–2020.

	Site J		Site L		Sites Mean		Mean
H1	**SR**	**TR**	**SR**	**TR**	**SR**	**TR**	
2016	71,685	73,840 *†	71,568	72,491 *	71,627	73,166 *	72,396
2017	72,207 *	71,454	73,272 *	72,143	72,740 *	71,799	72,269
2018	71,639	72,803 *	70,645	71,291	71,142	72,047 *	71,595
2019	73,236 *	72,157	72,349	71,887	72,793 *	72,022	72,408
2020	71,355	71,547	71,497	72,043 *	71,426	71,795	71,611
Mean	72,025	72,361 *	71,867	71,971	71,946	72,166	72,056
H2							
2016	72,081	73,095 *	71,942 *	70,602	72,012	71,849	71,930
2017	70,323	71,149 *	71,023	72,143 *	70,673	71,646 *	71,160
2018	71,621	72,661 *	70,638	70,957	71,130	71,809 *	71,470
2019	72,864 *	71,944	71,946	73,208 *	72,405	72,576	72,491
2020	71,959	72,789 *	72,739	72,491	72,349	72,640	72,495
Mean	71,770	72,328 *	71,658	71,881	71,714	72,104 *	71,910
H3							
2016	72,393	73,019 *	71,810 *	70,860	72,102	71,940	72,021
2017	70,717	71,904 *	71,406	72,593 *	71,062	72,249 *	71,655
2018	73,152	72,791	72,995	73,240	73,074	73,016	73,045
2019	72,252	72,549	71,888	72,694 *	72,070	72,622 *	72,346
2020	73,321 *	72,805	72,106	73,301 *	72,714	73,053	72,884
Mean	72,367	72,614 *	72,041	72,538 *	72,205	72,576 *	72,390
Year	2016: 72,116 ^{ab‡}; 2017:71,695 ^{a}; 2018: 72,037 ^{ab}; 2019: 72,415 ^{b}; 2020: 72,330 ^{b}						
Site	J: 72,244 ^{a}; L: 71,993 ^{a}						
Hybrid	H1: 72,056 ^{a}; H2: 71,910 ^{a}; H3: 72,390 ^{b}						
Pattern	SR: 71,955 ^{a}; TR: 72,282 ^{b}						
LSD(Year)$_{0\cdot05}$ = 482; LSD(Site)$_{0\cdot05}$ = 381 $^{n.s.}$; LSD(Hybrid)$_{0\cdot05}$ = 353; LSD(Pattern)$_{0\cdot05}$ = 256 LSD(Pattern ǀ Hybrid)$_{0\cdot05}$ = 362 LSD (Pattern ǀ Year × Hybrid)$_{0\cdot05}$ = 431 LSD (Pattern ǀ Year × Site × Hybrid)$_{0\cdot05}$ = 229 LSD (Pattern × Year × Site × Hybrid)$_{0\cdot05}$ = 487							

*‡ means labeled with the same letter are not significantly different at the $p < 0.05$ level.

3.2. Plant Population Density

The results of plant population density are presented in Table 3. They confirm that both seed drills performed similarly at both sites, although the J site showed somewhat higher plant density than the L site, which may be explained by somewhat higher precipitations at that site. Regarding hybrid reaction, only the H1 hybrid was not statistically better using the TR pattern treatment in comparison with the SR pattern, which can be contributed to generally better survival rates in different environmental conditions of earlier maturity groups [26].

3.3. Maize Grain Yield

Regarding the maize grain yield (Table 4), the highest impact came from environmental conditions, with more than 2000 kg ha^{-1} of difference between the year with the highest precipitation average (2020) and the year with the lowest precipitation average (2017), in which at both sites the average daily air temperatures for August 2017 were above 23.5 °C in combination with low precipitation (27.8 mm and 19.8 mm on sites J and L, respectively).

Table 4. Maize grain yields (kg ha^{-1}) of three hybrids (H1: Kashmir, H2: Kapitolis and H3: Konfites) at two sites (J: Jakšić, L: Lužani) and using two seeding patterns (SR: single-row, TR: twin-row) during the seasons 2016–2020.

	Site J		Site L		Sites Mean		Mean
H1	**SR**	**TR**	**SR**	**TR**	**SR**	**TR**	
2016	13,339	14,111	12,676	13,295	13,008	13,703	13,356
2017	12,183	12,898	11,895	12,955 *	12,039	12,927 *	12,483
2018	12,929	13,897 *	11,582	13,089 *	12,256	13,493 *	12,875
2019	12,663	13,744 *	13,705	14,233	13,184	13,989 *	13,587
2020	13,952	14,455	12,762	13,734 *	13,357	14,095 *	13,726
Mean	13,014	13,821 *	12,524	13,462 *	12,769	13,642 *	13,206
H2							
2016	14,006	15,021 *	12,584	13,403 *	13,295	14,212 *	13,754
2017	10,931	11,887 *	11,314	12,199 *	11,123	12,043 *	11,583
2018	10,406	11,587 *	11,032	12,230 *	10,719	11,909 *	11,314
2019	13,544	14,274	13,673	14,350	13,609	14,312	13,961
2020	13,502	14,213	14,079	14,887 *	13,791	14,550 *	14,171
Mean	12,478	13,397 *	12,537	13,414 *	12,508	13,406 *	12,957
H3							
2016	12,966	13,998 *	11,711	12,678 *	12,339	13,338 *	12,839
2017	10,058	11,627 *	10,288	11,487 *	10,173	11,557 *	10,865
2018	11,676	12,521 *	12,662	13,242	12,169	12,882	12,526
2019	12,782	13,826 *	12,667	13,539 *	12,725	13,683 *	13,204
2020	12,459	13,676 *	12,634	13,896 *	12,547	13,786 *	13,167
Mean	11,989	13,130 *	11,993	12,969 *	11,991	13,050 *	12,521
Year	2016: 13,316 ^{b‡}; 2017: 11,644 ^{a}; 2018: 12,238 ^{a}; 2019: 13,584 ^{b}; 2020: 13,688 ^{b}						
Site	J: 12,971 ^{a}; L: 12,816 ^{a}						
Hybrid	H1: 13,206 ^{a}; H2: 12,957 ^{ab}; H3: 12,521 ^{b}						
Pattern	SR: 12,422 ^{a}; TR: 13,365 ^{b}						

