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Evaluation of Nitrogen Yield-Forming Efficiency in the Cultivation of Maize (*Zea mays* L.) under Different Nutrient Management Systems

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Abstract: Failure to adjust the fertilization system to quantitative needs, and especially to the dynamics of mineral demand, causes plant metabolism disorders, low mineral utilization by the plant, and an increased risk of environmental pollution. Additionally, unbalanced mineral fertilization may reduce the assimilation surface actively involved in photosynthesis, which determines the yield potential of individual varieties. The aim of the strict field experiment was to determine the responses of two types of maize varieties (*Zea mays* L.) to treatments with different nutrient management systems, as expressed by the growth analysis of active organs during photosynthesis, SPAD (soil and plant analysis development) leaf greenness index, green mass yield, and unit nitrogen productivity from PFPFN mineral fertilization (partial factor productivity fertilizer nitrogen). It was demonstrated that the total area of leaf blades of a single plant and the LAI (leaf area index) value were significantly higher in the "stay-green" hybrid compared to the traditional variety. The analysis of leaf morphological structure of the "stay-green" hybrid, based on SLA (specific leaf area), indicated a highly effective utilization of nitrogen, leading to faster leaf production with a larger assimilation area, which formed the basis for effective absorption of solar radiation. The selection of "stay-green" varieties for silage cultivation guarantees high green mass yields. The risk of lower maize biomass intended for ensilage can only be reduced by applying balanced mineral fertilization of all nutrients. The omission of phosphorus (P) and potassium (K) in the mineral fertilization dose, regardless of the variety tested, was a factor reducing the yield of maize biomass intended for ensilage and a lower partial factor productivity of nitrogen fertilizer compared to the treatment optimally balanced with respect to the nitrogen dose.

Keywords: maize; mineral fertilization; SPAD; green mass yield

1. Introduction

Plant productivity depends on photosynthetic production, i.e., the amount of assimilates generated during the process of photosynthesis [1,2]. It largely determines the biological yield of plants, i.e., fresh or dry weight production potential per soil unit area. The structure of maize canopy also has a great influence on the rate and intensity of photosynthesis [3]. The efficiency of this physiological phenomenon would increase by about

12% per day if the duration of photosynthesis was prolonged in the extended maturity period [4]. Besides normal photosynthesis, typical of most species in our climate zone, maize begins to assimilate C_4 at higher air temperatures and high light intensity, doubling the photosynthesis efficiency. It combines two carbon dioxide molecules in one series [5,6]. C_4 photosynthesis is an evolutionary adaptive mechanism that is found mainly in plants inhabiting regions with high temperatures and water scarcity, when CO_2 abundance inhibits photosynthesis. To this end, the plant produces PEP carboxylase, which has a 10-fold greater CO_2 affinity. As a result, C_4 plants intensively absorb CO_2 when the content of this component in the atmosphere is approximately 0.001% [7]. Therefore, C_4 plants, including maize, have an adaptive advantage over C_3 plants, because the loss due to photorespiration in C_3 plants increases with raising temperatures [8,9].

The large assimilation area of leaves results in more efficient use of solar radiation by maize. There are many studies concerning the responses of C_3 plants to increased dioxide levels in the [10–12]. However, less attention has been paid to the reaction of C_4 plants due to the fact that such plants are insensitive to high levels of carbon dioxide in the atmosphere [11]. Although environmental conditions exert dramatic changes on photosynthesis, this process is genetically determined and differs between plant species and varieties [13].

Plant varieties that display very intensive photosynthesis, frequently generate lower yields than varieties with a lower intensity of this process. This is due to the fact that in addition to photosynthesis intensity, the size of assimilation area (leaves) also plays an important role in biomass production. Moreover, life expectancy and the ability of assimilation organs to function efficiently are also of particular significance. Certain studies have shown that modern maize varieties have a longer growth period, larger area, and slower rate of leaf aging, leading to a significant increase in dry matter accumulation [2,14,15]. Hence, the accumulation of dry matter by maize is closely related to leaf senescence [16,17].

In a previous work, Szulc et al. [18] demonstrated that the condition for using the biological progress represented by the “stay-green” maize variety is the simultaneous recognition of yield physiology aspects and development of plant nutrition on this basis. Selection of “stay-green” varieties for silage cultivation guarantees high biomass yields for ensilage. The relationship between dry matter production by maize and the content of nitrogen, phosphorus, potassium, and magnesium is presented in the study [14]. The obtained results have shown that nitrogen content in maize plants is a function of plant dry matter accumulation throughout the growing season. Regardless of the type of hybrid, the logarithmic function was most optimally fitted, followed by the power function, while the exponential function was the worst match. The results concerning the nitrogen dilution curve indicated the possibility of correction of the current model of Plenet and Cruz [19] due to the specificity of “stay-green” varieties, which resulted from partially different dynamics of nitrogen and biomass accumulation.

Thus, the aspect of dry matter accumulation by different maize varieties has already been recognized. This knowledge may be supplemented by research on the reactions of different types of maize varieties (classic, stay-green) to different nitrogen management systems. It is very important because in order to achieve the assumed yield one should aim at increasing the content of nutrients in the plant above the critical value and maintain a defined mineral balance in the plant. Water and the lack of mineral component balance in relation to the plants’ nutritional needs are the most frequent factors limiting the size of potential yields. Theoretically, crops can mitigate climate change by photosynthetic conversion of atmospheric CO_2 into carbohydrates and other organic compounds [20]. However, the direct and indirect effects of these changes on plants require better assessment, especially their impact on productivity [11].

Failure to adapt the fertilization system to quantitative needs, and especially the dynamics of mineral component uptake by plants growing in the field, is the cause of disturbances in the functioning of individual components, their low utilization by the plant and an increase in the risk of environmental pollution. Diversified fertilization systems shape the nitrogen balance of maize stands in critical phases of crop formation. This contributes to the improvement of the plants' nutritional status, which translates into an increase in unit nitrogen productivity. In addition, the study analyzed individual nitrogen fertilization systems (fertilization combinations) in the cultivation of two different types of maize varieties (traditional, stay-green) differing in the nitrogen remobilization coefficient, which is an indicator of the yielding capacity of a given variety. The combination of these two experimental factors, i.e., fertilization with the type of maize hybrid, will be the answer to the assessment of nitrogen yield efficiency in different nutrient management systems of two types of maize varieties. Maize growth and development and its yield are significantly affected by environmental conditions, and the ratio of individual growth factors should be harmonious, although different for individual cultivars. Any disturbances in the system of environmental factors result in disruption of the balance in plant life functions, thereby becoming a cause of stress. Maize yields are limited by a range of abiotic and biotic factors. Therefore, the production may not achieve the aims without introduction of technological solutions required by new cultivars. Plant yielding potential is usually assessed by comparison of cultivars grown with employment of up-to-date agronomic methods which eliminate also biotic stresses (diseases, pests, weed infestation). In such assessments, positive interactions between a given hybrid and agronomic conditions are especially valued. In real terms, the correlation between genetic and agronomic progress is an important factor in influencing plant yielding potential and cannot be attributed to neither breeding (cultivar) nor agronomy. Hence, experimental research—field experiments, aimed at assessment of cultivars depending on their type—are highly important.

