

Article

# The Response of Maize Lines to Foliar Fertilizing

Milan Brankov <sup>1,\*</sup> , Milena Simić <sup>1</sup> , Željko Dolijanović <sup>2</sup>, Miloš Rajković <sup>3</sup> ,  
Violeta Mandić <sup>4</sup>  and Vesna Dragičević <sup>1</sup> 

<sup>1</sup> Maize Research Institute “Zemun Polje”, Slobodana Bajića 1, 11185 Belgrade-Zemun, Serbia; smilena@mrizp.rs (M.S.); vdragicevic@mrizp.rs (V.D.)

<sup>2</sup> Faculty of Agriculture, University of Belgrade, 11080 Belgrade, Serbia; dolijan@agrif.bg.ac.rs

<sup>3</sup> Institute for Field and Vegetable Crops, 21000 Novi Sad, Serbia; milos.rajkovic@nsseme.com

<sup>4</sup> Institute for Animal Husbandry, 11080 Zemun, Serbia; violeta\_randjelovic@yahoo.com

\* Correspondence: mbrankov@mrizp.rs

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**Abstract:** The objective of this study was to evaluate the impact of two foliar fertilizers applied on five maize (*Zea mays* L.) lines. Fertilizers were applied at different growth stages of maize, during three consecutive years (2010–2012) at the experimental field of the Maize Research Institute “Zemun Polje”, Serbia. Maize growth parameters such as fresh matter, height, leaf area and grain yield were recorded. Foliar fertilizer with amino acids (FAA) was more advantageous to maize plants compared to fertilizer containing phosphorus (FP) as a main component. Applied FAA has shown positive effects by increasing fresh matter, leaf area index, and plant height in all three years. In 2012, due to unfavorable meteorological conditions, grain yield and harvest index were very low, compared to the previous two years, although, positive effects on morphological traits were observed 21 days after treatments (DAT), as well as in the anthesis stage. The best results of 30% of grain yield and harvest index increase were recorded in line L1 in 2010 and 2011. The same line had an increase of more than 40% of fresh matter and leaf area on average for all three years. The positive effects that have been noticed in this research could recommend foliar fertilizing with fertilizer containing N in a form of an amino acids complex.

**Keywords:** corn; macro elements; microelements

## 1. Introduction

Nutrients have an important role in plant growth and development. In most cases, when soil is optimally supplied with available nutrients, plants have a higher possibility to reach a genetic yield potential and quality [1]. Optimal growth is associated with better crop fitness, competition ability, and higher tolerance to various biotic (weeds, pests, diseases) or abiotic stresses (low or high temperatures, salinity). Plant nutrition provides optimal conditions for growth and development which makes it an important part of an Integrated Pest Management strategy [2].

Some soils have characteristics such as low or high pH, presence of poorly available minerals or have undergone certain processes (erosion, leaching, etc.), which make nutrients depleted [3]. Thus the lack of nutrients has become a worldwide problem [4]. Furthermore, the resources of mineral P will be exhausted in the near future, causing an even larger problem in agriculture [5]. In an intensive agriculture, plants lack of an optimal levels of essential nutrients, particularly micro-elements [6,7], which could be supplied by foliar fertilization. Micro elements availability in soil is closely related to their solubility.

Due to the fact that leaf tissue has the same morphological structure as root tissue (they originate from the meristem tissue), plants are able to rapidly absorb dissolved minerals [8]. Thus, soil deficiency in micro-elements can be successfully managed by foliar fertilizing [9,10]. In some cases, fertilizers

and herbicides can be combined in order to help crops to overcome possible herbicide stress [11]. Negative environmental factors such as salinity and drought can be mitigated with foliar fertilizing. Foliar application of kinetin and indole acetic acid increased maize dry matter, grain yield, and chlorophyll content under salinity stress [12]. Foliar application of ascorbic acid lowered drought stress in maize plants, increasing growth, biomass, and photosynthetic activity [13].

