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Effect of Split Basal Fertilisation and Top-Dressing on Relative Chlorophyll Content and Yield of Maize Hybrids

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Abstract: The aim of this study was to determine the nitrogen requirement of maize, the optimal timing and amount of nutrient application, based on long time series data. An additional objective was to examine the response of the relative chlorophyll content of maize to nitrogen fertilisation. The examinations were carried out in a long-term field experiment at the University of Debrecen between 2016 and 2022, using two maize hybrids with different genotypes. Spatial and temporal changes in the N status of maize leaves were monitored using the Soil and Plant Analysis Development (SPAD) instrument. In addition to the non-fertilised (A_0) treatment, six fertiliser treatments were applied (spring basal fertilisation: 60 and 120 kg N ha^{-1}, A_{60}; A_{120}). Basal fertilisation was followed by two occasions of top-dressing at phenological stages V6 and V12, at rates of +30–30 kg N ha^{-1} ($V6_{90}$ and $V6_{150}$, and $V12_{120}$ and $V12_{180}$). The CMR (Chlorophyll Meter Reading), averaged over the examined years, genotypes and fertiliser treatments, were lowest in the V6 phenological phase (40.23 ± 5.57, $p < 0.05$) and highest in R1 (49.91 ± 8.41, $p < 0.05$). A_{120} fertiliser treatment increased the relative chlorophyll content by 5.11 compared to the non-fertilised treatment, 1.67 more than A60 treatment. The basal fertilisation treatment substantially increased the yield (A_{60}: +30.75%; A_{120}: +66.68%) compared to the A_0 treatment averaged over years and genotypes. Based on the obtained research results, a basal treatment of 120 kg N ha^{-1} is recommended and it can be concluded that, under appropriate water supply conditions (rainfall, irrigation), nitrogen top-dressing applied in V6 phenophase results in a significant yield increase compared to basal fertilisation.

Keywords: Chlorophyll Meter Reading (CMR); crop change; hybrid; maize; nitrogen fertiliser

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1. Introduction

The authors' institute has been studying and analysing the response of maize to different agrotechnical parameters for more than 40 years. The long-term experiment presented in this study was also set up 13 years ago. Maize is the main focus because it is a major feed, energy and food crop in the world [1–5]. Maize research is extremely important, its production is becoming more intensive [6] and to meet the growing food demand, both the quantity and quality of yield must be increased [7–9], despite the reduction of good quality growing areas [10] and the increasing extremes of weather [11,12].

Maize is a very nitrogen-demanding crop, and nutrient supply is one of the most important agrotechnical parameters [13]. Long-term analysis of nitrogen demand can provide important information for farmers, thus helping agriculture from both a sustainability and an economical point of view. Macronutrient nitrogen, which has the greatest influence on maize development and yield [14–16], is nowadays a very expensive input. Optimal nutrient supply can improve maize nitrogen use efficiency (NUE) [17,18], which is essential for sustainability [19,20]. Ensuring adequate nitrogen supply contributes to homogeneous germination, emergence, development and yield safety [21]. Its deficiency can be a primary limiting factor for maize development and yield formation [22,23]. Since nitrogen is an essential building block of plant proteins, it also has a crucial influence on quality parameters [24,25].

The amount and timing of nitrogen fertiliser application has a significant impact on maize productivity. The effect of nitrogen is not only influenced by the cropping year and genotype, but also by the nutrient application technology used [26,27]. Spring basal fertilisation followed by top-dressing in the early vegetative stages (V6, V12) has a significant effect on yield [13,28,29]. The nutrient utilisation capacity of maize can be increased by adequate nutrient supply, thus achieving higher yields with lower environmental stress [30]. The optimal level and timing of nutrient supplementation can reduce nutrient stress, which can be a primary limiting factor for maize growth and yield [31]. Optimal levels of fertiliser application could contribute to yield increase [32], but inadequate nutrient application may have negative effects on management, water balance and nitrate pollution [33,34].

Chlorophyll is the photosynthetic pigment in plants, responsible for the green colour of photosynthetic plants. It plays an important role in light absorption and energy conversion in plants and is essential for organic matter formation [35]. There is a strong correlation between chlorophyll content and the nitrogen content of plant leaves [36]; therefore, analysing the chlorophyll content can provide information on the nitrogen supply, development and expected yield of the plant [37,38]. Leaf nitrogen supply can be effectively measured by optical sensors. One such accurate and gentle instrument is the SPAD relative chlorophyll meter, based on the radiation absorption of leaves in the red (650 nm) and near-infrared (940 nm) range. The relative chlorophyll content value (CMR—Chlorophyll Meter Reading) measured by the instrument is closely correlated with the nitrogen supply to the leaves and the total chlorophyll content [39–43]. During fertiliser application, different fertiliser doses influence the relative chlorophyll content [44]. As phenological stages progress, higher nitrogen rates result in higher relative chlorophyll content and there is a strong positive correlation between relative chlorophyll content and yield [45].

The objectives of this study were to analyse data from a long (7 years) time series database, to examine the effect of different doses and timing of nitrogen nutrient replenishment on relative chlorophyll content (Chlorophyll Meter Reading—CMR), nutrient supply and yield of maize. Further objectives are to investigate the nitrogen requirement of maize and the impact of basal and top dressing as an innovative nutrient replenishment technology on maize yield and plant development. Evaluation of the interaction between CMR and yield was also the objective of this study. The authors believe that research on the response of maize to the amount and timing of nutrient replenishment can contribute to improving the local and regional position of maize and maize farmers.

2. Materials and Methods

2.1. Experimental Site

The experimental site is located in Hungary, at the Látókép Experiment Site of the University of Debrecen (N 47°33′ N 21°27′ E, 111 m asl). The one and a half hectare, split-strip-plot, small plot, 2 × 2 replicates (irrigated, non-irrigated) long-term experiment was set up in 2011 by Adrienn Széles (Figure 1).

2.2. Soil Data

The soil of the experimental site is a calcareous chernozem with excellent properties [46]. The physical properties of the soil were classified as clay loam (K_A = 42). In addition, the soil is characterised by medium humus content (Hu% = 2.7) and medium lime content. The near neutral pH of the upper part of the soil (pH_{KCl} = 6.6) helps the uptake of nutrients by plants. The phosphorus supply of the soil is medium (AL-soluble P_2O_5 133 mg kg^{-1}) and the potassium supply is in the category of medium to good AL-soluble K_2O with 240 mg kg^{-1} [47,48].