Hence, the aim of the conducted field research was to determine the responses of two types of maize varieties (*Zea mays* L.) to various nutrient management systems, expressed as: (i) growth analysis of organs active during photosynthesis, (ii) SPAD leaf greenness index, (iii) green mass productivity, and (iv) unit nitrogen productivity from mineral fertilization.

2. Materials and Methods

2.1. Field Experiments

Field experiments were carried out at the Department of Agronomy of the Poznań University of Life Sciences, in the fields of the Research Institute in Swadzim (52°26′20″ N, 16°44′58″ E) in the years (Y) from 2009 to 2011. The study was conducted using a split-plot design with two experimental factors and four field replicates. Nine fertilizer combinations (no fertilization—control plot, NPK, N, NMg, NS, NK, NP, NPKMgS, and NMgS) constituted the first factor (A), while two types of maize varieties (ES Paroli (FAO 250)—the "stay-green" SG type and ES Palazzo (FAO 230-240)) were the second factor (B). The size of the plots was 30.8 m^2 (width—2.8 m, length—11.0 m); the harvest was collected from 15.4 m^2 after discarding two external rows considered outer seeding. Nitrogen at a dose of 120 kg N ha^{-1} was used in the form of ammonium nitrate and ammonium sulfate; phosphorus was applied in the form of granular triple superphosphate 46% P_2O_5 (at a dose of 30.8 kg P ha^{-1}), potassium in the form of potash salt 60% K_2O (at a dose of 107.9 kg K ha^{-1}), magnesium in the form of magnesium lime 15% MgO (at a dose of 15 kg Mg ha^{-1}), and sulfur in the form of ammonium sulfate (at a dose of 20 kg S ha^{-1}). Sulfur in the NS combination was applied as ammonium sulfate. All fertilizers were applied before sowing. Maize was sown with the use of a seeding machine equipped with a seed drill (row spacing—0.75 m). The varieties included in the experiment were derived from EURALIS Semences Breeding and Seed Production. The variety ES Palazzo (single hybrid, flint grain type, application—grain and silage, effective sum of temperature—1600 °C). The variety ES Paroli "stay-green" (single hybrid, flint-dent grain type, application—grain and silage, effective sum of temperature—1665 °C).

2.2. Soil Conditions

The soil with acidic pH (5.1–5.4) had a low content of available phosphorus, potassium, and magnesium. The properties of the soil are listed in Table 1 [18]. The morphological structure of the experimental field was typical of the bottom moraine of the North Polish (Baltic) glaciation, the Poznań stadium. Soil parental materials were clay or sandy-loam formations. Area configuration showed little diversification; the dominant terrain was flat and little undulating. Typologically, the test field soils belonged to the black earth type, a subtype of cambic black-earth that belonged to the order of black earth. According to the international WRB classification, these soils were assigned as Phaeozemes, and as Mollisols according to the US Soil Taxonomy. The test field was classified as IIIb, according to the soil valuation class. Black earths include soils with direct impact of groundwater or heavy rainfall covering the lower and part of the middle soil profile. Rainfall and water management is dominant in the surface horizon, and it can be modified to some degree by altering the water properties of the deeper parts of the soil profile.

Table 1. Soil fertility indicators (available content in soil) before the experimental setup [21].

Indicators		Years		
		2009	**2010**	**2011**
Phosphorus mg P kg^{-1}		66.7	40.5	37.8
Potassium mg K kg^{-1}		87.9	130.3	165.2
Magnesium mg Mg kg^{-1}		60.0	35.0	55.0
pH in 1 mol dm^{-3} KCl		5.2	5.4	5.1
N_{min} (kg ha^{-1}) in soil, layer 0–60 cm		68.5	79.2	71.4
C, org. %		1.01	0.99	0.99
Texture %	sand 2–0.05 mm	83	83	83
	silt 0.05–0.02 mm	6	6	6
	silt 0.02–0.002 mm	7	7	4
	clay <0.002 mm	4	4	4
	textural group	loamy sand	loamy sand	loamy sand

Soil science determinations:

- Content of available forms of phosphorus and potassium by the Egner-Riehm method,
- Assimilable magnesium by Schachtschabel method using Spectra AA 220 and FS atomic absorption spectrometry,
- Mineral nitrogen by the Kjeldahl method,
- Organic carbon with the Vario-Max autoanalyser, (percentage humus = %C × 1.724),
- Granulation using the Casagrande areometric method,
- pH using a radiometer pH meter.

2.3. Thermal and Humidity Conditions

The climatic dates refer to the three growing seasons of maize (2009–2011). The total atmospheric precipitation and average daily air temperature in consecutive study years are listed in Table 2. The years during which the field experiments were conducted varied significantly in temperature and humidity. The lowest rainfall was recorded in 2011 (424.2 mm), and the highest in 2010 (500.7 mm). The average daily air temperature, measured at 2 m height, fluctuated between 14.5 °C (2010) and 15.9 °C (2011).

Table 2. Air temperature and precipitation in vegetation seasons in Swadzim.

Years	Temperature in [°C]							
	IV	V	VI	VII	VIII	IX	X	Mean-Sum
2009	12.9	14.0	16.0	20.3	20.1	15.8	7.6	15.2
2010	9.3	12.2	18.4	22.6	19.2	13.0	7.0	14.5
2011	12.4	15.5	19.9	18.5	19.5	15.9	9.8	15.9
Years	Precipitation in [mm]							
2009	19.2	109.9	113.8	75.4	26.2	48.6	59.2	452.3
2010	26.8	110.5	43.4	97.5	143.5	69.9	9.1	500.7
2011	9.8	22.5	66.5	218.7	50.5	28.5	27.7	424.2

2.4. Biometric Measurements

Samples for analysis were collected each year at the cob flowering stage (BBCH 67). Each experimental plot consisted of four rows. Samples for analysis were taken from two middle rows of each plot, treating the outer rows as the so-called sowings (isolation).

The assimilation surface area of a single plant was calculated on the basis of the formula given in the work of Borowiecki and Filipiak [22]:

$$AS = -3.550 + 3.774 \cdot x,$$

where:

AS—assimilation surface area of a single plant,
x—sum of the surface areas of the fifth and sixth leaf.

The surface area of the 5th and 6th leaf was determined using Montgomery's (quoted after Borowiecki and Filipiak [22]): leaf length along the main nerve multiplied by the width determined in the widest place and the result multiplied by 0.75 coefficient.

$$SLA = LA/LW$$

where:

SLA—specific leaf area ($cm^2 \cdot g^{-1}$),
LA—leaf area (cm^2),
LW—leaf blade weight (g).

$$LAI = (LA \times LR)/10{,}000$$

where:

LAI—leaf area index,
LA—leaf area of a single plant (cm^2),
LR—plant density per 1 m^2 (plants$\cdot m^{-2}$).

2.5. SPAD Index

For the indirect method of determining nutritional status of maize plants, an optical device was applied, known in Europe as Hydro N-Tester, and as SPAD-502 in the USA [23–26]. In this study, these measurements were performed in the BBCH 15/16 (5–6 leaf stage) and BBCH 67 phases (beginning of pollination). In the BBCH 15/16 phase, the measurement was performed on the 5th leaf, while in the BBCH 67 phase, on the leaf near the ears.