Nowadays, fertilizer formulations are enriched with micro-elements. According to Ivanov et al., 2019 [14], application of foliar fertilizer containing Zn showed positive effects on maize yield and quality. Application of foliar fertilizers showed an improvement on maize aboveground and underground parts [15]. Similarly, Jakab et al., 2016 [16] reported an increase in maize yield by foliar fertilization. Plant growth is largely dependent on N metabolism [17]. The amino acids and amides are the main product of inorganic N accumulation in plants [18]. Changes in their content affect nitrogen metabolism. Fertilization with N influence on increase in amino acids content in plants [19,20]. Since various positive effects of foliar fertilization were reported, the aim of this research was to test the effects of two foliar fertilizers on five maize inbred lines by measuring dynamics of growth parameters, such as fresh matter, height, leaf area index, as well as grain yield and harvest index.

## 2. Materials and Methods

The field experiment was conducted during three consecutive years (2010–2012) at the experimental field of Maize Research Institute “Zemun Polje”, Serbia (44°52′ N 20°20′ E). Five maize inbred lines (L1–L5), belonging to different FAO maturity groups were tested, presenting the main plot of split plot experiment, while subplots presented foliar fertilizer treatments. Main information about maize lines is presented in Table 1.

**Table 1.** Maize lines, FAO maturity group, and maturity dates for each experimental year.

Maize Line	FAO Maturity Group	Maize Maturity Dates		
		2010	2011	2012
L1—PL38	200	77	75	70
L2—PL39	300	81	78	72
L3—L335/99	500	90	88	82
L4—L375/25-6	600	93	91	86
L5—L155/18-4/1 RfVg	600	93	91	86

Macro elements availability before planting is presented in Table 2. All required cropping practices for maize growth were performed, including basic fertilization for optimal maize growth (150 kg ha<sup>-1</sup> of mono-ammonium phosphate was applied every year in autumn, and in spring of 2010, 2011, and 2012, 180 kg ha<sup>-1</sup>, 250 kg ha<sup>-1</sup>, and 200 kg ha<sup>-1</sup> urea prior to sowing were applied, respectively, according to soil analyses). The soil on the experimental field was chernozem, analyzed by the following methods: soil pH in KCL was determined in a 1:2.5 soil<sup>-1</sup> M KCL suspension after a half-hour equilibration period. CaCO<sub>3</sub> was determined by Scheibler calcimeter method, organic matter content by Kotzmann’s method, total N by the Kjeldahl method, available phosphorus (P<sub>2</sub>O<sub>5</sub>), and potassium (K<sub>2</sub>O) content by the standard AL-method according to Egner–Riehm. Soil contains 32% of clay, 15% silt, and 53% sand, obtained from 0–30 cm layer and contains 3.3% organic matter.

**Table 2.** Macro elements availability before maize planting.

Soil Layer	2010			2011			2012		
	Elements Availability kg ha <sup>-1</sup>								
	N	P	K	N	P	K	N	P	K
0–30 cm	51.4	66.9	121.9	62.9	82.9	119.6	25.1	53.6	117.1

Foliar fertilizers (containing amino acids (FAA) and containing phosphorus (FP)) were applied in different stages of maize development. FAA was applied when maize plants developed 5–6 leaves (15–16 BBCH), while FP was applied when maize plants developed 11–12 leaves (21–22 BBCH) (Table 3). Application timings were proposed by the manufacturer (Angibaud & Spécialités, La Rochelle, France). Due to the maize requirements and manufacturer recommendations, FAA was applied in earlier growth stage when plants were prone to stress and highly available N (amino acids) is vital. Phosphorus is more important for generative phases and thus is required later in vegetation, but before flowering.

**Table 3.** Applied fertilizers in the experiment (Activeg (12-4-6+0.2MgO+ME+amino acids) and Soluveg Green (10-40-10+ME)).

