

Article

Yield and Chemical Composition of Maize (*Zea mays* L.) Green Fodder Depending on Different Sowing Dates as an Element of Sustainable Agriculture

Piotr Szulc ^{1,*}, Katarzyna Ambroży-Deręgowska ², Marek Selwet ³, Karolina Kolańska ⁴, Roman Wąsala ⁵ and Krzysztof Górecki ⁵

¹ Department of Agronomy, Poznań University of Life Sciences, Dojazd 11, 60-632 Poznań, Poland

² Department of Mathematical and Statistical Methods, Poznań University of Life Sciences, Wojska Polskiego 28, 60-637 Poznań, Poland; katarzyna.ambrozy@up.poznan.pl

³ Department of Soil Science and Microbiology, Poznań University of Life Sciences, Szydlowska 50, 60-656 Poznań, Poland; marek.selwet@up.poznan.pl

⁴ Lubusz Agricultural Advisory Centre, Kalsk 91, 66-100 Sulechów, Poland; k.kolanska@lodr.pl

⁵ Department of Entomology and Environmental Protection, Poznań University of Life Sciences, Dąbrowskiego 159, 60-594 Poznań, Poland; roman.wasala@up.poznan.pl (R.W.); krzysztof.gorecki@up.poznan.pl (K.G.)

* Correspondence: piotr.szulc@up.poznan.pl; Tel.: +48-61-848-7515

Abstract

The field study was conducted between 2016 and 2018 by the Department of Agronomy at Poznań University of Life Sciences. The experiment took place at the fields of the Research and Education Centre in Gorzyń, Złotniki branch. It was a single-factor trial involving six different sowing dates of an ultra-early maize cultivar: A1—12 April, A2—26 April, A3—10 May, A4—24 May, A5—7 June, and A6—21 June. The cultivar ‘Pyroxenia’ was used in the study. It is characterized by very early maturity (FAO 130), rapid early growth, and intensive stem elongation. In the present study, the optimal sowing time for the maize variety ‘Pyroxenia’ was late April (A2) and early May (A3). Later sowing of this variety resulted in a reduction in fresh and dry matter yields, as well as a reduction in the quality of the feed. The difference between the first (A1) and the last sowing date (A6) resulted in a 47% reduction in fresh weight and a 49% reduction in dry weight yield. No effect of sowing date was observed on starch content or structural carbohydrates, including crude fiber and its fractions (NDF, ADF, and ADL), in maize forage intended for ensiling. Data analysis for the years 2016–2018 showed that air temperature and precipitation had a significant effect on fresh and dry straw weight yields. Partial factor productivity of nitrogen (PFP_N) decreased with delayed sowing of maize. On average, this parameter for maize sown in June compared with April, was lower by 38.8% for straw dry yield, 54.5% for ear dry yield, and 46.3% for whole-plant dry yield.

Keywords: early maize; biomass; sowing date; meteorological conditions; linear mixed-effects regression model

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1. Introduction

For many years, maize (*Zea mays* L.) breeding has focused on developing ideal genotypes for given environments, prioritizing the creation of high-yielding varieties regardless of their specific agronomic requirements. In addition to being a staple food world-

wide for humans [1,2] and animals [3], maize is extensively used for biofuel production [4]. Maize cultivation will need to be maintained to meet the growing demand for energy and food in the coming decades [5,6]. Maize variety is considered one of the key factors determining crop production growth in modern agriculture [7,8]. Breeding progress in maize is achieved through targeted genetic modifications aimed at improving specific agronomic and quality traits of varieties. It is most commonly associated with increased yield, but it also involves many other traits that determine the economic value of varieties (EVV). In particular, this concerns yield quality as well as resistance or tolerance to various biotic (diseases, pests) and abiotic factors (low and high temperatures, soil quality or acidity, precipitation deficiency or excess, etc.) that limit productivity, along with other specific traits that determine the agronomic or quality characteristics of varieties [9]. A desirable trait of new varieties is also the ability to recover quickly once the stress has subsided. This is particularly important in the context of a changing climate and increasing frequency of extreme weather events [10]. The selection of a maize variety for silage production should take into account the specific region of Poland. In the northern region, early (FAO up to 220) and medium-early (FAO 240–250) varieties should be cultivated. In the central region, medium-early (FAO up to 250) and medium-late varieties (FAO 260–270) are preferred, while in the warmest regions, i.e., southwestern and southeastern Poland, medium-late varieties (FAO 260–290) are recommended. Early-maturing varieties produce lower yields than late-maturing counterparts. However, silage produced from varieties with a lower FAO number has a higher energy value than that from varieties with a higher FAO number. This is due to the fact that early varieties have a higher ear proportion in the forage. Hybrids with the “stay-green” trait should also be considered. Their stems and leaves retain greenness during grain maturation, allowing for longer accumulation of nutrients and a higher concentration of dry weight in the ears [11,12]. The long-green stems and leaves allow for effective chopping by the forage harvester and proper compaction of the silage material in the silo, reducing the rebound effect. The stems and leaves of “stay-green” hybrids are more resistant to pathogens causing stalk rot and Fusarium disease [13,14]. In Poland, early and medium-early varieties are recommended for maize cultivation intended as cattle feed. For maize cultivated for biogas production, late-maturing varieties should be selected. Amon et al. [15] recommend cultivating hybrids for biogas with an FAO 30–50 points higher than those used for feed production. According to recent research [16], crop yield and quality are determined by the interaction of genotype, environmental conditions, and management practices, with climate and agronomic factors often playing a dominant role over genetic improvements.

Thus, nearly one third of the effect depends on the choice of an appropriate variety. Meanwhile, a variety is a population of living plant organisms that undergo aging processes. It is estimated that the maximum yield potential of maize varieties persists for approximately five years, only rarely extending to 8–10 years. “Pyroxenia” maize is an exceptionally early variety (FAO 130) and is intended for universal cultivation [17]. Owing to the high proportion of ears in the silage mass, it is characterized by high digestibility. It forms tall plants that are resistant to lodging and perform well under periodic water deficits.

The main objective of the study was to determine the effect of different sowing dates of an ultra-early maize variety on: (i) yield, (ii) chemical composition of green forage for ensiling, and (iii) partial factor productivity of nitrogen (PFPF_N). In addition, the study presents linear relationships between the analyzed traits of maize forage and silage, as well as functional relationships between maize yield and selected climatic parameters, namely total precipitation, mean daily air temperature.