2.6. Partial Factor Productivity of Fertilizer Nitrogen (PFPFN)

$$PFPFN = P/Nr, (kg\ f \cdot m \cdot kg\ N)$$

where:

P—Fresh mass yield (kg·ha^{-1}),

N_r—Nitrogen dose (kg N·ha^{-1}),

2.7. Fresh Mass Yield

Weight measurements of the whole plants were carried out during maize harvest for silage (black spot at the base of the kernel). On this basis, the yield of green mass of whole plants was determined (stem + leaves + ear). For this purpose, plants from 2 m^2 were cut out from each experimental plot, and this yield was subsequently converted into the green mass yield (t·ha^{-1}). The silage maize was harvested during the period of obtaining black spots at the base of the kernel. This is the optimal time for harvesting this crop for silage. When adding maize varieties with the same FAO, the dry matter content in the silage material is 38% (regardless of the tested experiment factors).

2.8. Statistical Analysis

Statistical analyses, such as analysis of variance (ANOVA) and the Tukey HSD (honestly significant difference) test for pairwise comparisons of means, were conducted separately during the years of the study and in 2009–2011, according to the experimental data models designed as a split-plot experiment [27,28]. All calculations were performed using *Statistica* 13 (2017) and MS Excel. Statistical significance was set at p-value < 0.05.

3. Results

3.1. Number of Leaves, Mass of Leaves, Mass of Stems, and Mass of Ears on a Single Plant

The results in Table 3 show that, irrespective of the experimental factors (A and B), significantly, the highest mean number of leaves per plant (11.3), the highest mean of the mass of leaves on a single plant (116 g), and the highest mean mass of stems per single plant (393 g) were obtained in 2009. In the remaining years (2010–2011) these values were significantly lower and did not differ significantly between those two years. On the other hand, the mean mass of ears on a single plant varied by year (Table 3). Significantly, the highest mean mass was obtained in 2011 (268 g) and the lowest in 2010 (187 g).

Over the study years, the results also indicate the significant impact of N fertilizer combinations (A) on the considered traits of maize (Table 3). The highest (compared with the A1 control) number of leaves per plant was obtained using NPK (A2) or NPKMgS (A9) fertilizer combinations. The difference between the two mean leaf numbers for these combinations (10.9 and 10.7) is insignificant. However, there was also no significant change in the number of leaves compared with the other fertilizer combinations (A3–A8). Moreover, it was noted that application of only nitrogen (A3) or of a combination of nitrogen with magnesium (A4), sulfur (A5), phosphorus (A6), potassium (A7), or magnesium and sulfur (A8) did not significantly increase the number of leaves per plant compared with the control (A1). Per hectare (Table 3), the largest number of leaves was obtained for the NPK fertilizer combination (A2) compared with the NS (A5) combination or with the control (A1). Additionally, the NMg (A4) combination significantly increased the number of leaves per ha compared with the control. It should be noted, however, that for each of the fertilizer combinations considered here (except for the NS-A5 combination), similar numbers of leaves per ha were obtained (the differences between the means are insignificant). Furthermore, it can be seen (Table 3) that the real mean mass of leaves on a single plant increased significantly after the application of any fertilizer combination compared with the control (A1). Although the NPK (A2) combination gave the highest mean leaf mass per single plant, the differences between this and the other means are insignificant. A similar conclusion can be drawn with regard to the mass of stems on a single plant (Table 3). A difference relates to the NS (A5) and NP (A6) fertilizer combinations, where the real means of stem mass per plant for both combinations do not differ significantly from the control (A1). Significantly, the highest mean mass of ears per single plant was obtained using the NP fertilizer combination (A6). It differs significantly from the control mean (A1), but the differences between this mean and the means for the remaining fertilizer combinations are insignificant (Table 3).

Table 3. Mean values of the considered traits for the years (Y) and for the agrotechnical factors: fertilizer combinations (A) and maize varieties (B).

The Levels of Factors	Number of Leaves on Single Plant (pcs.)	Number of Leaves on 1 m^2 (pcs.)	Mass of Leaves on Single Plant (g)	Mass of Stems on Single Plant (g)	Mass of Ears on Single Plant (g)
2009	11.3 *a* (0.05)	79.3 (0.48)	116 *a* (1.83)	393 *a* (6.32)	234 *b* (5.03)
2010	10.3 *b* (0.05)	77.7 (0.44)	101 *ab* (1.53)	293 *b* (5.69)	187 *c* (5.12)
2011	10.2 *b* (0.10)	78.7 (0.73)	97 *b* (2.31)	321 *b* (7.17)	268 *a* (6.14)
control	10.2 *b* (0.19)	75.4 *c* (1.06)	92 *b* (3.34)	293 *b* (11.52)	200 *b* (9.12)
NPK	10.9 *a* (0.13)	81.4 *a* (0.78)	112 *a* (2.94)	367 *a* (11.46)	237 *ab* (10.30)
N	10.6 *ab* (0.13)	78.8 *abc* (0.93)	104 *a* (3.25)	337 *a* (14.22)	231 *ab* (11.73)
NMg	10.7 *ab* (0.14)	79.4 *ab* (0.68)	105 *a* (3.62)	344 *a* (14.84)	227 *ab* (10.12)
NS	10.6 *ab* (0.19)	77.2 *bc* (1.20)	103 *a* (4.20)	327 *ab* (13.85)	218 *ab* (12.45)
NP	10.5 *ab* (0.14)	78.3 *abc* (1.04)	106 *a* (3.80)	328 *ab* (13.95)	251 *a* (12.39)
NK	10.6 *ab* (0.12)	78.5 *abc* (0.80)	107 *a* (3.15)	351 *a* (12.59)	234 *ab* (12.25)
NMgS	10.6 *ab* (0.16)	79.1 *abc* (1.03)	106 *a* (4.41)	334 *a* (16.01)	232 *ab* (13.31)
NPKMgS	10.7 *a* (0.13)	78.8 *abc* (0.92)	106 *a* (3.90)	342 *a* (14.64)	238 *ab* (11.11)
ES Palazzo	10.8 *a* (0.06)	77.6 *b* (0.44)	101 *b* (1.45)	325 *b* (6.88)	217 *b* (4.95)
ES Paroli	10.5 *b* (0.08)	79.5 *a* (0.47)	108 *a* (1.98)	346 *a* (6.22)	243 *a* (5.69)

Values in columns marked with at least the same letter do not differ significantly ($\alpha = 0.05$). Standard errors are in brackets.

Over the study years, the results also indicate the significant impact of variety (B) on the considered traits of maize (Table 3). Analyzing the number of leaves per single plant, the mean number of leaves for the variety ES Palazzo (B1) was significantly higher than for ES Paroli (B2). This is in contrast to all of the remaining traits (Table 3), for which significantly higher mean values were obtained by the variety ES Paroli (B2).