Fertilizer * Trade Name	Macro Elements Content	Microelements Content	Applied Rate
Activeg (FAA)	nitrogen N 12%/ as amino acid complex phosphorus P (P <sub>2</sub> O <sub>5</sub> ) 4% potassium K (K <sub>2</sub> O) 6% magnesium Mg (MgO) 0.2%	boron (B) 0.01% copper (Cu) EDTA chelate 0.01% manganese (Mn) 0.01% molybdenum (Mo) 0.005% zinc (Zn) EDTA chelate 0,005%	4 l ha <sup>-1</sup>
Solveg Green (FP)	nitrogen (N) 10% phosphorus (P <sub>2</sub> O <sub>5</sub> ) 40% potassium (K <sub>2</sub> O) 10% magnesium (MgO) 4%	boron (B) 150 ppm iron (Fe) EDTA chelate 600 ppm manganese (Mn) 330 ppm molybdenum (Mo) 25 ppm zinc (Zn) EDTA chelate 150 ppm	250 g ha <sup>-1</sup>

\* fertilizers time of application: foliar fertilizer with amino acids (FAA)—when maize developed 5–6 leaves (15–16 BBCH); foliar fertilizer containing phosphorous (FP)—when maize developed 11–12 leaves (21–22 BBCH).

Each maize line was planted in four rows, with 0.7-m spacing between rows and 0.25 m between plants in the row, 16.8 m<sup>2</sup> of elementary plot. Fertilizer applications were made using a CO<sub>2</sub>-pressurized backpack sprayer (Bellspray INC dba R&D Sprayers, Opelousas, LA, USA) equipped with TeeJet XR11002-SS nozzles (TeeJet Spraying Systems, Wheaton, IL USA) calibrated to deliver a spray volume of 140 L ha<sup>-1</sup> of solution at 275.8 kPa. All plots were kept weed free manually.

Measured parameters included determination of fresh matter (FM), leaf area and plant heights (PH) 21 days after treatments (DAT) and in the anthesis stage. All measurements were calculated by measuring five plants per plot, from side rows. Leaf area was measured using LI-COR 3100 area meter (LICOR Biosciences, Lincoln, NE, USA). From central rows, grain yield (GY) was measured and calculated at 14% of moisture, as well as harvest index (HI).

Growth analyses—from obtained measurements, the following growth parameters were estimated: leaf area index (LAI, 21 DAT and anthesis stage) Equations (1) and (2).

$$\text{LAI} = (\text{area of leaf coverage per plant})/(\text{area of soil coverage per plant}) \quad (1)$$

$$\text{HI} = (\text{GY} \times 100)/\text{BY}, \text{ where GY is grain yield and BY is biomass yield.} \quad (2)$$

As maize lines belong to different FAO maturity groups, reaching the anthesis stage (point of maximum growth) was not reached at the same time for all lines (Table 4).

**Table 4.** Evaluation dynamics.

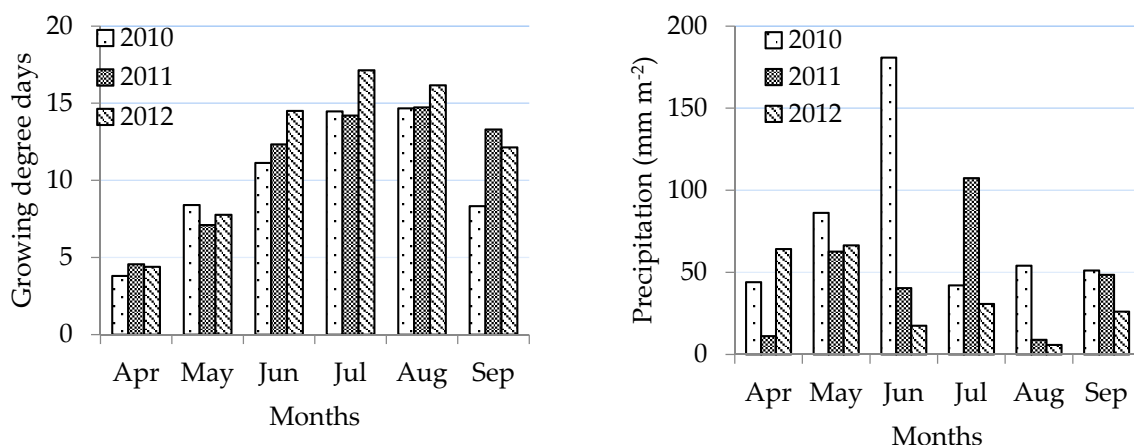
Year	Evaluations			
	Parameter	I	II	Harvest (GY and HI)
2010		Jun 11	Jul 13–28	Sep 5–Oct 12
2011	FM, LA, PH	Jun 9	Jul 10–27	Sep 5–Oct 29
2012		Jun 15	Jul 15–30	Sep 6–21