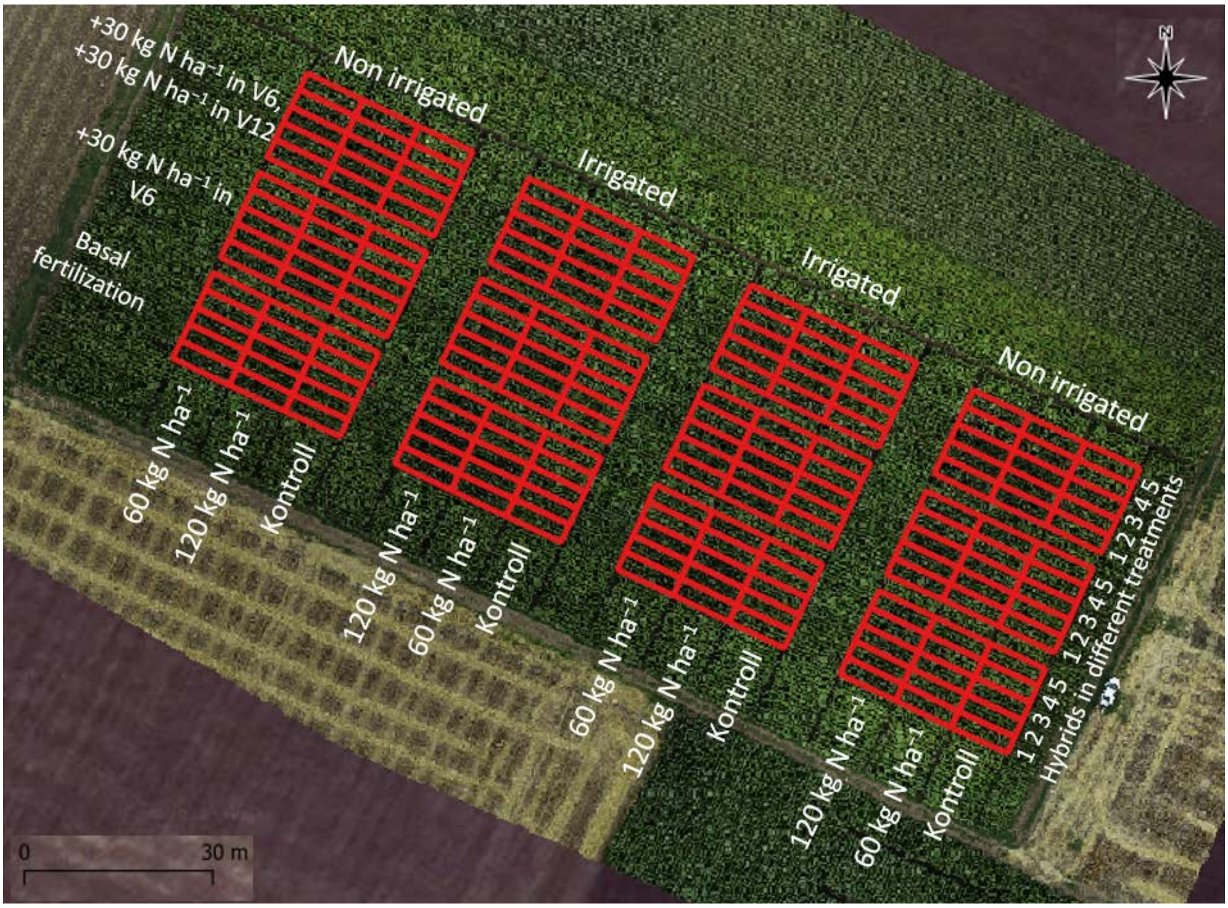

Figure 1. Design of the basal and top-dressing long-term experiment (established by Adrienn Széles in 2011).

2.3. Experimental Design

In the field experiment, nitrogen fertiliser rates were applied in split rates as basal and top-dressing in addition to the non-fertilised control (A_0) treatment. Basal fertiliser applications of 60 and 120 kg N ha^{-1} (A_{60}; A_{120}) applied in spring before sowing were followed by two applications of top-dressing at six and twelve leaf phenophases (V6; V12) at rates of +30 and +30 kg N ha^{-1} ($V6_{90}$; $V6_{150}$, and $V12_{120}$; $V12_{180}$). In the present study, tests were carried out with two maize hybrids of different genotypes (Armagnac-FAO 490; Fornad-FAO 420) under non-irrigated conditions, in growing years from 2016 to 2022. The number of plants was 73 thousand ha^{-1}. Grain yield corrected for 14% moisture content was provided in t ha^{-1}.

2.4. Weather Characteristics

Meteorological data were provided by an automatic weather station at the Látókép Experiment Site of the University of Debrecen. The obtained Values were compared to the averages (30-year average) of the period 1981–2011 (Tables 1 and 2). The 2016 growing season was rich in precipitation. The total rainfall during the growing season (April–September) was 453 mm, 107 mm above the multi-year average. The dry April saw only 16 mm (−37 mm) of rainfall, but the subsequent May–September period saw 144 mm of precipitation above the 30-year average. In total, there were 48 days of rainfall during the growing season. April was 2.1 °C, June 1.8 °C, July 1 °C and September 1.6 °C warmer than the multi-year average. Monthly mean temperatures in May and August were average.

Table 1. Monthly mean temperature characteristics for the period 2016–2022 (Debrecen-Látókép).

Months	Monthly Mean Temperature Data for the Examined Years (°C)													
	2016		2017		2018		2019		2020		2021		2022	
April	13.3	(+2.1)	10.7	(−0.5)	16.0	(+4.8)	12.4	(+1.2)	10.8	(−0.4)	8.2	(−3.0)	9.0	(−2.2)
May	16.5	(−0.1)	17.2	(+0.6)	197	(+3.1)	14.1	(−2.5)	14.0	(−2.6)	14.5	(−2.1)	17.6	(+1.0)
June	21.1	(+1.8)	22.2	(+2.9)	20.2	(+0.9)	22.8	(+3.5)	19.7	(+0.4)	22.1	(+2.8)	22.2	(+2.9)
July	22.3	(+1.0)	22.3	(+1.0)	21.7	(+0.4)	21.1	(−0.2)	21.0	(−0.3)	23.9	(+2.6)	23.4	(+2.1)
August	20.8	(0)	23.2	(+2.4)	23.2	(+2.4)	23.1	(+2.3)	22.6	(+1.8)	20.4	(−0.4)	23.5	(+2.7)
September	17.6	(+1.6)	16.4	(+0.4)	17.1	(+1.1)	17.1	(+1.1)	17.9	(+2)	16.2	(0)	15.3	(−0.9)

Note: deviations from 1981–2010 averages in brackets.

Table 2. Characteristics of monthly precipitation data for the period 2016–2022 (Debrecen-Látókép).

Months	Monthly Rainfall Data for the Examined Years (mm)													
	2016		2017		2018		2019		2020		2021		2022	
April	16	(−37)	51	(−2)	37	(−16)	33	(−20)	17	(−36)	27	(−26)	53	(0)
May	68	(+4)	27	(−37)	57	(−7)	76	(+12)	45	(−19)	64	(0)	10	(−54)
June	146	(+80)	67	(+1)	64	(−2)	32	(−34)	118	(+52)	10	(−56)	17	(−49)
July	87	(+21)	73	(+7)	55	(−11)	99	(+33)	148	(+82)	30	(−36)	22	(−44)
August	72	(+23)	61	(+12)	92	(+43)	15	(−34)	70	(+21)	32	(−17)	17	(−32)
September	64	(+16)	76	(+28)	14	(−34)	35	(−13)	50	(+2)	19	(−29)	152	(+104)

Note: deviations from 1981–2010 averages in brackets.

In 2017, the first two months of the growing season, there was 39 mm less rainfall than the 30-year average, followed by 277 mm of average rainfall between June and September, i.e., 48 mm more than the multi-year average. The total rainfall during the growing season was 355 mm. The monthly mean temperature of 10.7 °C in April was 0.5 °C below the multi-year average. After a cooler month, May closed with +0.6 °C, June with +2.9 °C, July with +1.0 °C, August with +2.4 °C and September with +0.4 °C above the 30-year average [49].

The 2018 growing season was poor in precipitation, with total rainfall (319 mm) below the multi-year average. August was the month with the highest rainfall (92 mm), 43 mm more than the 30-year average. The monthly mean temperature for all months of the growing season was higher than the multi-year average.

April 2019 was particularly dry (33 mm), with 20 mm less rainfall than the multi-year average. The month of May was characterised by cool and wet weather, with a monthly mean temperature of 14.1 °C, 2.5 °C below the 30-year average, and 76 mm of precipitation, 12 mm above the 30-year average. June and August were drier (−34 mm and −34 mm respectively) and warmer (+3.5 °C and +2.3 °C) than the multi-year average. The low mean temperature in July (21.1 °C) was accompanied by 99 mm of precipitation (+33 mm), but this was slightly late for maize [50].

Altogether, the weather conditions in 2020 were favourable for maize production. Following a cooler and less rainy April-May period, there was a total of 118 mm of rainfall on 15 rainy days, well above the multi-year average (52 mm). Major heat waves were absent and maize grew intensively. The 148 mm of rainfall in July was 66 mm above the 30-year average. The average monthly temperature of 22.6 °C in August and 21 mm more rainfall than the multi-year average (49 mm) also favoured maize.

Altogether, the agrometeorological conditions for the 2021 growing season are very unfavourable. From the last decade of June to August, the number of hot days was above average, with June 2.8 °C and July 2.6 °C warmer than the 30-year average. The very hot weather was accompanied by a severe lack of rainfall. In June, a total of 10 mm of rain fell, well below the 30-year average (66 mm). The drought persisted in July and August [51].

In April 2022, the monthly mean temperature (9 °C) was 2.2 °C lower than the multi-year average, and the amount of precipitation (53 mm) was the same. From May to August, rainfall was 179 mm less than the 30-year average. Total summer precipitation was 56 mm.