2. Materials and Methods

2.1. Experimental Design

The field study was conducted over the 2016–2018 growing seasons at the experimental facilities of the Department of Agronomy, Poznań University of Life Sciences, located at the Gorzyń Research and Education Center (Złotniki unit). The experiment was repeated annually using the same layout, arranged in four replications. A one-factor experimental design was applied, with the investigated factor being six sowing dates of an ultra-early maize cultivar: 12 April (A1), 26 April (A2), 10 May (A3), 24 May (A4), 7 June (A5), and 21 June (A6). All plots were managed under identical fertilization conditions. Mineral nutrients were applied at the following rates: 130 kg N·ha⁻¹ in the form of urea, 50 kg P₂O₅·ha⁻¹ as triple superphosphate, and 80 kg K₂O·ha⁻¹ as potassium salt. Weed control was carried out after sowing for each planting date using Lumax 557.5 SE at a rate of 4 L·ha⁻¹ (Syngenta Crop Protection AG, Basel, Switzerland). Sowing was performed with a Monosem precision seeder. The planned plant density was 7.95 plants·m⁻² (79,500 seeds·ha⁻¹), with a row spacing of 70 cm and a sowing depth ranging from 4 to 5 cm. Each plot had a total area of 24.5 m² (8.75 m × 2.8 m), while a central section of 12.25 m² was designated for measurements and sampling. Plant material was collected from the two middle rows of each plot. In all years, maize grown for green forage was harvested at the dough stage of grain development, regardless of sowing date. After harvest, the plant material was chopped into 1.0–1.5 cm fragments using a Viking GE 105 shredder (VIKING GmbH, Traun, Austria).

2.2. Climatic Conditions

Climatic conditions during the field experiment were characterized using data collected from the meteorological station located at the Research and Education Centre in Gorzyń (Złotniki branch). Thermal conditions throughout the maize growing season remained relatively uniform across the study years, irrespective of sowing date. The average air temperatures recorded were 15.8 °C in 2016, 14.2 °C in 2017, and 16.6 °C in 2018. In contrast, considerable interannual variation was observed in total precipitation. The highest rainfall was recorded in 2017 (553.0 mm), while the lowest occurred in 2018 (230.3 mm) (Table S1). In 2016, the greatest total precipitation was associated with the fifth sowing date (A5), which coincided with the lowest air temperature (Table S2). For this treatment, the sum of effective temperatures (SET) reached 1412.6 °C, and the growing season lasted 125 days. In contrast, the fourth sowing date (A4) experienced the lowest precipitation and the highest air temperature. Under these conditions, SET increased to 1479.7 °C, while the growing period was shortened to 118 days. In 2017, the highest precipitation totals were observed for the latest sowing date (A6), again corresponding to the lowest air temperature (Table S2). The SET for this treatment was 1285.6 °C, and the growing season extended to 135 days. Conversely, the earliest sowing date (A1) was characterized by the lowest precipitation and a mean daily air temperature of 14.73 °C. In this case, the SET reached 1003 °C, and the growing period lasted 114 days. In 2018, the maximum precipitation was recorded for the fifth sowing date (A5), with an average air temperature of 18.93 °C (Table S2). The SET for this treatment was 1501.7 °C, and the maize growing period lasted 116 days. The lowest precipitation occurred at the fourth sowing date (A4), which was accompanied by the highest mean daily temperature (19.87 °C). Under these conditions, the SET reached 1523 °C, and the growing season was reduced to 110 days. The sums of effective temperatures (SET, °C) were calculated using daily temperature data from sowing until maize reached physiological maturity (black layer stage), according to the method described by Weber et al. [18].

$$SET = \sum((T_{\max} + T_{\min})/2 - T_0), \quad (1)$$

where:

SET—Sum of Effective Temperatures (°C),

$T_{\max}$ —maximum temperature (°C),

$T_{\min}$ —minimum temperature (°C),

T_0 —base temperature (6 °C).

2.3. Soil Conditions

The Research and Education Centre in Gorzyń lies within the Poznań Upland at an altitude ranging from 105 to 110 m above sea level. This region was shaped by glacial processes associated with the Baltic glaciation, specifically the Poznań Stadial. The experimental site was located on a ground moraine plain formed of light clay deposits. Based on the Polish Soil Classification (PTG) [19], the soil was categorized as autogenic within the section level, belonging to brown earth soils at the order level. It was further identified as grey-brown podzolic soil, subtype typical, developed from glacial clay, with a surface layer of strong silty sand underlain by light clay at a shallow depth. In terms of international classification systems, the soil is recognized as an Albic Luvisol according to FAO guidelines and falls within the Alfisols order in the USDA Soil Taxonomy. From a textural perspective, it can be described as loamy sand over a loam subsoil. Agriculturally, the soil has been classified within the fourth suitability complex (very good rye complex) and assigned to soil quality class IIb. Detailed data on macro- and micronutrient concentrations are provided in Tables 1 and 2.

Table 1. Soil nutrient content and pH before the experiment during the maize growing seasons.

Specification	Years		
	2016	2017	2018
P [mg P kg ⁻¹ soil DM]	10.4	7.3	4.9
K [mg K kg ⁻¹ soil DM]	9.7	10.8	11.6
Mg [mg Mg kg ⁻¹ soil DM]	4.4	5.3	5.3
pH [in 1 mol dm ⁻³ KCl]	4.6	5.6	5.1

Table 2. Soil micronutrient content and pH before the experiment during the maize growing seasons.

Specification	Years		
	2016	2017	2018
Cu [mg Cu kg ⁻¹ soil DM]	2.3	2.6	1.7
Zn [mg Zn kg ⁻¹ soil DM]	18.3	9.7	9.7
Mn [mg Mn kg ⁻¹ soil DM]	260.0	90.0	170.0
Fe [mg Fe kg ⁻¹ soil DM]	950.0	510.0	703.0

2.4. Agronomic Conditions

In each year of the experiment, winter wheat was used as the preceding crop for maize. Standard agronomic operations were implemented according to a predefined schedule, with the corresponding dates listed in Table 3. Nitrogen fertilization and soil preparation for maize planting were carried out two days before each intended sowing date.

Table 3. Schedule of agronomic practices in 2016–2018.

Treatment Type	Years		
	2016	2017	2018
1. Deep tillage	9 November *	26 October *	20 November *
2. Harrowing	1 April	31 March	1 April
3. Application of P and K fertilizers	5 April	20 April	20 April

*—performed in the autumn of the preceding year.

2.5. Observations and Measurements

2.5.1. Determination of Maize Biomass Yield

Fresh weight of whole plants was recorded during maize harvest for silage, followed by separate measurements of ears. Total dry weight yield and the structural composition of the yield were determined based on these data. Dry weight percentage in the aerial maize parts was also determined to calculate the dry weight yield of straw, ears, and whole plants (straw + ears) per unit area.

2.5.2. Green Forage Chemical Composition Analysis

After delivery to the laboratory, maize samples were pre-dried for 72 h under 250 W infrared lamps and then ground using a Retsch SM100 laboratory mill equipped with a 0.25 mm screen. The prepared material was analyzed for the following components: dry matter determined by the oven-drying method using an SUP4 dryer (PN ISO 6496:2002); crude ash using an RT 921 muffle furnace (PN-76/R-64795); crude protein determined with a 2200 Kjeltex Auto Distillation Unit (Foss Tecator) (PN ISO 5983:2000); crude fat using a Soxtec HT 1043 Extraction Unit (Tecator) (PN ISO 6492:2005); and crude fibre using a Fibertec System 1010 Heat Extractor (Tecator) (PN EN ISO 6865:2002). Fibre fractions, including neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL), were determined following the Van Soest method using an Ankom 220 Fiber Analyzer. Starch content was analyzed according to PN-R-64785.