The analysis of variance showed significant interactions of N fertilizer combination (factor A) with year of research (Y), but only for the mass of leaves and the mass of stems on a single plant. It can be shown that significantly higher mean values of both traits were achieved in 2009 compared with the years 2010–2011. The applied N fertilizer combinations had an equal effect on both traits. The mean values were greater than the control (A1). In the remaining years, the means were significantly smaller and similar to each other. Significant interaction was also obtained between variety (factor B) and year (Y) for all traits considered here (Table 4). The highest number of leaves per plant for both varieties was observed in 2009, and the two mean values did not differ significantly. However, they differed from the mean number of leaves per plant for both varieties in the remaining years. The smallest number of leaves per single plant was recorded for the variety ES Paroli (B2) in 2011 (Table 4). The highest number of leaves was observed (Table 4) on the variety ES Paroli (B2) in 2009 and 2010, and on ES Palazzo (B1) in 2011. Examining the mass of leaves on a single plant (Table 4), the highest mean mass was recorded for variety B2, significantly different from the mean mass of leaves for variety B1 in 2009. In the remaining years of the study, the mean leaf masses per plant were significantly lower in both varieties. The results in Table 4 also indicate that the largest mass of stems on a single plant was obtained for both varieties in 2009, with the two mean values not being significantly different. The lowest values of mean stem mass per plant were observed for both varieties in 2010, and for the variety ES Palazzo (B1) in 2011. In turn, the largest mass of ears on a single plant was recorded on variety ES Paroli (B2) in 2011 (Table 4). In the remaining years, the means of the mass of ears on a single plant were significantly lower. The lowest values of the mean mass, similar for both varieties, were obtained in 2010. No significant interaction was obtained between N fertilizer combination (factor A) and variety of maize (factor B), in each year or over years (Y), with respect to the considered traits.

Table 4. Mean values for the combinations the years (Y) and maize varieties (B).

Y	B	Number of Leaves on Single Plant (pcs.)	Number of Leaves on 1 m^{-2} (pcs.)	Mass of Leaves on Single Plant (g)	Mass of Stems on Single Plant (g)	Mass of Ears on Single Plant (g)
2009	ES Palazzo	11.3 *a* (0.07)	77.5 *bc* (0.62)	109 *b* (2.19)	394 *a* (9.32)	218 *c* (6.44)
	ES Paroli	11.2 *a* (0.08)	81.1 *a* (0.62)	123 *a* (2.44)	392 *a* (8.65)	250 *b* (6.82)
2010	ES Palazzo	10.4 *b* (0.05)	76.4 *c* (0.57)	98 *c* (1.86)	284 *c* (7.03)	183 *d* (6.59)
	ES Paroli	10.3 *b* (0.07)	79.0 *ab* (0.61)	104 *bc* (2.34)	301 *c* (8.82)	192 *d* (7.84)
2011	ES Palazzo	10.5 *b* (0.12)	78.9 *abc* (0.98)	97 *c* (2.91)	298 *c* (9.62)	250 *b* (8.65)
	ES Paroli	9.9 *c* (0.14)	78.5 *bc* (1.09)	96 *c* (3.62)	345 *b* (9.18)	287 *a* (7.70)

Values in columns marked with at least the same letter do not differ significantly ($\alpha = 0.05$). Standard errors are in brackets.

3.2. Assimilation Area of a Single Plant, LAI (Leaf Area Index), SLA (Specific Leaf Area)

The results in Table 5 indicate that variable climatic conditions in the years of the study significantly influenced the above-mentioned traits. The highest means of assimilation area per single plant, LAI and SLA were obtained in 2011 (respectively: 4280 (cm^2), 3.30, 45.7 (cm^2g^{-1})). In 2009–2010, the means for these features were significantly lower, and the differences between these years were statistically insignificant, except in the case of SLA. The mean specific leaf area was the lowest in 2009. Over the study years, the results in Table 5 also indicate the significant impact of N fertilizer combinations (A), but only on the assimilation area of a single plant and LAI. The fertilizer combinations used (A2–A9) did not significantly differentiate the means of assimilation area of a single plant and LAI. Only for the two combinations NPK (A2) and NK (A7) do the obtained mean values differ significantly from the mean for the control (A1). Over the study years, the results also indicate the significant impact of variety (B) on the considered traits of maize (Table 5). Regarding the mean values of the assimilation area of a single plant, LAI and SLA are significantly higher for the variety ES Paroli (B2) than for ES Palazzo (B1). No significant interaction was found between the year of research (Y) and type of N fertilizer combination

(A). There is a significant interaction between the year of research (Y) and variety (B) for the considered traits (Table 6). In each year of the study, the B2 variety had higher mean values than the B1 variety. The means of the two varieties did not differ significantly only for the SLA trait in 2009–2010. For each of these three traits, the highest mean values were obtained by variety B2 in 2011. A significant interaction was also found between type of N fertilizer combination (A) and variety (B), but only for SLA (Figure 1). Significant differences between the means of the SLA occurred only between the configurations A1B1 and A1B2 and between A5B1 and A5B2. In both cases, the B2 variety has a significantly higher mean than the B1 variety. Moreover, the mean SLA values for variety B1 with combinations A1–A9 do not differ significantly. Hence, this variety reacted in the same way to all fertilizer combinations from A1 to A9, differently than the B2 variety (Figure 1).

Table 5. Mean values of the considered traits for the years (Y) and for the agrotechnical factors: fertilizer combinations (A) and maize varieties (B).

The Levels of Factors	Assimilation Area of a Single Plant (cm^2)	LAI—Leaf Area Index	SLA—Specific Leaf Area (cm^2·g^{-1})	SPAD—BBCH 15/16	SPAD—BBCH 67
2009	3396 *b* (42.23)	2.40 *b* (0.04)	29.5 *c* (0.40)	468.7 *a* (4.73)	740.6 *b* (12.61)
2010	3693 *b* (38.51)	2.78 *b* (0.04)	37.0 *b* (0.49)	368.8 *b* (4.00)	737.6 *b* (6.02)
2011	4280 *a* (56.11)	3.30 *a* (0.05)	45.7 *a* (1.06)	453.5 *a* (5.22)	830.7 *a* (2.58)
control	3607 *b* (140.18)	2.68 *b* (0.12)	40.1 (2.23)	427.3 *ab* (10.39)	768.3 *ab* (8.95)
NPK	3911 *a* (95.87)	2.93 *a* (0.10)	35.6 (1.34)	448.0 *a* (13.55)	769.9 *ab* (13.00)
N	3786 *ab* (105.10)	2.84 *ab* (0.09)	37.0 (1.25)	423.8 *ab* (12.74)	789.0 *a* (10.60)
NMg	3774 *ab* (109.98)	2.82 *ab* (0.10)	37.1 (1.80)	420.0 *ab* (11.38)	732.1 *b* (35.93)
NS	3830 *ab* (106.67)	2.83 *ab* (0.10)	39.5 (2.61)	425.4 *ab* (12.18)	790.0 *a* (11.76)
NP	3775 *ab* (101.71)	2.82 *ab* (0.10)	37.1 (1.97)	447.0 *a* (11.07)	790.7 *a* (9.96)
NK	3873 *a* (116.66)	2.89 *a* (0.11)	36.8 (1.56)	422.7 *ab* (11.43)	780.3 *ab* (10.76)
NMgS	3760 *ab* (103.55)	2.82 *ab* (0.10)	36.9 (1.76)	414.8 *b* (13.89)	772.6 *ab* (11.61)
NPKMgS	3790 *ab* (107.79)	2.79 *ab* (0.10)	36.7 (1.65)	444.0 *ab* (11.50)	733.6 *b* (16.79)
ES Palazzo	3610 *b* (52.33)	2.62 *b* (0.05)	36.3 *b* (0.71)	419.2 *b* (5.41)	757.1 *b* (9.34)
ES Paroli	3970 *a* (44.89)	3.03 *a* (0.04)	38.5 *a* (0.99)	441.4 *a* (5.80)	782.1 *a* (5.82)

Values in columns marked with at least the same letter do not differ significantly ($\alpha = 0.05$). Standard errors are in brackets.