FM—fresh matter, PH—plant height, LA—leaf area, GY—grain yield, HI—harvest index.

Meteorological conditions—temperatures were presented in Growing Degree Days (GDD Equation (3)), which is a measure of heat accumulation used to predict plant development [21]. In 2010 and 2011 GDD had similar values, but in 2012 GDD had much higher values, especially in July and August. The second part of the growth cycle was followed by low amounts of precipitation and extremely high air temperatures (Figure 1).

$$GDD = \frac{T_{max} - T_{min}}{2} - T_{base} \tag{3}$$

where  $T_{max}$  is maximum daily temperature,  $T_{min}$ —minimum daily temperature, and  $T_{base}$  is the basis temperature for maize and it is 10 °C.



**Figure 1.** Air temperatures presented in growing degree days (left) and precipitation totals (right) in Zemun Polje for 2010–2012 growing period.

Statistical analyses—since meteorological conditions had significant influence on observed parameters, results are presented separately for each year. The obtained data were processed using the statistical package STATISTICA 8.0 for Windows (TIBCO software Inc., Palo Alto, CA 94304). The differences between treatments were determined by analysis of the variance (ANOVA). Means were tested by the least significant difference test (LSD). Correlations between grain yield and fresh matter, plant height, and leaf area were calculated using regression analyses.

### 3. Results

According to the analyses of variance, all tested effect factors have significant effect on measured maize parameters (Table 5). Due to the large impact of meteorological factors on the maize parameters, all data are presented by year, and interactions between year and other factors were not presented in the table.

**Table 5.** Analyses of variance for effect of year, fertilizer, and maize line on fresh matter, leaf area index, plant height, grain yield, and harvest index.

Factor	Fresh Matter	LAI	Height	Grain Yield	Harvest Index
<i>p</i> Value					
Year	0.000	0.000	0.000	0.000	0.000
Fertilizer	0.001	0.001	0.021	0.000	0.000
Maize line	0.000	0.000	0.000	0.001	0.002

According to obtained data, FM was affected by foliar fertilizers (Table 6). In 2010 and 2011, FM was increased by both FAA and FP at 21 DAT, 5.5–51.6% and 5.1–24.1% respectively. In 2012, a similar trend was noticed: fertilizing with FAA increased the observed parameter in lines L1–L3,

14.3–60.0%. All lines had higher accumulation of FM when sprayed with FP, 5–29.5%. The highest increase in FM was observed in 2010, the most favorable year for maize. The time of the first evaluation has enough precipitation, with quite lower GDD compared to 2011 and 2012.

In the anthesis stage, FAA treated, and FP treated lines, had an increase of 4.4–25.5% and 3.5–17.7% compared to the control, respectively. FM in lines L1 and L4 in 2011 and L5 in 2012 did not differ to the control (Table 4). The reason for the lack of differences could be found in high GDD and low precipitation, where positive effects of applied fertilizers were not seen.

**Table 6.** Effects of applied fertilizers on maize fresh matter ( $\text{g plant}^{-1}$ ) and standard error ( $\pm\text{SE}$ ).