2.5.3. Partial Factor Productivity of Nitrogen

The partial factor productivity of fertilizer nitrogen (PFPF_N) for the dry weight yield of vegetative and generative plant parts was calculated using the formulas described by Szulc et al. [11]:

$$\begin{aligned}
 \text{PFPF}_N &= P/N_r, (\text{kg straw DM/kg N}), \\
 \text{PFPF}_N &= P/N_r, (\text{kg ear DM/kg N}), \\
 \text{PFPF}_N &= P/N_r, (\text{kg whole plant DM/kg N}),
 \end{aligned}
 \tag{2}$$

where:

P—Dry weight yield of straw, ears, and whole plants,

N_r—Nitrogen dose (130 kg N/ha).

2.6. Statistical Methods

All calculations were performed using the STATISTICA software package (version 13.3; TIBCO Software Inc., Palo Alto, CA, USA), Microsoft Excel and R Statistical analyses (Version 4.5.1) were conducted at the assumed significance level of $\alpha = 0.05$.

2.6.1. Split-Plot Design

Analysis of variance (ANOVA) was performed according to a split-plot design model [20]. In the experiment, years were considered as first-order units, and sowing dates of the maize variety Pyroxenia as second-order units.

In the split-plot design, the mathematical model of observations has the following form:

$$y_{ijk} = \mu + \gamma_i + \alpha_j + \eta_{ij} + \beta_k + (\alpha\beta)_{jk} + \varepsilon_{ijk}, \quad (3)$$

where:

y_{ijk} —observation obtained in the i -th replication (block), for j -th level of the factor ‘years’ and the k -th level of factor A,

μ —overall mean,

γ_i —random effect of the i -th replication (block) ($i = 1, 2, 3, 4$),

α_j —fixed effect of the j -th level of the factor ‘years’ ($j = 1, 2, 3$),

β_k —fixed effect of the k -th level of factor A ($k = 1, 2, 3, 4, 5, 6$),

$(\alpha\beta)_{jk}$ —fixed effect of the interaction between the j -th level of the factor ‘years’ and the k -th level of factor A,

η_{ij} —random error effect of first-order units,

ε_{ijk} —random error effect of second-order units,

Errors are assumed to have independent normal distributions:

$$\eta_{ij} \sim N(0, \sigma_\eta), \varepsilon_{ijk} \sim N(0, \sigma_\varepsilon). \quad (4)$$

When the main effects (years and sowing dates) or their interaction were found to be statistically significant in the analysis of variance (ANOVA), mean comparisons were performed using Tukey’s HSD post hoc test. The purpose of this analysis was to identify which means differed significantly.

2.6.2. Regression

Linear mixed-effects regression models (LMMs) were applied, to determine the relationships between six maize traits [fresh weight of straw (i), ears (ii), and whole plants (iii); dry weight of straw (iv), ears (v), and whole plants (vi)] and two selected meteorological factors: mean total precipitation during the study period and mean air temperature.

Separate models were fitted for each meteorological variable, using all observations collected during the three experimental years (2016–2018). In each model, the meteorological variable (mean air temperature or mean total precipitation), year, and their interaction were included as fixed effects to capture both the overall influence of environmental conditions and potential differences in responses among years. Random effects included random intercepts for the combination of year and sowing dates and for block nested within year, thereby accounting for the hierarchical structure of the experimental design and the non-independence of observations within experimental units. This modelling approach accounts for the dependency structure in the data and reduces the risk of pseudoreplication. Model performance was evaluated using marginal R^2 (R^2_m) and conditional R^2 (R^2_c). Marginal R^2 represents the proportion of variance explained by the fixed effects alone, whereas conditional R^2 represents the proportion of variance explained by both fixed and random effects. The difference between R^2_m and R^2_c reflects the contribution of the random effects to the overall model fit.

The Pearson correlation coefficient (r) was used to assess the direction of linear relationships between the selected traits of green forage.

3. Results

3.1. Fresh Weight Yield of Maize

The highest average fresh weight yields of maize ears and whole plants were obtained in 2016 and 2017 compared with 2018. No significant effect of the study years on the average fresh weight yield of straw was observed. Regardless of the study year, the lowest average yields for the traits considered were obtained in the June sowing dates (A5 and A6), while the highest average values were recorded for the maize sowing dates A1–A4. The present study also demonstrated an interaction between the study years and the maize sowing dates. In the final year of the study, 2018, the average fresh yields of straw, ears, and whole plants did not differ significantly despite six different maize sowing dates (A1–A6). In 2016, the lowest average fresh weight yield of maize straw was obtained for sowing date A6, which did not differ significantly from the average yields for sowing dates A5, A4, and A1. The lowest average fresh ear yield in 2016 was obtained for sowing date A6, which did not differ significantly from the yield recorded for sowing date A5. The highest average fresh yields of whole maize plants were recorded for the sowing dates A1–A4. In 2017, the significantly highest average fresh yields of straw and ears were observed for plots A1–A4. For the yield of fresh whole-plant biomass, the highest values of the trait were recorded for dates A1, A2, A3, and A5 (Tables 4 and 5).

Table 4. Mean values of maize fresh weight yield by year (Y) and sowing date (A).

Experimental Factor	Factor Level	Fresh Straw Yield (t/ha)	Fresh Ear Yield (t/ha)	Fresh Whole-Plant Yield (t/ha)
Years	2016	27.47 a	14.25 a	41.73 a
	2017	28.53 a	13.30 a	41.83 a
	2018	25.75 a	9.75 b	35.49 b
<i>p</i> -value		0.1019	0.0147	0.0175
Sowing dates	A1	33.64 a	13.86 a	47.50 a
	A2	33.47 a	15.51 a	48.97 a
	A3	32.36 a	15.78 a	48.14 a
	A4	27.53 ab	13.10 ab	40.63 ab
	A5	19.45 bc	8.26 bc	27.71 bc
	A6	17.05 c	8.09 c	25.14 c
<i>p</i> -value		0.0000	0.0000	0.0000

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

Table 5. Mean values of maize fresh weight yield for the Y × A interaction.

Years	Sowing Dates	Fresh Straw Yield (t/ha)	Fresh Ear Yield (t/ha)	Fresh Whole-Plant Yield (t/ha)
2016	A1	32.63 abcd	17.07 abc	49.69 abc
	A2	37.80 ab	18.47 a	56.27a
	A3	38.05 ab	18.00 ab	56.05 a
	A4	31.25 abcd	16.16 abcd	47.41 abcde
	A5	12.65 cd	8.33 de	20.98 cde
	A6	12.45 d	7.49 e	19.94 de
2017	A1	40.80 a	15.18 abcde	55.98 a
	A2	35.20 ab	14.73 abcde	49.93 abc
	A3	34.63 abc	16.70 abcd	51.33 ab
	A4	32.50 abcd	16.51 abcd	49.01 abcd
	A5	16.35 bcd	9.71b cde	26.06 bcde

	A6	11.70 d	6.95 e	18.65 e
2018	A1	27.50 abcd	9.32 cde	36.82 abcde
	A2	27.40 abcd	13.32 abcde	40.72 abcde
	A3	24.40 abcd	12.64 abcde	37.04 abcde
	A4	18.82 abcd	6.63 e	25.46 bcde
	A5	29.35 abcd	6.74 e	36.09 abcde
	A6	27.00 abcd	9.84 bcde	36.84 abcde
<i>p</i> -value		0.0005	0.0232	0.0011

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

3.2. SET Requirements for Producing 1 Ton of Maize Fresh Weight

In the present study, SET had no significant effect on the production of 1 ton of maize straw or ear fresh weight (Table 6). Years had a significant effect on SET requirements for producing fresh whole-plant weight (Table 6). The highest SET requirement was recorded in 2018, while the lowest was observed in 2017.