The exceptional drought was accompanied by high temperatures, with monthly mean temperatures 1.0 °C above the multi-year average in May, 2.9 °C in June, 2.1 °C in July and 2.7 °C in August. The significant rainfall (152 mm) in the colder month of September came too late for maize [52].

In summary, from the point of view of maize production, of the 7 years studied, 2016 and 2020 were rainy years, 2017 and 2019 were average years, and 2018, 2021 and 2022 were dry years.

2.5. Measuring Instrument and Test Method

The relative chlorophyll content of maize (Chlorophyll Meter Reading = CMR) was measured from the third 10-day period of May to the first 10-day period of July in three different phenological phases (V6, V12, R1) using the Konica Minolta SPAD-502. The instrument is equipped with two photodiodes, one red (max. 650 nm) and one infrared (max. 940 nm), which alternately illuminate an area of 6 mm2. Part of the light is reflected (reflection), part is absorbed (absorption) and the rest penetrates the leaf (transmission). The transmitted light is converted by a sensor into an analogue electrical signal. The instrument amplifies the electrical signal and converts it into a number. The calculation is based on the ratio of the intensity of the infrared and red light passing through the leaf. The ratio increases as more red light is absorbed by the leaves, which is closely related to the chlorophyll content. CMR may vary between 0 and 100 [53]. The instrument-derived relative chlorophyll content value (CMR) is closely related to the nitrogen supply to the leaves and thus the plant and the total chlorophyll content [39–43]. Application of different nitrogen doses affects the relative chlorophyll content [44]. The relative chlorophyll content value determined using the Konica Minolta SPAD-502 tool and its variation is a reliable indicator of maize nitrogen supply [54]. The tool, originally developed in Japan to assess nitrogen supply in rice, has also been tested in maize by several researchers [55–57]. For all tested genotypes, measurements were performed in two replicates for each fertiliser level. In each plot, from left to right, the second row of plants 6, 7 and 8 were measured in V6 and V12 phenophases in the last one-third of the last mature leaf at the latest emergence, and in R1 phenophase in the last one-third of the leaf opposite the ear [58].

2.6. Statistical Analysis

SPSS for Windows 21.0 was used for statistical evaluation. Mean values of treatments were compared using Duncan's test. Boxplots were made with the Jamovi program. Analysis of variance was performed to test the relationship between the dependent variable (CMR, yield) and the crop production factor (fertiliser, crop year, genotype) at the 5% significance level ($p < 0.05$). Linear regression analysis was used to examine the relationship between yield and CMR.

3. Results

3.1. Effect of Production Factors on Maize CMR

Factors influencing the relative chlorophyll content (CMR) of maize were examined (Table 3). A significant effect was found in terms of crop year, genotype, as well as fertiliser treatment ($p < 0.001$) and phenophase ($p < 0.01$) on the values. Of the interactions, genotype × crop year ($p < 0.01$), phenophase × crop year, and fertiliser treatment × crop year ($p < 0.001$) had significant effects on the relative chlorophyll content of maize. Phenophase × genotype and genotype × fertiliser treatment interactions had no effect on CMR. Of the different factors, phenophase had the highest influence on CMR of maize based on the SS value.

Table 3. Factors affecting the relative chlorophyll content (CMR) of maize (Debrecen-Latokép, 2016–2022).

Factors	SS	DF	F
Crop year	9778.75	6	71.77 ***
Phenophase	13,182.09	2	177.29 **
Genotype	38.72	1	18.69 ***
Fertiliser treatment	6950.3	6	81.22 ***
Genotype × Year	213.66	6	3.03 **
Phenophase × Crop year	3539.46	12	25.12 ***
Fertiliser treatment × Year	2205.97	36	5.22 ***
Phenophase × Genotype	68.36	2	2.91 NS
Phenophase × Fert. treatment	1696.49	12	12.04 ***
Genotype × Fertiliser treatment	59.14	6	0.84 NS

Note: *** = $p < 0.001$; ** = $p < 0.01$; NS = not significant.

The CMR—averaged over the examined years, genotypes and fertiliser treatments—was measured in three different phenological phases (V6, V12, R1) during the growing season. The lowest value (40.23 ± 5.57) was measured in the V6 phenological phase, which was significantly different ($p < 0.05$) from the other two phenophases according to Duncan's test. The relative chlorophyll content was statistically confirmed to be the highest at the 50% silking growth stage (49.91 ± 8.41). The obtained results indicate that the relative chlorophyll content of maize, and thus nitrogen accumulation, increased steadily between the V6 and R1 growth stages (Figure 2).

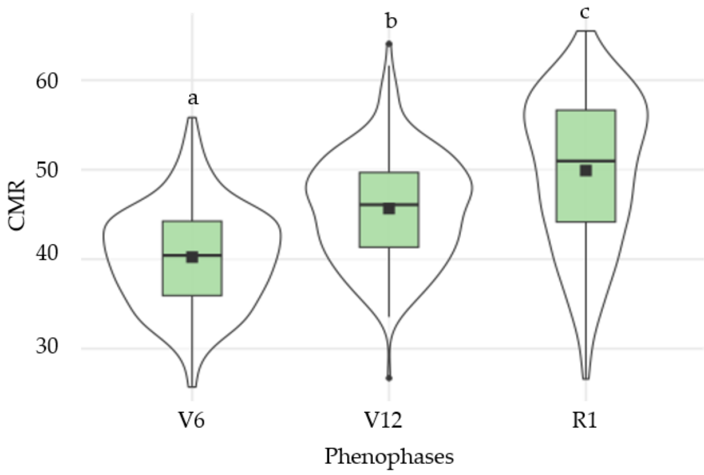

Figure 2. Variation of CMR during the breeding season in the different phenological phases (Debrecen-Látókép, 2016–2022). Note: $n = 252$. Values in lower case are significantly different at $p < 0.05$ probability levels according to Duncan's test.

When examining the effect of fertiliser treatment on CMR, it was found that increasing nitrogen doses, averaged over years, genotype, and phenological stages, also increased the relative chlorophyll content of maize. The non-fertilised plot (control, A_0) had the lowest value (41.29 ± 6.30), which was significantly different ($p < 0.05$) from the other treatments. The treatment A_{60} at the V6 phenophase supplemented with 30 kg N ha^{-1} dose ($V6_{90}$) had a significant ($p < 0.05$) CMR increasing effect (+2.81). Top-dressing applied at higher doses of basal fertiliser (A_{120}), V6 and V12 phenophases ($V6_{150}$ and $V12_{180}$) had a CMR-increasing effect (+1.99; +0.62), but the increase in value was significant ($p < 0.05$) only in the $V12_{180}$ treatment. The highest CMR (49.00 ± 8.94) was significant in the $V12_{180}$ fertiliser treatment ($p < 0.05$) (Figure 3). Based on the obtained results, the highest increase in CMR was provided by the basal fertilisation treatment ($p < 0.05$). A_{120} fertiliser treatment increased the relative chlorophyll content by 5.11 compared to no fertiliser treatment, 1.67 more than A_{60} treatment. Top-dressing applied to the basal fertilisation in phenological phases V6 and V12 resulted in a smaller increase in CMR.