Table 6. Mean values for the combinations the years (Y) and maize varieties (B).

Y	B	Assimilation Area of a Single Plant (cm^2)	LAI—Leaf Area Index	SLA—Specific Leaf Area ($cm^2 \cdot g^{-1}$)	SPAD—BBCH 15/16	SPAD—BBCH 67
2009	ES Palazzo	3212 *f* (54.12)	2.20 *e* (0.04)	29.7 *d* (0.58)	444.9 *b* (6.00)	734.6 (23.10)
	ES Paroli	3579 *d* (48.83)	2.60 *d* (0.04)	29.3 *d* (0.56)	492.5 *a* (4.75)	746.6 (10.43)
2010	ES Palazzo	3447 *e* (28.84)	2.52 *d* (0.02)	35.6 *c* (0.61)	359.3 *d* (5.05)	714.4 (8.19)
	ES Paroli	3938 *c* (41.70)	3.03 *c* (0.03)	38.4 *c* (0.71)	378.3 *c* (5.85)	760.8 (7.02)
2011	ES Palazzo	4169 *b* (84.59)	3.13 *b* (0.07)	43.6 *b* (1.04)	453.4 *b* (7.20)	822.3 (3.40)
	ES Paroli	4390 *a* (70.13)	3.47 *a* (0.06)	47.8 *a* (1.79)	453.6 *b* (7.68)	839.0 (3.37)

Values in columns marked with at least the same letter do not differ significantly (α = 0.05). Standard errors are in brackets.

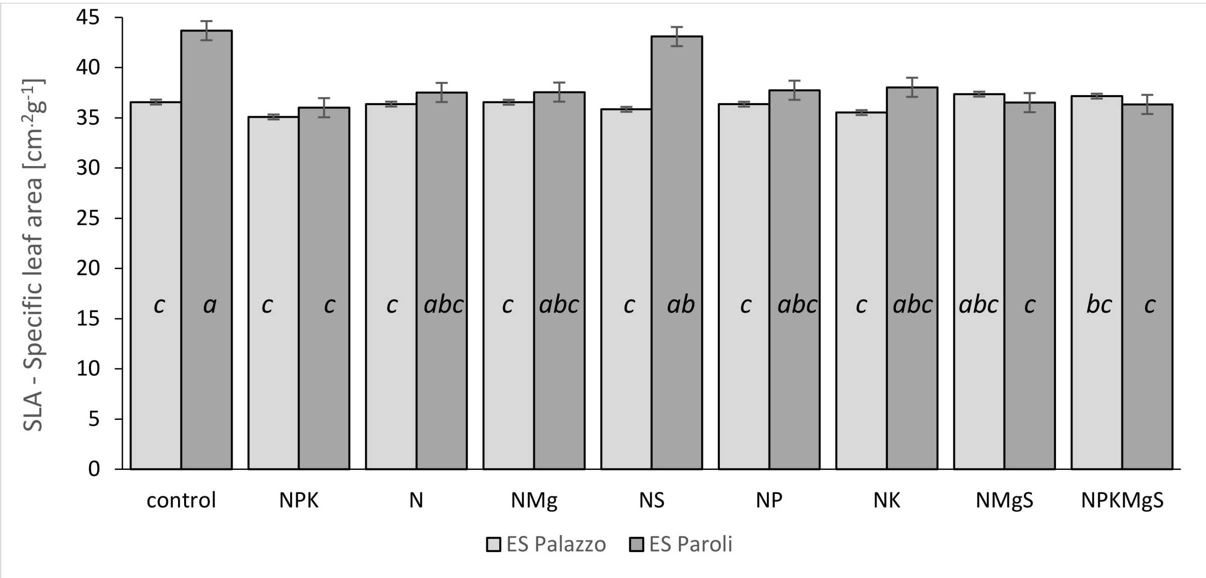

Figure 1. Mean values from 2009–2011 of SLA—Specific leaf area ($cm^2 \cdot g^{-1}$) for the combinations between the fertilizer combinations and maize varieties; *a*, *b*, *c*—homogeneous groups ($p \leq 0.05$). Error bars indicate 95% confidence intervals of the means.

3.3. Leaf Greenness Index (SPAD)

At the plant growth stage BBCH 15/16 and during the flowering stage (BBCH 67), the greenness index (SPAD) depends mainly on the year of research, on the type of N fertilizer combination (A)—within years and regardless of the year of research—and on the maize variety (B) and some interactions between factor A and year (Y). The results in Table 5 indicate that the year of the study influenced SPAD at both stages. At the BBCH 15/16 stage, the highest mean values of SPAD were obtained in 2009 (468.7) and 2011 (453.5). These two means are not significantly different. The SPAD value at that growth stage was significantly lower in 2010. In turn, at the BBCH 67 stage, the highest mean SPAD was recorded in 2011 only (830.7). In the remaining years, the mean values of SPAD were lower and there were no significant differences between them. Regardless of the study year and the variety (factor B), at the stage BBCH 15/16, the highest mean values of the SPAD index were recorded for plants fertilized with an NPK combination (A2) or NP combination (A6).

The obtained means for these combinations do not differ significantly from each other or from most other means. There was a significant difference between each of these means and the mean for the NMgS combination (A8) (Table 5). In turn, at BBCH 67 (Table 5), the mean index of leaf greenness did not differ significantly between fertilizer combinations, except for the two combinations NMg (A4) and NPKMgS (A9). For both of these, the means of the SPAD index were significantly lower than for the combinations N (A3), NS (A5) and NP (A6), for which the mean SPAD value was the highest. Considering only factor B, regardless of the year of research and the first factor A (Table 5), it was noted that both at the plant growth stage BBCH 15/16 and during the flowering stage (BBCH 67), the greenness index (SPAD) was significantly higher for the ES Paroli (B2) variety than for the ES Palazzo (B1) variety. The analysis of variance showed significant interactions of fertilizer combination (factor A) with the year of research (Y) for the SPAD index at both plant growth stages. At BBCH 15/16, the lowest SPAD index was recorded in 2010 (regardless of the fertilizer combination), and the highest in 2009 (regardless of the fertilizer combination). In the year 2011, the value of the index was variable depending on the fertilizer combination. In turn, at BBCH 67, the lowest SPAD index was recorded in 2010 (regardless of the fertilizer combination), and the highest in 2011 (regardless of the fertilizer combination). In 2009, the value of the index was variable depending on the fertilizer combination. A significant interaction was found (Table 6) between the year of research and variety (B), but at the BBCH 15/16 stage only. Significantly, the highest mean SPAD index was observed for the variety ES Paroli (B2) in 2009; the lowest mean SPAD indices for both varieties were recorded in 2010, where the SPAD index for variety B1 was clearly the lowest. A significant interaction was also found between fertilizer combination (A) and variety (B) at both plant growth stages (Figures 2 and 3). At BBCH 15/16, it can be seen (Figure 2) that the mean SPAD index for the ES Paroli (B2) variety is slightly higher than for the B1 variety for the different fertilizer combinations (the differences are insignificant). Only for the NPKMgS (A9) combination, a significant difference was observed between the mean SPAD indices for the varieties, with a higher mean for the variety B2. It was also found that the mean SPAD index for the variety B2 with the A9 fertilizer combination does not differ significantly from the means for this variety with the NPK (A2), N (A3), NS (A5), NP (A6), and NMgS (A8) fertilizer combinations. On the other hand, at BBCH 67, it can be seen (Figure 3) that a significant difference between the mean SPAD indices for both varieties occurred only for the fertilizer combination NMg (A4). The variety ES Paroli (B2) obtained a higher leaf greenness index than variety B1. It was also found that the value of this index for variety B1 with the fertilizer combination NMg (A4) was the lowest compared with the other fertilizer combinations and the control (A1).