LSD(Year)$_{0\cdot05}$ = 891; LSD(Site)$_{0\cdot05}$ = 195 $^{n.s.}$; LSD(Hybrid)$_{0\cdot05}$= 652; LSD(Pattern)$_{0\cdot05}$ = 349
LSD(Pattern | Hybrid)$_{0\cdot05}$ = 554
LSD (Pattern | Year × Hybrid)$_{0\cdot05}$ = 653
LSD (Pattern | Year × Site × Hybrid)$_{0\cdot05}$ = 709
LSD (Pattern × Year × Site × Hybrid)$_{0\cdot05}$ = 801

† Mean labeled with "" in compared "Pattern" pair is significantly higher at $p < 0.05$ level, otherwise, there is no significant difference between coupled "Pattern" means; *‡ means labeled with the same letter are not significantly different at the $p < 0.05$ level.

The sites were not statistically different regarding grain yield results, although landscape and soil quality (Table 1) were expected to be more favorable for the L site, given better, less acid soil reaction than for the J site.

The hybrid with the highest grain yield was H1 with statistically higher yield in comparison with H3, in spite of a potentially higher grain yield of that hybrid due to a higher maturity group (FAO 390 vs. FAO 450 for H1 vs. H3, respectively). It is locally observed (by many farmers) in widespread maize production that using shorter maturity maize group hybrids, such as the FAO 390 group, to which H1 belongs, usually has faster, early vegetative growth, thus avoiding unfavorable heat stress during pollination, which affects, in some cases very severely, longer maturity hybrids, thus disabling them to fulfill their genetic potential for higher grain yields.

It is also visible from Table 4 that overall maize reaction to the different seeding pattern was significant and in favor of the TR treatment, with an average grain yield of 943 kg ha^{-1} and higher in comparison with the SR treatment. This finding was in line with previous research conducted in Croatia and other countries [8–11,14–16,27–29].

Higher grain yields using TR treatments can be attributed to better spatial laydown where a single maize plant receives more light. The architecture of the canopy, which is affected by crop densities, crop height and row arrangement, was the deciding factor for crop intercepted PAR (photosynthetically active radiation) (Keating and Carberry, 1993) [30]. As described by Rahman et al. (2017), the intraspecific competition between weakened maize plants and the grain yields of maize reached a maximum with an increasing distance between maize narrow-row spacing [31]. Moreover, through their experiments and having tested planting geometry, the authors confirmed that more photosynthetically active radiation (PAR) is received per single maize plant, indicating higher grain yields and better land use advantages with this field setup in comparison with regular planting geometry.

It is interesting to observe that the H3 hybrid had, on average, a greater reaction to the seeding pattern when compared to the H1 and H2 hybrids, in spite of having the lowest difference between seeding pattern treatment survival rates and is in line with the statement that the zigzag pattern provides less competition between plants [30,31]. This is important for greater vegetative mass development which the higher maturity hybrid H3 is expected to develop during its vegetation. Unfortunately, weather conditions (namely, higher temperatures) usually favor shorter maturity groups due to the avoidance of heat stress during the generative stages and especially pollination.

Higher temperatures, alone or frequent, coupled with moisture deficit can also reduce grain yield, regardless of a successful silking stage. Authors Chukwudi et al. (2022) stated that kernel formation and ear development toward full grain maturity were crucial for lower grain yield in their research [32]. In our experiment, a reduction in grain yield was recorded in years 2017 and 2018 (the years with the lowest average precipitation in the observed experiment, according to meteorological data) mostly due to earlier described abiotic stresses, which corroborates with abiotic impact toward grain yield reduction as described by the above-mentioned authors.

4. Conclusions

Based on the results of this research conducted at two sites in Croatia (Jakšić and Lužani) during the time period of 2016–2020, it can be stated that the double-row seeding pattern, achieved by twin-row drilling (MaterMacc Twin Row-2), resulted in statistically higher maize grain yields for all three tested maize hybrids (H1-FAO 390, H2-FAO 400 and H3-FAO 450) representing the three most common maturity groups in this part of Europe (H1-FAO 390, H2-FAO 400 and H3-FAO 450) compared to standard seeding (PSK OLT seed drill). Its zigzag pattern, achieved by using a twin-row seeding drill, was more favorable for longer maturity group hybrids, due to lesser competition for environmental resources, especially light and water availability during the early growth and developmental stages.

Author Contributions: A.B.—writing—review and editing; Đ.B.—investigation, writing—original draft preparation; B.S.—methodology, supervision; F.N.—conceptualization, visualization. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: All data presented in results and discussion are available upon request from corresponding author.

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

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