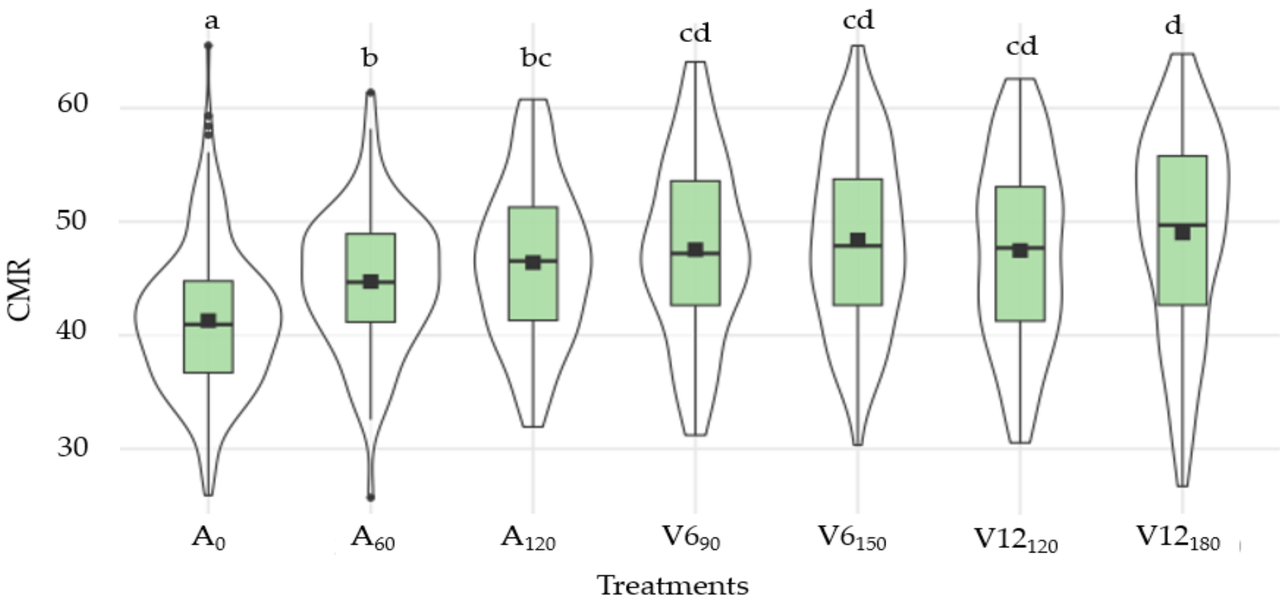

Figure 3. Effect of fertiliser treatments on relative chlorophyll content of maize (Debrecen-Látókép, 2016–2022). Note: $n = 84$. Values in lower case are significantly different at $p < 0.05$ probability levels using Duncan's test.

Examining the effect of fertilisation on CMR by year and genotype, averaged over the different phenophases, the obtained results show that, in 2016, 2017, 2020, 2021, 2022, the CMR was the lowest in the non-fertilised treatment for both examined genotypes (Table 4). These lowest values were significant ($p < 0.05$). In 2018, the least significant CMR (39.66 ± 5.11, $p < 0.05$) for hybrid Fornad was in treatment A_0. For the Armagnac hybrid, the lowest relative chlorophyll content (40.81 ± 8.91) was measured in treatment A_{60}, but this was not significant. In the 2019 growing year, the lowest CMR for the Armagnac hybrid were in treatments $V6_{90}$ and $V12_{120}$ for the Fornad hybrid (47.71 ± 6.66; 47.74 ± 9.25), which were not significant.

Increasing doses of fertiliser increased CMR. The most significant difference for both genotypes (56.77 ± 3.27 and 56.39 ± 5.10; 50.77 ± 5.31 and 53.12 ± 6.57) was observed in the $V12_{180}$ treatment ($p < 0.05$) in 2016 and 2020 (rainy crop years). Compared with the non-fertilised treatment (A_0), the lowest fertiliser dose (A_{60}) increased the relative chlorophyll content of the Armagnac hybrid by 6.94% on average over the years, while the increase was 9.71% for the Fornad hybrid. The treatment A_{60} had a significant effect on increasing the relative chlorophyll content of Armagnac in 2016 and both genotypes in 2022. The higher dose of the basal fertiliser (A_{120}) increased CMR by 12.37% compared to the A_0 treatment, averaged over the examined years. Based on Duncan's test, the CMR increasing effect of A_{120} treatment was significant for both genotypes in 2016 and for the hybrid Fornad in 2022.

Increasing the 60 kg N ha^{-1} basal fertilisation (A_{60}) in the V6 phenophase by an additional 30 kg N ha^{-1} ($V6_{90}$), averaged over the years, the authors observed higher CMR by 6.45% for the Armagnac hybrid and by 6.10% for the Fornad hybrid, with a significant increase in 2018 for the Armagnac hybrid ($p < 0.05$). In the phenological phase V6, the top-dressing applied to the fertiliser treatment A_{120} ($V6_{150}$) had an increasing effect of 3.95% and 4.63% on CMR for the hybrid Armagnac and Fornad, respectively, with no significant increase in values. For the treatment $V12_{120}$, a decrease in CMR was observed for the hybrid Armagnac in 2017, 2018 and 2021 and for the hybrid Fornad in 2019, 2021 and 2022 compared to the treatment $V6_{90}$. For the $V12_{180}$ treatment, the authors observed a decrease in CMR for both genotypes in 2019 and 2021, and for the Armagnac hybrid in 2017 and 2018 compared to the $V6_{150}$ treatment. The obtained results confirm that higher doses of nitrogen application and the splitting of nitrogen as a basal and top-dressing nutrient will be effective under optimal water availability.

Table 4. Effect of nitrogen fertilisation on CMR by year and genotype (Debrecen-Látókép, 2016–2022).

Years	Genotype	Treatments						
		A_0	A_{60}	A_{120}	$V6_{90}$	$V6_{150}$	$V12_{120}$	$V12_{180}$
2016	Armagnac	43.65 ± 3.96 ^{a}	48.13 ± 2.92 ^{b}	52.91 ± 3.67 ^{cd}	51.53 ± 3.74 ^{bc}	52.84 ± 2.70 ^{cd}	54.47 ± 4.07 ^{cd}	56.77 ± 3.27 ^{d}
	Fornad	45.23 ± 3.75 ^{a}	49.87 ± 3.50 ^{ab}	53.14 ± 5.67 ^{bc}	52.86 ± 5.67 ^{bc}	53.58 ± 6.45 ^{bc}	54.71 ± 5.33 ^{bc}	56.39 ± 5.10 ^{c}
2017	Armagnac	39.63 ± 4.95 ^{a}	44.16 ± 5.36 ^{a}	46.27 ± 7.69 ^{a}	47.56 ± 9.21 ^{a}	48.48 ± 9.54 ^{a}	46.11 ± 8.68 ^{a}	47.83 ± 10.66 ^{a}
	Fornad	39.07 ± 3.82 ^{a}	42.69 ± 2.73 ^{ab}	42.30 ± 4.30 ^{ab}	44.61 ± 9.09 ^{ab}	46.77 ± 7.01 ^{b}	45.47 ± 7.53 ^{ab}	47.44 ± 8.16 ^{b}
2018	Armagnac	41.24 ± 5.65 ^{a}	40.81 ± 8.91 ^{a}	46.95 ± 4.27 ^{ab}	53.74 ± 9.18 ^{b}	52.64 ± 10.05 ^{b}	50.10 ± 7.63 ^{ab}	51.09 ± 11.84 ^{b}
	Fornad	39.66 ± 5.11 ^{a}	44.08 ± 7.91 ^{ab}	43.69 ± 6.39 ^{ab}	51.22 ± 9.84 ^{b}	50.84 ± 11.98 ^{b}	52.42 ± 9.69 ^{b}	52.51 ± 12.00 ^{b}
2019	Armagnac	48.03 ± 4.95 ^{a}	48.70 ± 6.28 ^{a}	50.07 ± 8.65 ^{a}	47.71 ± 6.66 ^{a}	51.39 ± 7.16 ^{a}	49.70 ± 7.88 ^{a}	49.27 ± 4.82 ^{a}
	Fornad	49.40 ± 7.70 ^{a}	49.01 ± 4.90 ^{a}	50.14 ± 5.92 ^{a}	50.84 ± 8.20 ^{a}	50.00 ± 7.65 ^{a}	47.74 ± 9.25 ^{a}	49.77 ± 7.57 ^{a}
2020	Armagnac	42.84 ± 3.31 ^{a}	45.86 ± 3.46 ^{ab}	46.62 ± 6.04 ^{ab}	48.14 ± 4.81 ^{ab}	47.71 ± 4.80 ^{ab}	48.26 ± 5.65 ^{ab}	50.77 ± 5.31 ^{b}
	Fornad	44.03 ± 4.26 ^{a}	48.77 ± 6.82 ^{ab}	48.90 ± 8.65 ^{ab}	50.21 ± 5.39 ^{ab}	50.39 ± 5.98 ^{ab}	51.33 ± 6.53 ^{ab}	53.12 ± 6.57 ^{b}
2021	Armagnac	38.93 ± 4.42 ^{a}	39.43 ± 5.50 ^{a}	44.37 ± 6.63 ^{a}	43.37 ± 7.60 ^{a}	45.85 ± 9.13 ^{a}	40.94 ± 8.09 ^{a}	42.03 ± 9.79 ^{a}
	Fornad	36.66 ± 5.11 ^{a}	40.92 ± 6.21 ^{ab}	43.91 ± 6.48 ^{ab}	45.12 ± 6.93 ^{b}	46.38 ± 5.41 ^{b}	41.47 ± 8.68 ^{ab}	45.30 ± 10.66 ^{b}
2022	Armagnac	35.03 ± 3.69 ^{a}	42.35 ± 2.99 ^{b}	38.53 ± 2.87 ^{ab}	37.36 ± 1.08 ^{ab}	39.68 ± 2.42 ^{ab}	41.03 ± 5.22 ^{b}	40.71 ± 7.57 ^{b}
	Fornad	34.63 ± 2.92 ^{a}	41.38 ± 4.41 ^{b}	41.76 ± 2.67 ^{b}	41.17 ± 3.93 ^{b}	40.86 ± 3.26 ^{b}	40.71 ± 3.09 ^{b}	43.03 ± 4.30 ^{b}

Note: $n = 6$. Values marked with letters are significantly different at $p < 0.05$ probability levels by Duncan's test within examination years and genotypes.