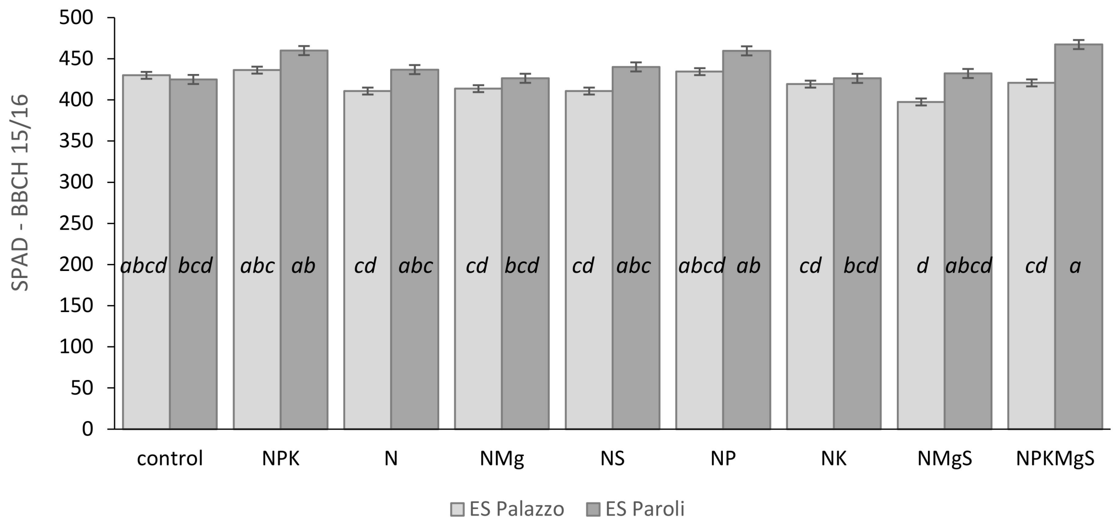

Figure 2. Mean values from 2009 to 2011 of SPAD—BBCH 15/16 for the combinations between the fertilizer combinations and maize varieties; *a*, *b*, *c*, *d*—homogeneous groups ($p \leq 0.05$). Error bars indicate 95% confidence intervals of the means.

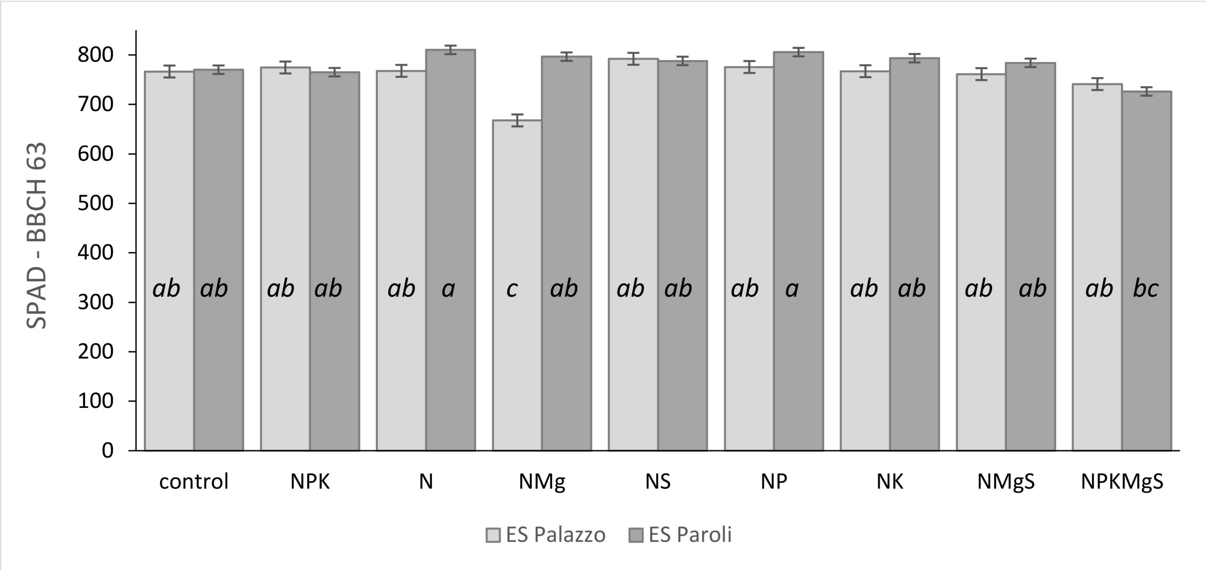

Figure 3. Mean values from 2009 to 2011 of SPAD—BBCH 63 for the combinations between the fertilizer combinations and maize varieties; *a*, *b*, *c*—homogeneous groups ($p \leq 0.05$). Error bars indicate 95% confidence intervals of the means.

3.4. Fresh Mass of a Single Plant, Fresh Mass Yield, PFPFN (Partial Factor Productivity of Fertilizer Nitrogen)

The results in Table 7 indicate that variable climatic conditions in the years of the study significantly influenced the above-mentioned traits. Irrespective of the experimental factors (A and B), in 2009 and 2011, the highest means of the fresh mass of a single plant, fresh mass yield, and PFPFN were obtained. In 2010, the mean values of these features were significantly lower, equal to 581 g, 43.7 t·ha^{-1} and 364.3 kg f·m·kg^{-1} N, respectively.