Year	21 DAT			Anthesis			
2010	FAA	C	FP	C	FAA	FP	C
L1	31.6 $\pm$ 2.1	15.3 $\pm$ 1.1	321.4 $\pm$ 20.1	303.8 $\pm$ 22.9	421.2 $\pm$ 33.1	360.3 $\pm$ 22.1	361.1 $\pm$ 9.9
L2	33.4 $\pm$ 1.8	23.1 $\pm$ 1.7	404.1 $\pm$ 15.1	306.5 $\pm$ 21.1	537.4 $\pm$ 30.1	532.3 $\pm$ 17.8	513.7 $\pm$ 17.7
L3	62.3 $\pm$ 2.1	37.6 $\pm$ 2.1	514.4 $\pm$ 30.3	460.2 $\pm$ 30.6	731.5 $\pm$ 50.5	711.8 $\pm$ 20.9	670.5 $\pm$ 22.8
L4	44.9 $\pm$ 3.1	30.5 $\pm$ 1.9	567.4 $\pm$ 40.5	456.2 $\pm$ 22.7	981.1 $\pm$ 39.9	942.0 $\pm$ 33.1	872.9 $\pm$ 19.9
L5	35.1 $\pm$ 1.8	25.2 $\pm$ 2.5	427.6 $\pm$ 35.1	373.6 $\pm$ 17.9	638.9 $\pm$ 40.9	598.8 $\pm$ 27.7	489.2 $\pm$ 10.1
Average	41.5 a	26.3 b	447.0 B	380.1 B	662.0 aa	629.0 bb	581.5 cc
2011							
L1	48.9 $\pm$ 2.3	31.1 $\pm$ 1.7	455.4 $\pm$ 40.1	425.9 $\pm$ 26.6	529.3 $\pm$ 35.6	480.8 $\pm$ 30.0	478.2 $\pm$ 13.1
L2	39.2 $\pm$ 2.6	30.0 $\pm$ 1.1	472.5 $\pm$ 33.2	403.7 $\pm$ 20.0	589.0 $\pm$ 20.9	561.3 $\pm$ 15.1	469.4 $\pm$ 14.4
L3	40.1 $\pm$ 2.8	30.1 $\pm$ 0.9	497.6 $\pm$ 31.0	460.4 $\pm$ 17.9	756.1 $\pm$ 17.9	726.6 $\pm$ 41.1	640.4 $\pm$ 21.1
L4	50.3 $\pm$ 3.1	30.3 $\pm$ 2.2	586.2 $\pm$ 35.6	556.7 $\pm$ 19.9	715.9 $\pm$ 40.0	697.4 $\pm$ 15.2	706.3 $\pm$ 20.5
L5	37.8 $\pm$ 1.9	24.3 $\pm$ 2.3	421.0 $\pm$ 29.8	360.7 $\pm$ 11.0	596.3 $\pm$ 41.7	594.6 $\pm$ 40.1	545.6 $\pm$ 17.7
Average	43.3 a	29.1 b	486.5 A	441.5 A	637.3 aa	612.1 bb	568.0 cc
2012							
L1	60.1 $\pm$ 3.1	24.0 $\pm$ 2.4	105.9 $\pm$ 9.9	100.9 $\pm$ 9.9	572.8 $\pm$ 44.4	455.2 $\pm$ 30.6	383.6 $\pm$ 10.9
L2	49.7 $\pm$ 4.1	42.6 $\pm$ 3.1	106.9 $\pm$ 8.7	100.3 $\pm$ 7.8	669.5 $\pm$ 31.9	595.7 $\pm$ 22.4	537.2 $\pm$ 17.7
L3	74.2 $\pm$ 4.2	49.6 $\pm$ 4.1	208.3 $\pm$ 11.9	150.2 $\pm$ 10.0	1087.9 $\pm$ 80.1	920.9 $\pm$ 30.9	810.3 $\pm$ 35.5
L4	54.9 $\pm$ 3.1	56.9 $\pm$ 4.2	191.2 $\pm$ 8.4	134.8 $\pm$ 5.5	1050.3 $\pm$ 71.1	1039.3 $\pm$ 71.1	908.6 $\pm$ 42.5
L5	22.9 $\pm$ 1.1	22.9 $\pm$ 2.1	71.5 $\pm$ 6.5	53.6 $\pm$ 4.1	887.3 $\pm$ 40.1	612.9 $\pm$ 29.1	611.1 $\pm$ 40.1
Average	52.4 a	39.2 a	136.8 B	108.0 B	853.6 aa	724.8 bb	650.2 cc