The effect of nitrogen fertilisation on the average of genotypes was examined in relation to years and different phenological stages (Table 5). The lowest CMR were in most cases in A_0 treatment, in 2016 and 2022 in all threephenophases (2016—V6: 44.63 ± 3.05; V12: 41.61 ± 2.74; R1: 47.08 ± 3.86; 2022—V6: 36.23 ± 2.64;V12: 35.82 ± 2.22; R1: 32.44 ± 3.62; $p < 0.05$). In 2017, 2018, 2020 and 2021, the lowest relative chlorophyll content was observed in the growth stages V12 and R1 after A_0 treatment (2017—V12: 40.72 ± 2.94; R1: 42.16 ± 3.16; 2018—V12: 41.66 ± 4.19; R1: 42.73 ± 6.23; 2020—V12: 40.84 ± 2.20, R1: 46.71 ± 4.41; 2021—V12: 39.23 ± 2.55; R1: 40.41 ± 4.47; $p < 0.05$).

The highest CMR in 2016 and 2020, i.e., the rainy crop years, were also provided by the $V12_{180}$ treatment in V6, V12 and R1 phenological phases (2016—V6: 53.51 ± 2.83; V12: 54.77 ± 1.41; R1: 61.47 ± 1.57; 2020—V6: 47.03 ± 1.64; V12: 49.44 ± 1.39; R1: 59.35 ± 2.50; $p < 0.05$). In the R1 growth stage, which is the most important for yield formation, the highest CMR was observed in the $V12_{180}$ treatment in 2017 (55.52 ± 0.69; $p < 0.05$), 2021 (52.72 ± 5.12; $p < 0.05$), and 2022 (47.68 ± 0.94; $p < 0.05$). The obtained results indicate that in all years, the highest CMR was observed in R1 phenological stage due to the effect of higher amounts of basal fertilisation or subsequent top-dressing.

Compared to the A_0 treatment, A_{60} basal fertilisation increased CMR by 10.29% in 2016, 10.34% in 2017, 4.94% in 2018, 0.29% in 2019, 8.94% in 2020, 6.32% in 2021 and 20.20% in 2022, averaged over the phenological phases.

Compared to control plots, A_{120} treatment increased CMR by 19.32% in 2016, 12.55% in 2017, 12.06% in 2018, 2.85% in 2019, 9.97% in 2020, 16.78% in 2021, 15.26% in 2022, on average over the phenological phases.

Increasing the basal fertilisation rate of 60 kg N ha^{-1} (A_{60}) by an additional 30 kg N ha^{-1} in the V6 phenophase ($V6_{90}$) has a significant effect ($p < 0.05$) on increasing CMR in 2016 in R1, in 2017 in V12, in 2018 in V6 and R1 and in 2021 in V12. In the phenophase V12, applying +30 kg N ha^{-1} active ingredient ($V12_{120}$) resulted in no significant increase in CMR.

Table 5. Effect of treatments on the relative chlorophyll content in the phenological phases (Debrecen-Látókép, 2016–2022).

Years	Phen.	Treatments						
		A_0	A_{60}	A_{120}	$V6_{90}$	$V6_{150}$	$V12_{120}$	$V12_{180}$
2016	V6	44.63 ± 3.05 ^{a}	45.96 ± 2.56 ^{a}	48.65 ± 2.21 ^{ab}	48.37 ± 1.05 ^{ab}	48.28 ± 3.42 ^{ab}	51.72 ± 1.11 ^{bc}	53.51 ± 2.83 ^{c}
	V12	41.61 ± 2.74 ^{a}	48.81 ± 1.68 ^{b}	51.96 ± 0.47 ^{cde}	50.17 ± 1.04 ^{bc}	54.3 ± 2.79 ^{de}	51.63 ± 0.69 ^{bcd}	54.77 ± 1.41 ^{e}
	R1	47.08 ± 3.86 ^{a}	52.23 ± 1.38 ^{b}	58.47 ± 2.11 ^{c}	58.05 ± 2.40 ^{c}	57.05 ± 2.98 ^{c}	60.43 ± 2.32 ^{c}	61.47 ± 1.57 ^{c}
2017	V6	35.17 ± 3.50 ^{a}	39.39 ± 3.45 ^{a}	37.32 ± 3.39 ^{a}	35.02 ± 4.37 ^{a}	37.83 ± 2.90 ^{a}	35.96 ± 2.50 ^{a}	35.78 ± 2.22 ^{a}
	V12	40.72 ± 2.94 ^{a}	44.83 ± 1.46 ^{b}	46.45 ± 2.74 ^{bc}	49.32 ± 2.52 ^{cd}	49.56 ± 0.62 ^{cd}	48.45 ± 1.17 ^{cd}	51.61 ± 1.98 ^{d}
	R1	42.16 ± 3.16 ^{a}	46.04 ± 3.87 ^{ab}	49.09 ± 4.93 ^{bc}	53.92 ± 1.80 ^{d}	55.48 ± 3.51 ^{d}	52.95 ± 2.48 ^{cd}	55.52 ± 0.69 ^{d}
2018	V6	36.96 ± 3.84 ^{ab}	32.62 ± 4.70 ^{a}	39.93 ± 6.09 ^{bc}	43.72 ± 2.58 ^{c}	39.96 ± 5.39 ^{bc}	41.53 ± 2.46 ^{bc}	36.80 ± 2.93 ^{ab}
	V12	41.66 ± 4.19 ^{a}	46.71 ± 1.89 ^{ab}	47.32 ± 2.88 ^{ab}	51.98 ± 8.96 ^{bc}	53.15 ± 6.46 ^{bc}	53.29 ± 6.30 ^{bc}	58.71 ± 2.18 ^{c}
	R1	42.73 ± 6.23 ^{a}	48.02 ± 5.21 ^{a}	48.73 ± 2.01 ^{a}	61.74 ± 2.05 ^{b}	62.12 ± 2.95 ^{b}	58.96 ± 1.47 ^{b}	59.90 ± 3.36 ^{b}
2019	V6	41.75 ± 2.89 ^{a}	43.16 ± 1.13 ^{a}	42.04 ± 2.27 ^{a}	41.63 ± 4.91 ^{a}	42.37 ± 3.86 ^{a}	41.56 ± 3.06 ^{a}	42.55 ± 2.99 ^{a}
	V12	49.27 ± 2.56 ^{ab}	48.83 ± 1.40 ^{ab}	50.63 ± 3.23 ^{ab}	49.69 ± 4.07 ^{ab}	53.05 ± 1.64 ^{b}	47.06 ± 7.77 ^{a}	50.97 ± 1.80 ^{ab}
	R1	55.12 ± 4.26 ^{a}	54.58 ± 3.97 ^{a}	57.64 ± 2.15 ^{a}	56.51 ± 2.70 ^{a}	56.67 ± 4.46 ^{a}	57.55 ± 2.00 ^{a}	55.05 ± 3.73 ^{a}
2020	V6	42.75 ± 1.50 ^{ab}	44.22 ± 1.24 ^{b}	41.21 ± 3.10 ^{a}	44.24 ± 1.37 ^{b}	45.01 ± 1.30 ^{b}	44.09 ± 1.07 ^{b}	47.03 ± 1.64 ^{c}
	V12	40.84 ± 2.20 ^{a}	44.90 ± 3.16 ^{b}	45.48 ± 1.71 ^{b}	47.98 ± 1.32 ^{bc}	46.52 ± 1.87 ^{bc}	48.3 ± 3.34 ^{bc}	49.44 ± 1.39 ^{c}
	R1	46.71 ± 4.41 ^{a}	52.83 ± 5.77 ^{b}	56.6 ± 3.13 ^{bc}	55.31 ± 1.74 ^{bc}	55.63 ± 3.45 ^{bc}	57.00 ± 2.39 ^{bc}	59.35 ± 2.50 ^{c}
2021	V6	33.74 ± 4.54 ^{abc}	34.93 ± 1.74 ^{abc}	36.14 ± 1.95 ^{abc}	38.43 ± 7.31 ^{bc}	39.66 ± 7.17 ^{c}	32.04 ± 1.23 ^{ab}	31.32 ± 1.76 ^{a}
	V12	39.23 ± 2.55 ^{a}	41.59 ± 3.97 ^{ab}	47.35 ± 1.92 ^{d}	44.88 ± 2.55 ^{bcd}	46.41 ± 4.02 ^{cd}	42.28 ± 3.19 ^{abc}	46.97 ± 1.91 ^{d}
	R1	40.41 ± 4.47 ^{a}	44.02 ± 6.24 ^{ab}	48.92 ± 2.54 ^{bc}	49.43 ± 6.16 ^{bc}	52.29 ± 3.72 ^{c}	49.29 ± 4.76 ^{bc}	52.72 ± 5.12 ^{c}
2022	V6	36.23 ± 2.64 ^{a}	39.14 ± 4.04 ^{a}	39.84 ± 2.04 ^{a}	38.68 ± 2.35 ^{a}	39.77 ± 2.20 ^{a}	39.52 ± 1.50 ^{a}	39.73 ± 1.09 ^{a}
	V12	35.82 ± 2.22 ^{a}	42.48 ± 2.67 ^{b}	40.14 ± 1.77 ^{ab}	40.97 ± 3.39 ^{ab}	39.83 ± 3.42 ^{ab}	42.02 ± 1.60 ^{b}	38.21 ± 7.79 ^{ab}
	R1	32.44 ± 3.62 ^{a}	43.98 ± 2.91 ^{bc}	40.46 ± 5.33 ^{b}	38.15 ± 4.38 ^{ab}	41.22 ± 3.25 ^{b}	41.08 ± 7.24 ^{b}	47.68 ± 0.94 ^{c}