Considering SET requirements for producing fresh weight of straw, ears, and whole plants for different sowing dates, it was found that delaying the sowing date increased SET requirements per unit of fresh weight for straw, ears, and whole plants (Table 6).

The present study also demonstrated an interaction between years and maize sowing dates for SET requirements to produce 1 ton of fresh straw and whole plants (Table 7). In the first two years of the study, delaying the maize sowing date increased SET requirements for producing a unit of fresh straw and whole-plant yield. In the last year of the study (2018), the effect of SET on the measured traits was largely evened out.

Table 6. Mean SET requirements for producing 1 ton of maize fresh weight by year (Y) and sowing date (A).

Experimental Factor	Factor Level	Straw Fresh Yield (°C) SET	Ear Fresh Yield (°C) SET	Whole-Plant Fresh Yield (°C) SET
Years	2016	61.52 a	108.96 a	39.14 b
	2017	55.50 a	106.69 a	36.20 c
	2018	58.67 a	169.10 a	42.50 a
	<i>p</i> -value	0.2340	0.1071	0.0058
Sowing dates	A1	34.77 c	89.02 b	24.78 c
	A2	39.42 bc	85.35 b	26.90 bc
	A3	46.20 bc	92.91 b	30.83 bc
	A4	57.48 b	135.56 ab	39.86 b
	A5	82.82 a	196.42 a	54.81 a
	A6	90.68 a	170.26 ab	58.49 a
<i>p</i> -value		0.0001	0.0026	0.0000

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

Table 7. Mean SET requirements for producing 1 ton of maize fresh weight for the Y × A interaction.

Years	Sowing Dates	Straw Fresh Yield (°C) SET	Whole-Plant Fresh Yield (°C) SET
2016	A1	35.45 c	23.30 cd
	A2	33.87 c	22.87 cd
	A3	36.94 c	25.04 cd
	A4	47.38 bc	31.21 cd
	A5	111.81 a	67.52 a
	A6	103.65 a	64.90 a

2017	A1	24.61 c	17.96 d
	A2	34.38 c	24.20 cd
	A3	39.57 c	26.71 cd
	A4	42.18 bc	27.99 cd
	A5	81.86 ab	51.37 abc
	A6	110.40 a	68.95 a
2018	A1	44.25 bc	33.09 bcd
	A2	50.00 bc	33.65 bcd
	A3	62.08 bc	40.74 abcd
	A4	82.88 ab	60.39 ab
	A5	54.79 bc	45.55 abcd
	A6	57.99 bc	41.61 abcd
<i>p</i> -value		0.0001	0.0008

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

3.3. Maize Dry Weight Yield

In the present study, no significant effect of the study years was found on the mean dry straw yield, mean dry whole-plant yield, or the percentage of ears in the total dry weight yield of whole plants. The highest value of the mean dry ear yield was recorded in 2016 (9.0 t/ha), whereas a significantly lower value was observed in 2018 (6.51 t/ha). In contrast, a significantly higher dry weight content in straw and ears was recorded in 2018, whereas the lowest values were observed in the 2017 growing season. Regardless of the study year, the mean straw and ear dry yields were significantly lowest for sowing date A6 compared to dates A1–A4. For whole-plant dry yield, significantly higher values of the analyzed trait were recorded for sowing dates A1–A4 compared with dates A5–A6. The dry weight content of straw was significantly highest for sowing date A4 and lowest for sowing date A3, irrespective of the study year. For the dry weight content of whole plants, the highest mean values of the trait were recorded for sowing dates A2–A4, while the lowest value was obtained for date A6. In contrast, the lowest percentage contribution of ears to the total dry weight yield of whole plants was recorded for sowing date A3, and the highest for date A6. The present study also demonstrated an interaction between the study years and the maize sowing dates. In 2016, sowing date A4 produced significantly higher mean values of straw dry yield, ear dry yield, whole-plant dry weight yield, and ear dry weight content compared with date A6.

In 2017, the lowest mean straw dry yield was recorded for sowing date A6 compared with dates A1 and A4. Meanwhile, the highest mean dry weight yield of ears was recorded for sowing date A4 compared with date A6. The highest mean whole-plant dry weight yield was obtained for sowing date A4 compared with date A6. For ear dry weight content, the lowest mean value of the trait was recorded for sowing date A6, whereas the highest was observed for date A4.

In 2018, the lowest mean ear dry weight content was recorded for sowing date A1 compared to dates A2 and A3. The highest mean percentage contribution of ears to the whole-plant dry weight yield was recorded for sowing dates A2 and A3 compared with date A5 (Tables 8 and 9).

Table 8. Mean values of maize dry weight yield by year (Y) and sowing date (A).

Experimental Factor	Factor Level	Straw Yield (t/ha)	Ear Yield (t/ha)	Whole Plant Yield (t/ha)	Straw DM Content (%)	Ear DM Content (%)	Ear Percentage in DM Yield (%)
Years	2016	7.54 a	9.00 a	16.54 a	28.76 ab	60.32 ab	52.85 a
	2017	7.58 a	8.13 ab	15.71 a	27.28 b	58.38 b	50.69 a
	2018	8.23 a	6.51 b	14.74 a	32.82 a	65.09 a	42.64 a
<i>p</i> -value		0.2697	0.0481	0.1400	0.0455	0.0466	0.1084
Sowing dates	A1	8.94 a	8.23 ab	17.17 a	26.57 b	58.52 b	47.02 ab
	A2	9.08 a	10.41 a	19.49 a	27.70 ab	67.26 ab	52.98 ab
	A3	8.32 ab	10.38 a	18.70 a	26.84 b	66.79 ab	55.54 a
	A4	9.18 a	9.76 a	18.94 a	34.25 a	72.27 a	49.07 ab
	A5	6.20 bc	4.66 bc	10.86 b	31.71 ab	57.09 b	44.94 ab
	A6	5.01 c	3.82 c	8.83 b	30.62 ab	45.66 c	42.79 b
<i>p</i> -value		0.0000	0.0000	0.0000	0.0206	0.0000	0.0041

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

Table 9. Mean dry weight yield of maize for the Y $\times$ A interaction.