Over the study years, the results in Table 7 also indicate the significant impact of N fertilizer combinations (A) on the above-mentioned traits. The use of any fertilizer combination in the experiment resulted in a significant increase in the mean values of the fresh mass of a single plant, fresh mass yield, and PFPFN in relation to the control (A1). Differences in the mean values of the traits between these fertilizer combinations are negligible. A slight decrease in the mean values of these features occurred with the combination NS (A5), when similar values were obtained as with the control (A1). Considering only factor B, regardless of the year of research and the first factor A (Table 7), it was noted that significantly higher means for each of these traits were obtained for variety B2. These are: for the fresh mass of a single plant 697 g, for the fresh mass yield 53.1 t·ha^{-1}, and for PFPFN 442.4 kg f·m·kg^{-1} N. The analysis of variance showed significant interaction between the fertilizer combination (factor A) and year of research (Y), but only for the fresh mass of a single plant. Significantly higher mean values of that trait were achieved in 2009 and 2011 for all N fertilizer combinations than for the control (A1). In 2010, the means of the fresh mass of a single plant for the fertilizer combinations (A2–A9) were the lowest and did not differ from the mean for the control (A1). A significant interaction was also obtained (Table 8) between variety (factor B) and year (Y) for all of the traits considered here. In 2009 and 2011, the mean fresh mass per plant was significantly higher for variety B2. It may also be noted that the mean of the fresh mass per plant for this variety did not differ significantly between 2009 and 2011. For the variety B1, the means of the fresh mass per plant differed significantly between these years, the mean in 2011 being significantly lower. In 2010, the means of the fresh mass per plant of both varieties were the lowest and did not differ from each other. The results in Table 8 also indicate that in the years of the study, the varieties had significantly different green mass yields, the B2 variety obtaining a significantly higher average yield in each year than the B1 variety. It should be noted that both varieties reacted in a similar way to changing climatic conditions in 2009 and 2011 (the average yields of each variety were similar in these years). In 2010, both varieties had significantly lower yields than in 2009 and 2011; additionally, variety B1 obtained the lowest mean fresh mass yield in these three years. Similar results (Table 8) as for the fresh mass yield were obtained in relation to the partial factor productivity of fertilizer nitrogen (PFPFN).

Table 7. Mean values of the considered traits for the years (Y) and for the agrotechnical factors: fertilizer combinations (A) and maize varieties (B).

The Levels of Factors	Fresh Mass of a Single Plant (g)	Yield Fresh Mass (t·ha^{-1})	PFPFN Partial Factor Productivity of Fertilizer Nitrogen (kg f·m·kg^{-1} N)
2009	743 *a* (10.58)	52.4 *a* (0.84)	436.9 *a* (6.97)
2010	581 *b* (9.63)	43.7 *b* (0.77)	364.3 *b* (6.42)
2011	686 *a* (13.60)	53.0 *a* (1.15)	441.8 *a* (9.57)
control	586 *b* (19.97)	43.4 *b* (1.66)	361.4 *b* (13.81)
NPK	716 *a* (17.38)	53.4 *a* (1.42)	444.7 *a* (11.83)
N	672 *a* (24.53)	50.1 *a* (1.87)	417.7 *a* (15.54)
NMg	675 *a* (23.47)	50.2 *a* (1.67)	418.4 *a* (13.92)
NS	648 *ab* (25.56)	47.5 *ab* (1.95)	395.9 *ab* (16.27)
NP	684 *a* (24.38)	50.9 *a* (1.88)	424.0 *a* (15.63)
NK	693 *a* (22.18)	51.3 *a* (1.79)	427.7 *a* (14.90)
NMgS	672 *a* (28.75)	50.1 *a* (2.11)	417.1 *a* (17.59)
NPKMgS	687 *a* (22.15)	50.6 *a* (1.57)	421.9 *a* (13.08)
ES Palazzo	644 *b* (10.67)	46.4 *b* (0.75)	386.3 *b* (6.23)
ES Paroli	697 *a* (11.40)	53.1 *a* (0.85)	442.4 *a* (7.08)

Values in columns marked with at least the same letter do not differ significantly ($\alpha = 0.05$). Standard errors are in brackets.

Table 8. Mean values for the combinations the years (Y) and maize varieties (B).

Y	B	Fresh Mass of a Single Plant (g)	Yield Fresh Mass (t·ha^{-1})	PFPFN Partial Factor Productivity of Fertilizer Nitrogen (kg f·m·kg^{-1} N)
2009	ES Palazzo	721 *b* (14.27)	49.3 *b* (1.06)	410.8 *b* (8.83)
	ES Paroli	765 *a* (14.61)	55.6 *a* (1.07)	463.0 *a* (8.94)
2010	ES Palazzo	565 *d* (11.40)	41.3 *c* (0.84)	344.1 *c* (6.97)
	ES Paroli	597 *d* (15.21)	46.1 *b* (1.17)	384.5 *b* (9.76)
2011	ES Palazzo	645 *c* (18.75)	48.5 *b* (1.48)	403.9 *b* (12.36)
	ES Paroli	728 *ab* (17.36)	57.6 *a* (1.40)	479.7 *a* (11.70)

Values in columns marked with at least the same letter do not differ significantly (α = 0.05). Standard errors are in brackets.

4. Discussion

The leaf assimilation area of the plant and the number of leaves are important elements in assessing the intensity of photosynthesis [29,30]. Pandey et al. [31] found that individual maize genotypes (varieties) differ in the number of developed leaves, growth rate, and biomass production under conditions of different water and nitrogen doses. The rate of leaf blade aging is also very important in the assessment of photosynthesis [32,33]. According to these authors, aging of the canopy is often used by breeders as an indicator of the phenological and physiological state of the crop after flowering, because this feature significantly correlates with grain physiological maturity.

In the present study, the number of formed leaf blades on a single maize plant depended on the fertilizer combination and maize hybrid. Significantly fewer leaf blades were found on the control object (10.23), while maize in the NPK and NPKMgS fertilizer combinations developed the highest number of leaf blades (10.94 and 10.74, respectively). The results of the present study were consistent with a previous report of Addai and Alimiyawo [34]. They noted a significant increase in leaf number and area (LAI), as well as grain yield of sorghum on the objects with mineral fertilization compared to the control object. The data indicated that the LAI was highly positively correlated with tassel length and leaf number. The relationship between the LAI and 100 seed weight and grain yield was also significant but negative. Considering the influence of the variety on the value of the studied trait, it was found that the "stay-green" variety was characterized by a significantly lower number of formed leaf blades on a single plant compared to the traditional variety. The difference between the examined types of varieties was 0.31 pcs. Subedi and Ma [35] demonstrated a different effect of the type of maize hybrid on the number of developed leaf blades. According to these authors, hybrids of the "stay-green" type had a higher number of leaf blades per plant and a total area compared to conventional varieties. Andrews et al. [36] and Costa et al. [37] reported that due to the heavier (larger) foliage and higher production of vegetative biomass, the nitrogen demand of "stay-green" varieties was higher than that of traditional counterparts. Various methods are used to assess the plant assimilation area [23,30]. The present study used a method described by Borowiecki and Filipiak [22]. Determining the maize leaf area using this method is very easy to perform, as it only requires measuring the area of two leaf blades. The assimilation area of a single maize plant is large. According to Szulc [38], one hectare of maize (*Zea mays* L.) cultivation may contain about 4.5 ha of leaves. The LAI characterizes the surface area of plant organs capable of absorbing radiation, on which photosynthesis depends, and thus indirectly also biomass increments as well as vegetative and generative yield, i.e., grain [30,39]. Novelli et al. [40] found that the LAI was the main gas exchange surface between the atmosphere and biosphere. The optimal value of this index for the maximum maize production ranges from 3 to 5. At such a plant density, the growth rate is maximal, because all leaf blades are involved in the process of photosynthesis (they are illuminated). The higher the LAI, the greater the use of solar energy [41,42]. In turn, Paponov et al. [43] reported that the value of this index was strictly positively correlated with the grain number and their weight at the BBCH 71–79 stage.