Note: $n = 4$. Values with lettering are significantly different at $p < 0.05$ probability levels by Duncan's test within examination years and phenological phases. Phen. = Phenological stages.

The 120 kg N ha^{-1} basal fertilisation (A_{120}) in the V6 phenophase increased by +30 kg N ha^{-1} ($V6_{150}$) in 2017 and 2018 in the R1 and in 2020 in the V6 growth stages showed a significant increase in CMR. An additional dose of 30 kg N ha^{-1} applied at the 12-leaf stage ($V12_{180}$) showed a significant ($p < 0.05$) increase in relative chlorophyll content in the phenophase V6 in 2016 and 2020 and in the pheonphase R1 in 2022.

In 2016–2022, the highest CMR were measured in the R1 phenological phase in all fertiliser treatments during the growing season, except in 2022 for treatments A_0, $V6_{90}$, $V12_{180}$ where the highest relative chlorophyll content was observed in the V12 phenological phase.

3.2. Effects of Fertiliser Treatments, Crop Year and Genotype on Maize Yield, Correlation Analysis between Yield and CMR

The greatest effect ($p < 0.001$) of crop year and Fertiliser treatment on maize yield was statistically confirmed (Table 6). Among the interactions, genotype × crop year, fertiliser treatment × crop year, and genotype × fertiliser treatment also had significant effects on yield ($p < 0.001$).

Table 6. Factors affecting maize yields (Debrecen-Látókép, 2016–2022).

Factors	SS	DF	F
Crop year	4701.32	6	58.08 ***
Genotype	33.17	1	2.35 ^{NS}
Fertiliser treatment	3709.44	6	47.87 ***
Genotype × Year	78.33	6	9.24 ***
Fertiliser treatment × Year	707.17	36	13.91 ***
Genotype × Fertiliser treatment	32.06	6	3.78 ***

Note: *** = $p < 0.001$; NS = not significant.

Examining the effect of fertiliser application on yield by genotype and year, it was found that in all examined years, the control treatment (A_0) had the lowest yield for both maize hybrids, which was a significant effect ($p < 0.05$) (Table 7). In 2016, for the Armagnac hybrid, the $V12_{120}$ treatment provided the highest yield (18.61 ± 0.12 t ha^{-1}), but the highest significant difference ($p < 0.05$) was obtained in the $V6_{150}$ treatment. For the hybrid Fornad, the $V6_{150}$ treatment gave the highest yield (19.74 ± 0.07 t ha^{-1}; $p < 0.05$).

Table 7. Effect of treatments on the yield of maize hybrids of different genotypes (t/ha) (Debrecen-Látókép, 2016–2022).

Years	**Gen.**	**Treatments**						
		A_0	**A_{60}**	**A_{120}**	**$V6_{90}$**	**$V6_{150}$**	**$V12_{120}$**	**$V12_{180}$**
2016	Arm.	11.65 ± 1.74^{a}	13.38 ± 1.48^{ab}	14.67 ± 0.42^{bc}	17.58 ± 0.69^{de}	18.30 ± 1.47^{e}	18.61 ± 0.12^{e}	15.98 ± 2.81^{cd}
	For.	12.01 ± 2.16^{a}	12.95 ± 0.74^{a}	14.66 ± 0.54^{b}	17.75 ± 1.29^{c}	19.75 ± 0.07^{d}	17.54 ± 0.18^{c}	18.88 ± 0.74^{cd}
2017	Arm.	8.99 ± 1.29^{a}	10.31 ± 1.58^{b}	14.09 ± 1.63^{d}	12.81 ± 0.99^{c}	14.39 ± 0.71^{d}	14.44 ± 0.40^{d}	14.92 ± 0.10^{d}
	For.	7.55 ± 1.29^{a}	9.33 ± 1.10^{b}	11.89 ± 0.98^{cd}	11.05 ± 1.93^{c}	12.81 ± 1.32^{de}	13.42 ± 0.49^{e}	13.44 ± 0.72^{e}
2018	Arm.	6.84 ± 2.08^{a}	10.46 ± 0.69^{b}	$13.48 \pm 0{,}10^{c}$	9.73 ± 6.40^{b}	12.03 ± 1.85^{bc}	14.25 ± 0.42^{c}	14.83 ± 1.27^{c}
	For.	7.11 ± 0.75^{a}	10.02 ± 1.19^{b}	12.70 ± 1.01^{c}	9.77 ± 2.49^{b}	13.11 ± 0.25^{c}	13.61 ± 0.72^{c}	12.94 ± 0.93^{c}
2019	Arm.	9.70 ± 1.00^{a}	12.97 ± 0.97^{b}	14.53 ± 0.51^{c}	13.01 ± 0.29^{b}	12.81 ± 1.09^{b}	12.67 ± 1.58^{b}	12.05 ± 1.95^{b}
	For.	9.16 ± 1.54^{a}	12.12 ± 0.75^{bc}	12.71 ± 0.47^{c}	11.81 ± 0.55^{bc}	14.02 ± 0.55^{d}	11.03 ± 0.73^{b}	12.23 ± 1.32^{bc}
2020	Arm.	6.50 ± 0.92^{a}	9.63 ± 1.04^{b}	13.55 ± 0.10^{c}	9.62 ± 2.60^{b}	12.82 ± 0.99^{c}	13.88 ± 1.12^{c}	13.72 ± 0.40^{c}
	For.	6.77 ± 1.02^{a}	9.85 ± 1.66^{b}	14.19 ± 0.55^{e}	12.68 ± 0.31^{cd}	13.82 ± 0.97^{e}	12.55 ± 0.55^{c}	13.70 ± 0.68^{de}
2021	Arm.	5.65 ± 1.14^{a}	7.69 ± 0.73^{b}	12.02 ± 0.56^{d}	10.62 ± 0.50^{cd}	12.06 ± 0.89^{d}	9.48 ± 2.34^{c}	9.72 ± 2.53^{c}
	For.	5.54 ± 1.19^{a}	6.83 ± 0.70^{b}	10.88 ± 0.15^{d}	8.89 ± 1.13^{c}	10.25 ± 0.94^{d}	8.84 ± 0.43^{c}	9.89 ± 0.99^{cd}
2022	Arm.	4.24 ± 1.08^{a}	7.27 ± 0.38^{b}	9.45 ± 0.60^{c}	6.86 ± 2.47^{b}	6.92 ± 1.67^{b}	7.50 ± 0.98^{b}	6.50 ± 0.44^{b}
	For.	4.46 ± 1.48^{a}	6.03 ± 1.19^{abc}	8.15 ± 1.32^{c}	5.17 ± 2.23^{ab}	5.78 ± 1.99^{ab}	5.99 ± 0.27^{abc}	7.38 ± 3.35^{bc}