Years	Sowing Dates	Straw Yield (t/ha)	Ear Yield (t/ha)	Whole Plant Yield (t/ha)	Ear DM Content (%)	Ear Percentage in DM Yield (%)
2016	A1	8.72 abcd	10.61 abcd	19.33 abc	62.03 ab	54.75 a
	A2	9.28 abc	11.98 ab	21.26 ab	63.95 ab	55.76 a
	A3	8.64 abcde	11.23 abc	19.87 abc	62.40 ab	56.55 a
	A4	10.38 a	12.44 a	22.82 a	76.96 a	54.50 a
	A5	3.98 de	4.84 abcd	8.82 cd	58.01 abcd	55.13 a
	A6	4.24 cde	2.89 cd	7.13 d	38.56 d	40.38a b
2017	A1	10.83 a	8.97 abcd	19.81 abc	59.02 abcd	45.13 ab
	A2	8.51 abcde	8.86 abcd	17.37 abcd	59.85 abcd	50.84 ab
	A3	7.77 abcde	10.22 abcd	17.99 abcd	61.15 abc	56.95 a
	A4	10.09 a	12.60 a	22.70 a	75.93 ab	55.22 a
	A5	4.73 bcde	5.32 abcd	10.04 bcd	54.76 bcd	52.91 a
	A6	3.58 e	2.80 d	6.38 d	39.58 cd	43.06 ab
2018	A1	7.25 abcde	5.12 abcd	12.37 abcd	54.51 bcd	41.19 ab
	A2	9.46 ab	10.39 abcd	19.84 abc	77.98 a	52.35 a
	A3	8.54 abcde	9.70 abcd	18.24 abcd	76.81 a	53.12 a
	A4	7.05 abcde	4.25 abcd	11.31 abcd	63.91 ab	37.48 ab
	A5	9.88 a	3.83 bcd	13.71 abcd	58.50 abcd	26.77 b
	A6	7.21 abcde	5.78 abcd	12.98 abcd	58.83 abcd	44.92 ab
<i>p</i> -value		0.0002	0.0078	0.0016	0.0008	0.0094

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

3.4. SET Requirements for Producing 1 Ton of Maize Dry Weight

In the present study, no significant effect of SET on the production of 1 ton of dry matter from straw, ears, or whole maize plants was observed (Table 10). Considering SET requirements for producing fresh weight of straw, ears, and whole plants for different sowing dates, it was found that delaying the sowing date increased SET requirements per unit of fresh weight for straw, ears, and whole plants (Table 10). The present study also demonstrated an interaction between years and maize sowing dates for SET requirements

to produce 1 ton of fresh straw and whole plants (Table 11). In the first two years of the study, delaying the maize sowing date increased SET requirements for producing a unit of dry straw and whole-plant yield. In the last year of the study (2018), the effect of SET on the measured traits became more uniform.

Table 10. Mean SET requirements for producing 1 ton of maize dry weight by year (Y) and sowing date (A).

Experimental Factor	Factor Level	Straw Dry Weight (°C) SET	Ear Dry Weight (°C) SET	Whole-Plant Dry Weight (°C) SET
Years	2016	208.03 a	202.40 a	100.39 a
	2017	199.07 a	209.02 a	99.20 a
	2018	178.14 a	269.35 a	102.23 a
<i>p</i> -value		0.2965	0.3422	0.7444
Sowing dates	A1	131.35 b	156.27 c	69.83 b
	A2	142.53 b	128.09 c	67.02 b
	A3	172.15 b	137.90 c	76.41 b
	A4	164.88 b	197.85 bc	87.01 b
	A5	267.96 a	338.31 ab	136.85 a
	A6	291.63 a	403.11 a	166.51 a
<i>p</i> -value		0.0000	0.0002	0.0000

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

Table 11. Mean SET requirements for producing 1 ton of maize dry weight for the Y × A interaction.

Years	Sowing Dates	Straw Dry Weight (°C) SET	Whole-Plant Dry Weight (°C) SET
2016	A1	132.78 d	60.16 f
	A2	139.67 d	62.32 f
	A3	162.72 cd	70.60 def
	A4	142.56 d	64.85 ef
	A5	366.40 a	163.08 abc
	A6	304.07 ab	181.33 ab
2017	A1	92.68 d	50.90 f
	A2	142.86 d	69.64 def
	A3	179.11 bcd	76.73 def
	A4	136.04 d	61.08 f
	A5	283.08 abc	133.30 bcde
	A6	360.65 a	203.56 a
2018	A1	168.58 cd	98.42 cdef
	A2	145.06 d	69.11 def
	A3	174.62 cd	81.91 def
	A4	216.03 bcd	135.10 abcd
	A5	154.39 d	114.18 bcdef
	A6	210.16 bcd	114.63 bcdef
<i>p</i> -value		0.0002	0.0004

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

3.5. Chemical Composition of Maize Forage

The highest mean dry weight in maize forage was recorded in 2018 (40.13%), while the lowest was observed in 2017 (33.58%). The highest mean crude fat content was recorded in 2016, whereas the lowest was obtained in 2017. The highest crude protein content was recorded in 2018, while the lowest was in 2017. For starch content, the highest mean

value was recorded in 2016, while the lowest was in 2018. Regardless of the study year, the highest dry weight in maize forage was recorded for sowing date A1, whereas the lowest was observed for dates A5 and A6.

In the present study, the highest crude ash content was recorded for sowing date A3 in 2016, whereas the lowest was observed for the same date in 2018. For crude fat, the highest content was recorded in 2016 for sowing date A5, while the lowest was observed in 2017 for sowing date A3 (Tables 12 and 13).

Table 12. Mean chemical composition of green forage by year (Y) and sowing date (A).

Experimental Factor	Factor Level	Dry Weight (%)	Crude Ash (% DM)	Crude Protein (% DM)	Crude Fat (% DM)	Crude Fiber (% DM)	NFE (% DM)	Starch (% DM)
Years	2016	37.93 ab	4.54 a	8.03 a	3.06 a	17.88 a	66.49 ab	33.60 a
	2017	33.58 b	4.14 a	7.85 a	2.64 b	20.38 a	64.99 b	30.34 ab
	2018	40.13 a	3.84 a	7.84 a	2.82 ab	17.74 a	68.02 a	27.52 b
<i>p</i> -value		0.0089	0.0520	0.1899	0.0187	0.0889	0.0273	0.0241
Sowing dates	A1	39.25 a	4.31 a	7.98 a	3.07 a	17.60 a	67.04 a	32.89 a
	A2	38.44 ab	4.09 a	7.55 a	2.71 a	18.65 a	67.01 a	28.21 a
	A3	37.84 ab	4.27 a	8.26 a	2.82 a	18.80 a	65.85 a	32.58 a
	A4	37.83 ab	4.11 a	7.85 a	2.91 a	18.98 a	66.16 a	30.49 a
	A5	34.83 b	4.12 a	7.69 a	2.81 a	18.87 a	67.04 a	29.86 a
	A6	35.11 b	4.14 a	8.11 a	2.73 a	19.11 a	65.91 a	28.92 a
<i>p</i> -value		0.0016	0.7576	0.1162	0.0505	0.4079	0.5539	0.2384

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

Table 13. Mean chemical composition of green forage for the Y × A interaction.