Modern maize varieties have a longer growth period, a larger leaf area, and a slower aging rate of the leaf blades, leading to a significant increase in the dry matter accumulation index. Hence, the accumulation of dry matter is closely related to leaf senescence [16]. This also explains the greater yield of the "stay-green" variety compared to the classic variety. In addition, the productivity of maize depends on chloroplast pigment contents in the leaf blades. The chlorophyll content in the ear flowering phase (BBCH 67) is strictly dependent on the assimilation area of a single plant, as indicated by the rectilinear relationship between the content of chlorophyll a + b, expressed in SPAD units, and the assimilation area of a single plant, as well as the LAI value [44]. In the current study, the size of a single plant assimilation area and the LAI value significantly depended on fertilizer combination and variety. When considering the fertilizer combination, it was found that the significantly lowest values of these traits were recorded in the control object (3607.17 cm^2; 2.68, respectively), while the highest values were recorded for the NPK fertilizer combination (3910.84 cm^2; 2.93) and for the NK fertilizer combination (3872.96 cm^2; 2.89). Oscar and Tollennar [45] argued that the size of the leaf blade area and the LAI value were higher under increased (balanced) mineral fertilization. This was also confirmed by Pandey et al. [31], who reported that maize cultivations differed in the LAI value at different levels of mineral fertilization. Considering the influence of the varietal factor on the size of the surface absorbing solar rays, it was shown that the "stay-green" hybrid developed a significantly higher value of this feature as compared to the traditional variety. The increased assimilation area under the influence of balanced mineral fertilization, especially of leaves, and extension of its physiological efficiency period, together with an increase in the intensity of photosynthesis per unit area or mass, were shown to elevate the photosynthetic activity of whole plants [33]. Therefore, it informed about greater potential yielding capabilities of "stay-green" varieties compared to traditional ones. This also could explain the possibility of obtaining a higher biomass yield for ensilage compared to traditional varieties [26]. Mueller and Vyn [46] also argued that plant aging in the case of maize was considered a key feature affecting grain yield.

"Stay-green" varieties are potentially capable of incorporating C and N over an extended period of time, which may be beneficial for such traits as grain yield and silage quality [47]. Delayed aging of maize plants can be advantageous for varieties that have a dual cultivation purpose, e.g., grain, silage, and biogas [48]. However, longer leaf viability may adversely affect nutrient re-mobilization from the leaves or stems and reduce nitrogen availability for the seeds, which in turn may have a detrimental effect on yield and grain quality [49]. The leaf growth rate determines the amount of light energy that can be transformed into new mass by the plant. The relationship between the size of the leaf surface and leaf mass indicates the intensity of growth processes of assimilation organs. The basic parameter of the relative leaf thickness, known as the specific leaf area (SLA), expresses their ratio to weight. The present study showed no significant influence of differentiated mineral fertilization on the value of this parameter. There was only a tendency recorded for mineral fertilization (regardless of nutrient combination) to reduce the value of the SLA index compared to control. It was also shown that the "stay-green" variety developed thinner leaf blades compared to the traditional variety. The difference between the studied types of maize varieties was 2.19 $cm^2 \cdot g^{-1}$.

Assimilates can be accumulated in the form of starch in chloroplasts. When the accumulation of starch in chloroplasts exceeds the daily export of sugars from chloroplasts, their export from the leaf blades and leaves becomes the buffer acceptors of assimilates. They become thicker as their biomass increases [50]. In extreme cases, starch grains can occupy up to 90% of the chloroplast volume, but they impede photosynthesis due to reduced light penetration into the photosystem [51]. When the demand for organic compounds exceeds the capabilities of the current assimilate production, these nutrient reserves are released, thereby reducing the leaf blade thickness. Hence, from a physiological point of view, thinner leaf blades are more favorable for plants, because the production and transport of assimilates is not disturbed. All the assimilates produced in the leaves are immediately transported to the acceptor organs. Comparing the sizes of the leaf blades of the studied varieties, they turned out to be larger in the "stay-green" variety. On this basis, it could be assumed that the accumulation of plant biomass was far more efficient in the "stay-green" variety than in the traditional hybrid. It could also be concluded that the transport of assimilates was very efficient in the "stay-green" variety, as evidenced by the lower leaf thickness (SLA).

Water and the lack of balance of mineral components in relation to the plants' nutritional needs are the most common factors limiting yielding potential [52]. NS fertilizer played a significant role in the present study, as the yield of fresh maize mass intended for ensilage and the PFPFN (partial productivity factor of fertilizer nitrogen) value in this combination were at the same level of significance as in the control object. In turn, particular attention should be paid to fertilization treatments in which phosphorus and potassium were applied (NPK, NP, NK, NPKMgS). Incorporation of these components in maize mineral fertilization resulted in a tendency towards increased yields of fresh maize mass and the PFPFN index. The lack of fertilization with these components caused a decrease in the value of these traits in comparison to the treatment optimally balanced with respect to the nitrogen dose. According to Shenoy and Kalagudi [53], an insufficient amount of available phosphorus could reduce the yield in the range of 10 to 15% compared to the maximum yield. The role of potassium in shaping the size of maize yield was emphasized by many researchers, pointing at the same time to the importance of using this component from subsoil layers [54]. According to Gaj et al. [21], in order to increase the efficiency of nitrogen activity, apart from the dose size, attention should be paid to other nutritional factors that determine nitrogen utilization from fertilizers, such as phosphorus, potassium, magnesium, or sulfur.

5. Conclusions

1. The temperature and humidity conditions in the maize growing seasons determined the structure of maize canopy, plant assimilation surface, value of the SPAD leaf greenness index, PFPFN, and the green mass yield of maize harvested for silage.
2. The plants of the "stay-green" maize variety developed fewer leaves per plant, but their weight was greater compared to the classic variety. In addition, the total leaf blade area of a single plant and the value of the LAI index were significantly higher in the "stay-green" hybrid compared to the traditional variety.
3. Morphological analysis of specific leaf area (SLA) of the "stay-green" hybrid demonstrated a highly effective nitrogen utilization, leading to faster generation of leaves with a larger assimilation surface, which formed the basis for effective absorption of solar radiation. Hence, the accumulation of plant biomass in the "stay-green" type was significantly more effective compared to traditional varieties. For this reason, one can infer that the transport of assimilates is highly efficient in this type of maize variety.
4. The selection of "stay-green" varieties for silage cultivation guarantees high biomass yields for ensilage. The high yielding potential of stay green maize can only be utilized under adequate conditions. In poor conditions (cold and wet), the leaves may mature too late.

5. The risk of a lower biomass of maize intended for ensilage can be reduced by using only balanced mineral fertilization of all nutrients. The omission of phosphorus (P) and potassium (K) in the mineral fertilization dose, regardless of the variety tested, was a factor reducing the yield of maize biomass intended for ensilage and a lower PFPFN compared to the treatment optimally balanced in terms of the nitrogen dose.
6. The results obtained in the study can be implemented in integrated maize cultivation, as well as in organic cultivation (selection of maize variety).

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