Note: $n = 2$. Values marked with letters are significantly different at $p < 0.05$ probability levels by Duncan's test within the years and genotypes studied. Gen. = Genotypes. Arm. = Armagnac. For. = Fornad. Quantity: t ha^{-1}.

In the 2017 growing year, the highest yield was observed in the $V12_{180}$ treatment for both genotypes (Armagnac: 14.92 ± 0.10 t ha^{-1}; Fornad: 13.44 ± 0.72 t ha^{-1}), with the highest yield in the A_{120} treatment for Armagnac and in the $V6_{150}$ treatment for the Fornad hybrid.

In the subsequent year (2018), the highest yields were measured in the $V12_{180}$ (Armagnac, 14.83 ± 1.27 t ha^{-1}) and $V12_{120}$ (Fornad, 13.61 ± 0.72 t ha^{-1}) treatments, with the highest significant difference in treatment A_{120} for both hybrids.

In 2019, the highest yields were observed in the Armagnac hybrid in treatment A_{120} (14.53 ± 0.51 t ha^{-1}; $p < 0.05$) and in the Fornad hybrid in treatment $V6_{150}$ (14.02 ± 0.55 t ha^{-1} $p < 0.05$).

In 2020, the highest ($p < 0.05$) yields were obtained with treatment A_{120} (Armagnac: 13.55 ± 0.11 t ha^{-1}; Fornad: 14.19 ± 0.55 t ha^{-1}). The highest yields for the Armagnac hybrid (13.878 ± 1.121 t ha^{-1}) were obtained with treatment $V12_{120}$.

In the penultimate examined year (2021), the $V6_{150}$ treatment had the highest yield of the Armagnac hybrid (12.06 ± 0.89 t ha^{-1}), but the A_{120} treatment had the highest yield, which was significant (12.02 ± 0.56 t ha^{-1}; $p < 0.05$). For Fornad, the treatment A_{120} had the highest yield (10.88 ± 0.15 t ha^{-1}), which was significant ($p < 0.05$).

In 2022, the A_{120} treatment gave the highest yields for both genotypes (Armagnac: 9.45 ± 0.60 t ha^{-1}; Fornad: 8.15 ± 1.32 t ha^{-1}; $p < 0.05$).

The A_{60} treatment increased the yield by 11.27% in 2016, 18.72% in 2017, 46.72% in 2018, 33.04% in 2019, 46.80% in 2020, 29.73% in 2021 and 52.79% in 2022 compared to the data for the non-fertilised plots, averaged over the genotypes ($p < 0.05$).

Compared to the A_0 treatment, the higher rate basal fertilisation increased the yield by 23.98% in 2016, 57.06% in 2017, 87.53% in 2018, 44.44% in 2019, 109.03% in 2020, 104.71% in 2021, 102.38% in 2022, averaged over the genotypes ($p < 0.05$).

Averaged over years and genotypes, the A_{60} fertiliser treatment resulted in 30.75% higher yields and the A_{120} basal fertiliser treatment in 66.68% higher yields compared to the non-fertilised treatment. The 60 kg N ha^{-1} basal fertiliser application (A_{60}) at six leaf phenophases increased yield by an additional 30 kg N ha^{-1} dose ($V6_{90}$) by 13.33% on average across years and genotypes. The $V6_{90}$ treatment had a significant effect ($p < 0.05$), resulting in higher yields for both genotypes in 2016, (Armagnac: +4.20 t ha^{-1}; Fornad: +4.80 t ha^{-1}), 2017, (Armagnac: +2.50 t ha^{-1}; Fornad +1.72 t ha^{-1}), 2021, (Armagnac: +2.93 t ha^{-1}; Fornad: +2.06 t ha^{-1}) and 2020 for the hybrid Fornad (+2.83 t ha^{-1}). In the V12 phenological phase, an additional 30 kg N ha^{-1} of active ingredient ($V12_{120}$) showed a significant yield increase in the hybrid Armagnac in 2016 (+1.03 t ha^{-1}) in 2017

(+1.63 t ha^{-1}) in 2018 (+4.52 t ha^{-1}) and 2020 (+4.26 t ha^{-1}) and in the hybrid Fornad in the growing years 2017 (+2.37 t ha^{-1}) and 2018 (+3.84 t ha^{-1}). Averaged over years and genotypes, the $V12_{120}$ treatment provided 10.47% higher yield compared to the $V6_{90}$ treatment.

The 120 kg N ha^{-1} basal fertilisation (A_{120}) increased with +30 kg N ha^{-1} active ingredient ($V6_{150}$) in the V6 phenophase resulted in a 1.06% increase in yield, averaged over the years and genotypes. Significant ($p < 0.05$) yield increases were observed in 2016 (+5.09 t ha^{-1}), 2017 (+0.92 t ha^{-1}) and 2019 (+1.31 t ha^{-1}) for the hybrid Fornad, and in 2016 (+3.63 t ha^{-1}) for Armagnac. No significant yield increase was observed when an additional 30 kg N ha^{-1} of active ingredient was applied at the twelve-leaf growth stage ($V12_{180}$) compared to the $V6_{150}$ treatment.

For yield, averaged over the applied fertiliser treatments, differences were observed between maize hybrids of different genotypes for the examined years. In the years 2016 and 2020, which were the wetter years for maize production, the hybrid Fornad had a higher yield (2016: +0.45 t ha^{-1}; 2020: +0.49 t ha^{-1}). In the dry years 2018, 2021, 2022, the longer maturing hybrid Armagnac had a higher yield (2018: +0.2 t ha^{-1}; 2021: +0.71 t ha^{-1}; 2022: +0.60 t ha^{-1}). In 2017 and 2019, which were average cropping years based on weather data, the hybrid with a longer maturity also gave a higher yield (2017: +1.48 t ha^{-1}; 2019: +0.64 t ha^{-1}). The differences in yield between hybrids could not be statistically verified.

A correlation analysis was performed between relative chlorophyll content and maize yield (Table 8). As the phenological stages progressed, different levels of correlation were observed between years and genotypes. The strongest correlations were observed in the V12 and R1 growth stages, except in 2019 for the hybrid Fornad (r = 0.385). CMR measured at this time had the most significant effect on yield. For the genotype Armagnac, the strongest correlations were observed in 2016 (r = 0.733 ***), in 2018 (r = 0.711 ***) at the phenological stage of V12 and in the other years at the 50% silking (R1) stage (2017: r = 0.903 ***; 2019: r = 0.742 ***; 2020: r = 0.791 ***; 2021: r = 0.759 ***; 2022: r = 0.570 *). In the case of Fornad, the strongest correlations were found in the R1 growth phase (2016: r = 0.829 ***; 2020: r = 0.874 ***; 2022: r = 0.625 ***), except for 2017 (r = 0.858 ***), 2018 (r = 0.769 ***), 2019 (r = 0.385 ^{NS}), 2021 (r = 0.797 ***).

Table 8. Correlation analysis of relative chlorophyll content and yield (Debrecen-Látókép, 2016–2022).