L1–L5—maize lines, FAA—amino acid foliar fertilizer, FP—phosphorus foliar fertilizer, C—control. Means followed by the same letter do not differ by least significant difference test (LSD) test at  $\alpha = 0.05$  (small letter for FAA and the control; capital letter for FP and the control; double small letter for the anthesis stage). L1—FAO 200; L2—FAO 300; L3—FAO 500; L4—FAO 600; L5—FAO 600.

LAI followed the similar pattern as FM (Table 7). When FAA was applied in 2010, LAI was higher compared to the control (25.0–50.0%), 21 DAT, in all lines except L2. LAI was increased in all lines as well in 2011 and 2012 by up to 24% and 50%, respectively. Similar results were obtained spraying with FP; in 2010 lines L3 and L5 had higher LAI compared to control, while in 2011 and 2012 all lines had higher LAIs compared to the control.

In the anthesis stage, all lines sprayed by FAA by all year had higher LAIs (6.6–23%). Fertilizing by FP increased LAIs L4 in 2010 and 2012 by 17.7% and 6.9% respectively, L3 (7.4%) in 2012 by 7.4%, and L1 in 2011 and 2012 by 8.3% and 7.8%, respectively.

**Table 7.** Effects of applied fertilizers on maize leaf area index.

Year	21 DAT				Anthesis		
2010	FAA	C	FP	C	FAA	FP	C
L1	0.14 ± 0.01	0.07 ± 0.00	0.55 ± 0.02	0.62 ± 0.04	0.94 ± 0.08	0.70 ± 0.02	0.70 ± 0.05
L2	0.12 ± 0.02	0.11 ± 0.01	0.69 ± 0.04	0.76 ± 0.05	1.36 ± 0.09	1.30 ± 0.08	1.25 ± 0.09
L3	0.20 ± 0.03	0.16 ± 0.01	0.96 ± 0.06	0.87 ± 0.10	2.26 ± 0.15	2.29 ± 0.15	2.29 ± 0.18
L4	0.15 ± 0.02	0.08 ± 0.01	0.92 ± 0.06	1.01 ± 0.09	2.48 ± 0.21	2.43 ± 0.21	2.00 ± 0.17
L5	0.13 ± 0.01	0.07 ± 0.00	0.90 ± 0.05	0.73 ± 0.05	1.36 ± 0.08	1.26 ± 0.10	1.28 ± 0.15
Average	0.15 a	0.09 b	0.80 A	0.78 A	1.68 aa	1.59 bb	1.50 cc
2011							
L1	0.80 ± 0.07	0.67 ± 0.05	1.40 ± 0.11	1.25 ± 0.08	1.46 ± 0.11	1.33 ± 0.07	1.22 ± 0.11
L2	0.62 ± 0.04	0.47 ± 0.03	1.73 ± 0.21	1.51 ± 0.09	1.84 ± 0.15	1.51 ± 0.09	1.60 ± 0.11
L3	0.60 ± 0.04	0.52 ± 0.07	2.64 ± 0.17	2.47 ± 0.22	3.07 ± 0.22	3.00 ± 0.28	2.95 ± 0.21
L4	0.83 ± 0.06	0.68 ± 0.03	2.47 ± 0.24	2.20 ± 0.18	2.66 ± 0.19	2.48 ± 0.14	2.51 ± 0.18
L5	0.54 ± 0.02	0.40 ± 0.03	1.93 ± 0.13	1.73 ± 0.19	1.92 ± 0.12	1.83 ± 0.09	1.81 ± 0.16
Average	0.68 a	0.55 b	2.03 A	1.83 B	2.19 aa	2.03 bb	2.02 bb
2012							
L1	0.68 ± 0.05	0.34 ± 0.02	0.74 ± 0.11	0.62 ± 0.04	0.84 ± 0.07	0.80 ± 0.04	0.65 ± 0.04
L2	0.45 ± 0.02	0.32 ± 0.02	0.81 ± 0.06	0.68 ± 0.04	1.08 ± 0.09	0.80 ± 0.07	0.99 ± 0.05
L3	0.74 ± 0.02	0.43 ± 0.01	1.45 ± 0.12	1.17 ± 0.12	1.96 ± 0.08	1.91 ± 0.13	1.76 ± 0.08
L4	0.59 ± 0.01	0.52 ± 0.02	1.48 ± 0.13	1.26 ± 0.11	1.84 ± 0.11	1.74 ± 0.12	1.62 ± 0.11
L5	0.21 ± 0.01	0.15 ± 0.01	0.55 ± 0.02	0.44 ± 0.03	1.28 ± 0.12	1.27 ± 0.05	1.15 ± 0.09
Average	0.53 a	0.35 b	1.01 A	0.83 B	1.40 A	1.30 B	1.23 C