Years	Sowing Dates	Dry Weight (% DM)	Crude Ash (% DM)	Crude Fat (% DM)
2016	A1	37.46 abc	5.01 ab	3.16 ab
	A2	37.43 abc	4.67 ab	2.78 ab
	A3	38.00 abc	5.18 a	3.04 ab
	A4	37.23 abc	4.62 ab	3.15 ab
	A5	38.63 abc	3.88 ab	3.33 a
	A6	38.86 abc	3.91 ab	2.91 ab
2017	A1	36.87 abc	4.17 ab	3.26 ab
	A2	36.21 abc	3.84 ab	2.88 ab
	A3	34.38 bcd	4.10 ab	2.34 b
	A4	36.73 abc	3.94 ab	2.63 ab
	A5	26.58 d	4.50 ab	2.35 ab
	A6	30.69 cd	4.29 ab	2.39 ab
2018	A1	43.43 a	3.76 ab	2.81 ab
	A2	41.67 ab	3.78 ab	2.46 ab
	A3	41.14 ab	3.52 b	3.09 ab
	A4	39.52 ab	3.76 ab	2.95 ab
	A5	39.29 abc	3.99 ab	2.74 ab
	A6	35.77 abc	4.21 ab	2.88 ab
<i>p</i> -value		0.0027	0.0081	0.0055

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

3.6. Fiber Fraction Content in Green Forage

In the present study, no significant effect of study year or maize sowing date was observed on the fiber fraction content in maize forage. The field experiments demonstrated a significant interaction between study year and maize sowing date with respect to the NDF fiber fraction content. In 2016, the highest mean content of this fiber fraction in the forage was recorded for date A2, while the lowest was observed for dates A1, A5, and A6. In 2017, the highest mean content of this fiber fraction in the forage was recorded for date A3, while the lowest was observed for dates A1, A5, and A2. In the last year of the study (2018), the mean content of the fiber fraction was significantly highest for sowing date A5 and lowest for the first sowing date, A1 (Tables 14 and 15).

Table 14. Mean values of fiber fractions in maize forage by year (Y) and sowing date (A).

Experimental Factor	Factor Level	NDF (% DM)	ADF (% DM)	ADL (% DM)
Years	2016	34.23 a	19.04 a	2.41 a
	2017	37.34 a	21.13 a	2.21 a
	2018	38.57 a	21.36 a	2.27 a
	<i>p</i> -value	0.0981	0.1296	0.4539
Sowing dates	A1	33.53 a	19.51 a	2.09 a
	A2	37.46 a	20.39 a	2.42 a
	A3	37.90 a	20.40 a	2.56 a
	A4	37.46 a	20.61 a	2.18 a
	A5	37.46 a	21.25 a	2.04 a
	A6	36.47 a	20.90 a	2.49 a
	<i>p</i> -value	0.1292	0.7628	0.2480

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

Table 15. Mean NDF fiber fraction content for the Y $\times$ A interaction.

Sowing Dates	Years		
	2016	2017	2018
A1	31.78 e	33.52 de	35.30 bcde
A2	40.99 ab	33.26 de	38.15 abcd
A3	35.96 abcde	41.03 ab	36.72 abcde
A4	34.52 cde	38.25 abcd	39.62 abc
A5	31.30 e	39.73 abc	41.35 a
A6	30.87 e	38.25 abcd	40.28 abc

Statistical significance was set at $p = 0.0303 < 0.05$. Values sharing the same letter are not significantly different.

3.7. Partial Factor Productivity of Nitrogen

Regardless of the study year, the highest mean partial factor productivity of nitrogen for the dry weight yield of straw and ears was obtained at sowing dates A1–A4, whereas the lowest value was recorded at A6. For the dry yield of whole plants, significantly higher values of the trait were recorded at sowing dates A1–A4, whereas the lowest occurred at A5 and A6.

The mean partial factor productivity of nitrogen for the dry yield of straw, ears, and whole plants was significantly affected by variable weather conditions during the study years and by maize sowing date. In 2016, the highest partial factor productivity of nitrogen for straw dry yield was recorded for sowing date A4, whereas the lowest value was observed for A5. For ear dry yield and whole-plant dry weight yield, the highest values

of the analyzed trait were recorded for sowing dates A1–A4, whereas the lowest value was observed for sowing date A6. In 2017, the highest partial factor productivity of nitrogen for straw dry yield was recorded for sowing dates A1 and A4, whereas the lowest value was obtained for A6. For ear and whole-plant dry weight yield, the analyzed trait reached its highest value at sowing date A4, while a significantly lower value was recorded at A6. In 2018, maize sowing dates had no significant effect on the partial factor productivity of nitrogen for the dry yield of straw, ears, or whole plants (Tables 16 and 17).

Table 16. Mean values of partial factor productivity of nitrogen by year (Y) and sowing date (A).

Experimental Factor	Factor Level	Straw Dry Yield (kg Straw DM/kg N)	Ear Dry Yield (kg Ear DM/kg N)	Whole-Plant Dry Yield (kg Whole-Plant DM/kg N)
Year	2016	58.01 a	69.21 a	127.22 a
	2017	58.35 a	62.53 a	120.87 a
	2018	63.32 a	50.08 a	113.40 a
<i>p</i> -value		0.2697	0.0581	0.1400
Sowing date	A1	68.75 a	63.32 ab	132.07 a
	A2	69.85 a	80.06 a	149.91 a
	A3	63.98 ab	79.87 a	143.85 a
	A4	70.59 a	75.10 a	145.70 a
	A5	47.66 bc	35.87 bc	83.54 b
	A6	38.52 c	29.40 c	67.92 b
<i>p</i> -value		0.0000	0.0000	0.0000

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

Table 17. Mean values of partial factor productivity of nitrogen for the Y × A interaction.

Year	Sowing Date	Straw Dry Yield (kg Straw DM/kg N)	Ear Dry Yield (kg Ear DM/kg N)	Whole-Plant Dry Yield (kg Whole-Plant DM/kg N)
2016	A1	67.11 abcd	81.59 abcd	148.70 abc
	A2	71.36 abc	92.15 ab	163.51 ab
	A3	66.46 abcde	86.39 abc	152.85 abc
	A4	79.87 a	95.67 a	175.54 a
	A5	30.64 de	37.24 abcd	67.88 cd
	A6	32.62 cde	22.21 cd	54.83 d
2017	A1	83.34 a	69.01 abcd	152.35 abc
	A2	65.43 abcde	68.14 abcd	133.58 abcd
	A3	59.78 abcde	78.60 abcd	138.38 abcd
	A4	77.64 a	96.94 a	174.58 a
	A5	36.37b cde	40.90 abcd	77.27 bcd
	A6	27.51 e	21.56 d	49.07 d
2018	A1	55.79 abcde	39.36 abcd	95.16 abcd
	A2	72.76 ab	79.89 abcd	152.65 abc
	A3	65.71 abcde	74.62 abcd	140.33 abcd
	A4	54.27 abcde	32.70 abcd	86.97 abcd
	A5	75.98 a	29.48 bcd	105.46 abcd
	A6	55.43 abcde	44.43 abcd	99.86 abcd
<i>p</i> -value		0.0002	0.0078	0.0016

Statistical significance was set at $p < 0.05$. Values sharing the same letter are not significantly different.