Years	Genotype	Phenological Stages					
		V6		V12		R1	
		r	R^2	r	R^2	r	R^2
2016	Armagnac	0.589	0.347 **	**0.733**	0.537 ***	0.698	0.487 ***
	Fornad	0.553	0.306 *	0.718	0.515 ***	**0.829**	0.687 ***
2017	Armagnac	0.269	0.072 ^{NS}	0.883	0.781 ***	**0.903**	0.816 ***
	Fornad	0.021	0.000 ^{NS}	**0.858**	0.737 ***	0.847	0.717 ***
2018	Armagnac	0.141	0.020 ^{NS}	**0.711**	0.506 ***	0.283	0.080 ^{NS}
	Fornad	0.253	0.064 ^{NS}	**0.769**	0.592 ***	0.730	0.532 ***
2019	Armagnac	0.105	0.011 ^{NS}	0.174	0.030 ^{NS}	**0.742**	0.551 ***
	Fornad	**0.385**	0.148 ^{NS}	0.362	0.131 ^{NS}	0.017	0.000 ^{NS}
2020	Armagnac	0.203	0.041 ^{NS}	0.686	0.471 **	**0.791**	0.625 ***
	Fornad	0.471	0.221 *	0.822	0.675 ***	**0.874**	0.764 ***
2021	Armagnac	0.059	0.003 ^{NS}	0.656	0.430 **	**0.759**	0.577 ***
	Fornad	0.266	0.071 ^{NS}	**0.797**	0.635 ***	0.681	0.464 **
2022	Armagnac	0.244	0.060 ^{NS}	0.283	0.023 ^{NS}	**0.570**	0.325 *
	Fornad	0.514	0.264 *	0.428	0.183 ^{NS}	**0.625**	0.391 **

Note: *** = $p < 0.001$; ** = $p < 0.01$; * = $p < 0.05$; NS = not significant. Bold values indicate the maximum values of each line.

When examining the effect of crop year, it was found that the V12 phenological stage had the strongest correlation between CMR and yield in all three years, except for the Armagnac hybrid in the average crop year, where the R1 phenological stage showed the strongest correlation (r = 0.762 ***) (Table 9). It was found that under rainy weather conditions there was a moderately strong correlation between relative chlorophyll content and yield even at phenological stage V6 (Armagnac: 0.624 ***; Fornad: 0.649 ***). Among the hybrids, Fornad showed the strongest correlation except at growth stages V12 and R1 in the average vintage.

Table 9. Correlation between relative chlorophyll content and yield in different crop years (Debrecen-Látókép).

Crop Year	Genotype	Phenological Stages					
		V6		V12		R1	
		r	R^2	r	R^2	r	R^2
Rainy	Armagnac	0.624	0.390 ***	**0.751**	0.563 ***	0.681	0.464 ***
	Fornad	0.649	0.421 ***	**0.755**	0.570 ***	0.740	0.547 ***
Average	Armagnac	0.073	0.005 NS	0.625	0.391 ***	**0.762**	0.580 ***
	Fornad	0.227	0.051 NS	**0.623**	0.388 ***	0.528	0.278 ***
Dry	Armagnac	0.111	0.012 NS	**0.728**	0.529 ***	0.622	0.387 ***
	Fornad	0.195	0.038 NS	**0.796**	0.634 ***	0.795	0.632 ***

Note: *** = $p < 0.001$; NS = not significant. Bold values indicate the maximum values of each line.

4. Discussion

Nitrogen is one of the most important nutrients for the development, growth and yield of maize. It is essential for safe and sustainable cultivation, but it is expensive to produce, obtain and apply. Taking into account production, economical and environmental issues, it is important to determine the amount of basal and top-dressing fertiliser and to apply it at the right time to achieve a good yield. These objectives inspired the present research using a long time series of CMR and yield data.

Similar to the results of [59,60], the CMR was always highest in the R1 phenological phase in all examined years and fertiliser treatments. This was statistically confirmed ($p < 0.05$) as an average over years, genotypes and treatments. The obtained results suggest that the relative chlorophyll content of maize, and thus its nitrogen accumulation and incorporation, increased steadily between the V6 and R1 growth stages. In agreement with the results of [17,36,61], increasing fertiliser rates also increased the relative chlorophyll content of maize. It was found that the greatest increase in CMR, averaged over years, genotype and phenological stages, was provided by basal fertilisation ($p < 0.05$). A_{120} fertiliser treatment increased relative chlorophyll content by 5.11 compared to the non-fertilised treatment, 1.67 more than A_{60} treatment. An additional 30 kg of N ha^{-1} applied at phenophase V6 increased CMR by an additional 6.27% on average compared to the basal treatments A_{60} and A_{120} by an additional 4.29%. Top-dressing applied at V12 no longer caused a significant increase in CMR. Except for the 2016 and 2018 growing years, even with the higher dose of nutrient supplementation, the CMR did not reach the range of 52–56 CMR recommended by [55]. In the highly unfavourable years 2021 and 2022 for maize, the average CMR values for genotypes and fertiliser treatments were 42.48 and 39.87, respectively, which are significantly below the recommended values. Based on the obtained results, it can be concluded that the lack of precipitation may lead to nitrogen utilisation problems, in line with the research of [62], and thus the CMR may be lower. In rainy years (2016, 2022), the highest fertiliser dose ($V12_{180}$) gave the highest significant CMR for both examined maize hybrids, which may indicate that the higher fertiliser dose and the split application of fertiliser can only be effectively utilised under very good water availability.

In this study, the significant lowest yields were obtained in the non-fertilised treatment, A_0, similar to the results of [13,14]. Increasing doses of active ingredient applied during basal fertilisation positively influenced the yield trend, as shown in [13,29]. Treatment with A_{60} resulted in 30.75% and A_{120} basal fertilisation resulted in 66.68% higher yield compared to the non-fertilised treatment, averaged over the years and genotypes. The statistically proven highest yields for the examined years and genotypes were in most cases observed with the A_{120} basal fertilisation, in agreement with the results of [63]. Similar to the findings in [29], an additional 30 kg of N ha^{-1} applied at the V6 phenological stage resulted in an increase in yield ($V6_{90}$: +13.33%; $V6_{150}$: +1.06%), averaged over years and genotypes. Top-dressing applied at the 12-leaf phenological stage resulted in an increase in yield (+10.47%) only in the $V12_{120}$ treatment, and a decrease in yield in the $V12_{180}$ treatment.

In the analysis of the correlation between CMR and yield, it was found that, as the phenological stages progressed, different levels of correlation were observed between years and genotypes. The strongest correlations were observed in the V12 and R1 growth stages. Between 2016 and 2021, correlations were observed at the 0.1% level for both hybrids, while in 2022, the correlation between CMR and yield was 5% for the Armagnac hybrid and 1% for the Fornad hybrid. It was found that there was a moderately strong correlation between CMR and yield already at phenological stage V6 under rainy weather conditions (Armagnac: 0.624 ***; Fornad: 0.649 ***). When examining the hybrid effect, it was found that Fornad showed a closer correlation, except in the average year growth stages V12 and R1.

5. Conclusions

The results of this paper confirm that the appropriate choice of the optimal amount of active ingredient and application timing is an important agrotechnological factor in the nutrient supplementation of maize hybrids with different genotypes. Safe and sustainable production coupled with optimal yields is an essential factor for future agriculture.

Based on this research, the authors recommend the use of fertiliser treatment A_{120} for practice. The period between the phenological phases V12-R1 is very important for future yield formation, nutrient supply disturbances can lead to yield losses. It is particularly important to pay attention to possible nutrient replenishment during this period. In a very rainy year (2016), a significant yield increase was observed with nitrogen top-dressing applied at 6 leaf phenophases compared to basal fertilisation, averaged over the genotypes ($V6_{90}$: +34.20% $V6_{150}$: +29.69%). The role of irrigation could thus be enhanced in the future. Without irrigation, the application of a larger amount of basal fertiliser is justified. When allocating the application of nutrients, it is important to take into account other agrotechnical factors and soil conditions. From an economical point of view, it is recommended to use precision technology for nutrient application. The application of top-dressing should be combined with weed control or foliar fertilisation, and differential application of inputs can save time, energy and money. The obtained results suggest that a shorter maturity maize hybrid may be justified in a rainy season. In a dry year, longer maturity hybrids may be safer for optimal yields.

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