L1–L5—maize lines, FAA—amino acid foliar fertilizer, FP—phosphorus foliar fertilizer, C—control. Means followed by the same letter do not differ by LSD test at  $\alpha = 0.05$  (small letter for FAA and the control; capital letter for FP and the control; double small letter for the anthesis stage). L1—FAO 200; L2—FAO 300; L3—FAO 500; L4—FAO 600; L5—FAO 600.

Plant height did not follow the same pattern as FM and LAI (Table 8). In 2010, lines L4 (15.0%) and L5 (21.6%) had higher PH, compared to the control. In 2011 and 2012, all lines positively reacted with increased PH by 7.4–13.7% and by 7.0–18.0%, respectively. When FP was applied, no differences were recorded in 2010 and 2011. Lines L1 (10.9%) and L5 (11.6%) had higher PH in 2012.

No differences in PH in the anthesis stage were observed when FP was applied. Positive effects of spraying by FAA were recorded on L1 (8.0%), L4 (5.1%) and L5 (13.8%) in 2010, and all lines in 2011 (3.9–11.6%) and 2012 (6.6–14.6%). Although negative effects of high temperatures and GDD were during the anthesis stage, fertilizing influence significantly increased plant height.

**Table 8.** Effects of applied fertilizers on maize plant height (cm plants<sup>-1</sup>) and standard error (±SE).

Year	21 DAT				Anthesis		
2010	FAA	C	FP	C	FAA	FP	C
L1	34.8 ± 2.2	32.5 ± 1.7	72.2 ± 4.6	77.5 ± 0.9	128.3 ± 7.9	120.0 ± 7.2	118.0 ± 9.1