3.8. Linear Relationships Between Selected Forage Characteristics

The study analyzed the presence of linear relationships between five selected traits in maize forage, considered separately for each study year and collectively, independent of year.

Analysis of all observations from 2016 to 2018 showed statistically significant negative linear relationships between crude fiber and crude fat, and crude fiber and starch. Thus, as the crude fiber content in maize forage increased, crude fat and starch declined. The study further confirmed significant positive linear relationships between starch content in maize forage and levels of crude protein and crude fat. An increase in starch content in maize forage led to higher levels of crude protein and crude fat (Table S3).

Research conducted in 2016, 2017, and 2018 revealed significant negative linear relationships between crude fiber content in maize forage and the levels of starch. This indicates that as the crude fiber content in maize forage increased, the levels of starch decreased. The experiments conducted in 2016 confirmed the presence of positive linear relationships between starch content in maize forage and the levels of crude protein and crude fat. This indicates that as starch content in maize forage increases, the levels of crude protein and crude fat also rise. In 2017, the study showed that an increase in crude fiber content in the forage was accompanied by a simultaneous decrease in crude fat. Studies conducted in 2018 demonstrated negative linear relationships between the crude fiber content in the forage and the total protein content, as well as between the starch and crude ash contents. Thus, as the crude fiber content in the forage increased, the total protein content decreased. Additionally, as the starch content in the forage increased, the proportion of crude ash declined (Table S4).

3.9. Functional Relationships

The study analysed functional relationships between six traits [fresh weight of straw (i), ears (ii), whole plants (iii), dry weight of straw (iv), ears (v), and whole plants (vi)] and two selected meteorological factors: mean air temperature and total precipitation. Tables S5–S10 present these relationships estimated using separate linear mixed-effects models fitted independently for each climatic variable. The year-specific regression equations presented in the tables represent simple slopes derived from a single linear mixed-effects model including the interaction between year and the environmental variable, and do not reflect independently fitted models for each year.

Table S5 presents the functional relationships between fresh straw yield (y) and mean air temperature (x_1) as well as total precipitation (x_2). The results show that climatic variables were associated with fresh straw yield, with differences in the magnitude and direction of effects between variables and years. Mean air temperature showed a positive relationship with yield in 2016 ($p = 0.0452$), while no statistically significant effects were observed in 2017 and 2018. The marginal R^2 indicates that air temperature explained a limited proportion of the variability in yield. Total precipitation showed a negative relationship with yield in 2016 ($p = 0.0115$) and a positive relationship in 2018 ($p = 0.0228$), while no significant effect was observed in 2017. The marginal R^2 for precipitation was 37.36%, compared with 23.23% for temperature. The conditional R^2 values (86.40%; 84.53) indicate that a substantial proportion of the variability in yield was associated with random effects included in the model (year, sowing date, and block).

Table S6 presents the functional relationships between fresh ear yield (y) and mean air temperature (x_1) as well as total precipitation (x_2). The results show that climatic variables were associated with fresh ear yield, with differences in the magnitude and direction of effects between variables and years. Mean air temperature showed a positive relationship with yield in 2016 ($p = 0.0415$), whereas no statistically significant effects were observed in 2017 and 2018. The marginal R^2 indicates that air temperature explained a lim-

ited proportion of the variability in yield ($R^2_m = 37.36\%$). Total precipitation showed a negative relationship with yield in 2016 ($p = 0.0342$), while no statistically significant effects were observed in 2017 and 2018. The marginal R^2 for precipitation was higher ($R^2_m = 40.71\%$) than that for temperature. The conditional R^2 values (84.53%; 84.32%) indicate that a substantial proportion of the variability in yield was associated with random effects included in the model (year, sowing date, and block).

Table S7 presents the functional relationships between fresh yield of whole plants (y) and mean air temperature (x_1) as well as total precipitation (x_2). The results show that climatic variables were associated with fresh yield of whole plants, with differences in the magnitude and direction of effects between variables and years. Mean air temperature showed a positive relationship with yield in 2016 ($p = 0.0387$), whereas no statistically significant effects were observed in 2017 and 2018. The marginal R^2 indicates that air temperature explained a limited proportion of the variability in yield ($R^2_m = 27.01\%$). Total precipitation showed a negative relationship with yield in 2016 ($p = 0.0143$) and a positive relationship in 2018 ($p = 0.0496$), while no statistically significant effect was observed in 2017. The marginal R^2 for precipitation (46.30%) was higher than that for temperature. The conditional R^2 values (87.34%; 86.35%) indicate that a substantial proportion of the variability in yield was associated with random effects included in the model (year, sowing date, and block).

Table S8 presents the functional relationships between straw dry yield (y) and mean air temperature (x_1) as well as total precipitation (x_2). The results show that climatic variables were associated with straw dry yield, with differences in the magnitude and direction of effects between variables and years. Mean air temperature showed a positive relationship with yield in 2016 ($p = 0.0357$), whereas no statistically significant effects were observed in 2017 and 2018. The marginal R^2 indicates that air temperature explained a limited proportion of the variability in yield ($R^2_m = 24.48\%$). Total precipitation showed a negative relationship with yield in 2016 ($p = 0.0078$) and a positive relationship in 2018 ($p = 0.0382$), while no statistically significant effect was observed in 2017. The marginal R^2 for precipitation (48.20%) was higher than that for temperature. The conditional R^2 values (87.06%; 85.80%) indicate that a substantial proportion of the variability in yield was associated with random effects included in the model (year, sowing date, and block).

Table S9 presents the functional relationships between dry ear yield (y) and mean air temperature (x_1) as well as total precipitation (x_2). The results show that climatic variables were associated with dry ear yield, with differences in the magnitude and direction of effects between variables and years. Mean air temperature showed a positive relationship with yield in 2016 ($p = 0.0353$), whereas no statistically significant effects were observed in 2017 and 2018. The marginal R^2 indicates that air temperature explained a moderate proportion of the variability in yield ($R^2_m = 33.81\%$). Total precipitation showed a negative relationship with yield in 2016 ($p = 0.0399$), while no statistically significant effects were observed in 2017 and 2018. The marginal R^2 values were comparable for both variables (31.20% for precipitation and 33.81% for temperature). The conditional R^2 values (84.35%; 84.51%) indicate that a substantial proportion of the variability in yield was associated with random effects included in the model (year, sowing date, and block).

Table S10 presents the functional relationships between whole-plant dry yield (y) and mean air temperature (x_1) as well as total precipitation (x_2). The results show that climatic variables were associated with whole-plant dry yield, with differences in the magnitude and direction of effects between variables and years. Mean air temperature showed a positive relationship with yield in 2016 ($p = 0.0276$), whereas no statistically significant effects were observed in 2017 and 2018. The marginal R^2 indicates that air temperature explained a limited proportion of the variability in yield ($R^2_m = 29.28\%$). Total precipitation showed a negative relationship with yield in 2016 ($p = 0.0178$), while no statistically significant

effects were observed in 2017 and 2018. The marginal R^2 values were slightly higher for precipitation (36.53%) than for temperature. The conditional R^2 values (86.74%; 83.36%) indicate that a substantial proportion of the variability in yield was associated with random effects included in the model (year, sowing date, and block).

4. Discussion

Maize yield and its feed value vary considerably under the influence of agronomic and environmental factors [21,22]. Of the latter, temperature, precipitation, and soil quality have a strong influence on maize yield and its structure [23]. The present results demonstrate that thermal conditions during the study years were favorable for maize growth and development. The mean air temperatures during the maize growing season ranged from 14.2 °C in 2017 to 16.6 °C in 2018. Therefore, based on data reported in the literature, the thermal requirements for maize growth and development were met. According to Szulc and Bocianowski [24], the level of maize yield depends to a higher extent on precipitation than on temperature. Total precipitation during the growing seasons in the study years varied considerably, ranging from 230.3 mm in 2018 to 553.0 mm in 2017. An important criterion for evaluating the effects of the study years and sowing dates in the current experiment was the yield of fresh ears and whole plants. In the present experiment, a high degree of variation in these traits was observed in silage maize plants during the study period. On average for the study years, significantly higher fresh weight yields of both ears and whole plants were recorded in the first two years (2016 and 2017) compared to the final year of the study. This result can be attributed to the markedly decreased total precipitation in 2018, which was more than 100 mm lower than in the first two years of the study. Similar findings were reported in recent studies [25]. The authors indicated that maize yields, including fresh and dry matter, may vary greatly under drought conditions, with significantly reduced minimum values compared to maximum yields due to water deficit during the growing season. When the sowing date was considered in relation to these traits, it was found that sowing maize in June, compared with April or May, reduced silage yield by more than 21 t/ha. Therefore, the results obtained in this study clearly demonstrate a strong photoperiodic response of maize, confirming that it is a short-day plant.

The maize sowing date depends on several factors, primarily the intended use of the yield, climatic and soil conditions, agronomic practices, and the region of the country in which the crop is cultivated [26,27]. Any deviation from the optimal sowing date is usually associated with lower yields and the need to adjust agronomic practices. Due to its long growing season, maize should be sown relatively early, directly after other spring crops typical for the region. The use of modern breeding methods has significantly lowered the germination temperature of maize and increased early growth vigor [28,29]. The soil temperature allowing kernel germination of currently cultivated maize varieties ranges from 6 to 8 °C. In the southern and central-western regions of Poland, this time occurs between 10 and 20 April, while in other regions it starts from 20 April to the first days of May. Later sowing is conducive to faster and more uniform emergence but reduces yields and extends growing season. The earliest possible sowing should be preferred for grain production, whereas for silage, the sowing date can be slightly delayed, as the growing season is shorter and later sowing facilitates vegetative biomass accumulation. Although early sowing of maize is a yield-promoting factor due to the shorter day at the beginning of emergence, early and uniform emergence also plays a crucial role in generative yield formation [30,31]. In maize stands emerging within 15–20 days after sowing, plant losses in the field till the harvest can reach 10–20%. Plants that emerged just 3–4 days later than their neighbors in the stand are likely to develop less vigorously throughout the growing season due to reduced light availability and a weaker root system. This,

in turn, will lead to poorer ear formation and, in many cases, even to their incomplete development and premature maturation. A very significant problem resulting from uneven maize emergence caused by early or delayed sowing is the proper selection of the timing for weed control in the plantation. The aforementioned later-emerging plants may develop only 3 leaves, while the more advanced ones are often already at the 6-leaf stage. These more developed plants are significantly more sensitive to active ingredients applied to the foliage. Due to the fact that herbicide application occurs in the mid-stage of ear formation, it further reduces their yielding potential. Field study results clearly indicate that maize sowing date has a major impact on grain yield [32,33] and forage yield [34]. In the current experiment, grain yield decreased as a result of delayed sowing, despite a higher number of plants and ears per unit area. However, this increase in the number of ears did not compensate for the reduction in grain weight per ear caused by the delayed maize sowing date. This was determined by the shortened ear length (fewer grains per ear) and a significant reduction in the 1000-grain weight. Additionally, the decrease in grain yield in the plot with the latest sowing date (21 June) was due to a reduced number of ears per unit area. Maize is a short-day plant. For early sowing, the differentiation of the ear meristem occurs under short-day conditions, resulting in a higher number of grains per row than in late sowing, when development takes place when days are long. The sowing date of maize also has a significant effect on seed maturation. Delaying the sowing date, especially in years with unfavorable weather conditions, leads to delayed grain maturation.

5. Conclusions

In the present study, late April and early May were the optimal sowing periods for the maize variety 'Pyroxenia'. Sowing this variety at later dates resulted in a reduction in fresh and dry weight yields, accompanied by a deterioration in the quality of maize forage parameters. The results indicate that mean air temperature and mean total precipitation were associated with whole-plant dry yield and other maize yield traits; however, the direction and magnitude of these relationships varied across years and traits. In 2016, a positive linear relationship with air temperature and a negative linear relationship with total precipitation were observed for six of the traits studied. Thus, higher temperatures favored the increase in the analyzed traits, whereas greater precipitation had a negative effect on them. This indicates that warmer conditions were more beneficial for plant development, while excessive rainfall could restrict their growth. High conditional coefficients of determination indicate that a substantial proportion of variability was associated with factors related to year, sowing date, and the experimental design structure. Overall, climatic variables were associated with maize yield components; however, their effects were not consistent across years or traits.

Partial factor productivity of nitrogen (PFP_N) decreased with delayed sowing of maize. On average, this parameter for maize sown in June compared with April sowing dates, was lower by 38.8% for straw dry yield, 54.5% for ear dry yield, and 46.3% for whole-plant dry weight yield.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/agronomy16131300/s1>, Table S1: Average monthly air temperature and total precipitation during the growing season; Table S2: Meteorological data on individual sowing dates in the study years; Table S3: Linear correlation coefficients between selected traits of maize green forage (regardless of the year of the study); Table S4: Linear correlation coefficients between selected traits of maize green forage; Table S5: Functional relationships between fresh straw yield and climatic variables derived from a single mixed-effects model fitted across all study years; Table S6: Functional relationships between fresh ear yield and climatic variables de-

rived from a single mixed-effects model fitted across all study years; Table S7: Functional relationships between fresh yield of whole plants and climatic variables derived from a single mixed-effects model fitted across all study years; Table S8: Functional relationships between straw dry yield and climatic variables derived from a single mixed-effects model fitted across all study years; Table S9: Functional relationships between dry ear yield and climatic variables derived from a single mixed-effects model fitted across all study years; Table S10: Functional relationships between whole-plant dry yield and climatic variables derived from a single mixed-effects model fitted across all study years.

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