L2	41.8 ± 2.1	41.1 ± 2.8	75.0 ± 5.0	81.8 ± 1.9	161.5 ± 10.0	157.3 ± 3.8	160.3 ± 8.7
L3	58.9 ± 3.1	58.0 ± 2.6	95.3 ± 7.0	98.1 ± 5.3	168.5 ± 11.0	167.8 ± 5.9	164.7 ± 6.7
L4	37.4 ± 1.9	31.8 ± 1.1	97.3 ± 5.5	102.7 ± 5.1	197.1 ± 12.4	181.6 ± 9.7	187.6 ± 7.6
L5	36.3 ± 1.5	28.7 ± 0.9	85.9 ± 4.4	84.6 ± 6.5	179.0 ± 9.9	159.4 ± 8.7	154.3 ± 10.3
Average	41.8 a	38.4 b	85.1 A	88.9 A	166.9 aa	157.2 bb	156.9 bb
2011							
L1	83.1 ± 2.9	76.8 ± 2.2	139.8 ± 5.1	136.0 ± 2.9	155.8 ± 7.9	140.4 ± 4.5	137.7 ± 9.1
L2	72.2 ± 3.3	65.1 ± 4.0	119.3 ± 7.9	124.4 ± 8.0	179.2 ± 8.7	163.4 ± 7.1	161.7 ± 6.5
L3	80.8 ± 4.1	71.3 ± 3.7	121.2 ± 10.1	119.9 ± 7.1	187.5 ± 7.7	178.1 ± 9.3	180.2 ± 10.9
L4	79.8 ± 4.2	68.8 ± 3.7	123.0 ± 11.8	119.0 ± 3.3	196.6 ± 6.6	184.3 ± 9.3	184.8 ± 12.5
L5	64.7 ± 3.9	59.9 ± 3.6	105.6 ± 7.8	109.6 ± 8.1	181.7 ± 15.0	172.1 ± 5.5	169.9 ± 14.5
Average	76.1 a	68.4 b	121.8 A	121.8 A	180.2 aa	167.7 bb	166.9 bb

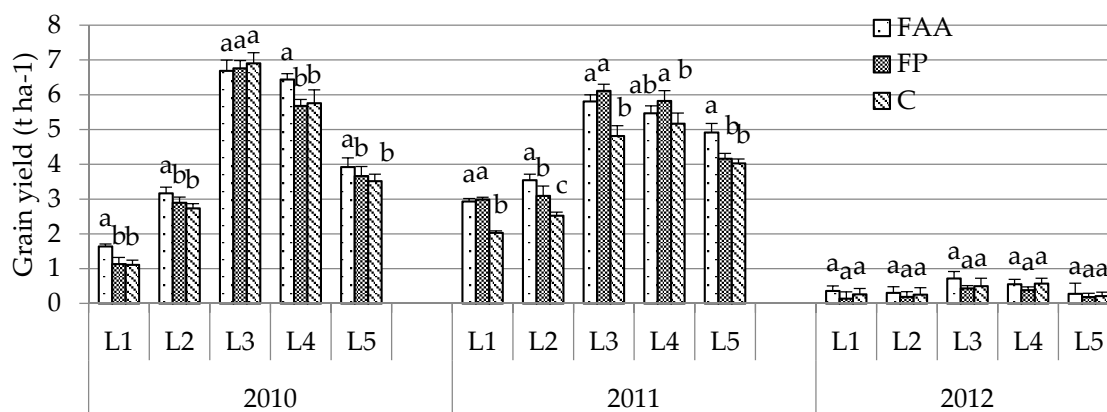
Table 8. Cont.

Year	21 DAT				Anthesis		
2012							
L1	63.2 ± 3.4	53.9 ± 4.1	81.5 ± 6.5	72.6 ± 4.7	100.7 ± 11.0	87.9 ± 6.1	86.0 ± 3.3
L2	61.6 ± 3.4	57.3 ± 4.0	62.6 ± 5.9	64.2 ± 2.5	109.3 ± 7.8	94.9 ± 8.1	95.1 ± 6.8
L3	76.6 ± 3.0	65.4 ± 3.6	91.7 ± 5.7	91.3 ± 4.5	150.7 ± 9.1	135.4 ± 7.8	139.8 ± 7.5
L4	60.0 ± 2.1	52.8 ± 2.0	69.5 ± 7.7	76.3 ± 2.9	130.5 ± 8.6	121.9 ± 9.9	119.6 ± 9.1
L5	54.0 ± 2.1	44.3 ± 1.9	54.3 ± 5.1	48.0 ± 2.3	141.7 ± 8.1	130.6 ± 11.1	131.9 ± 6.7
Average	63.1 a	54.7 a	71.9 A	70.5 A	126.6 aa	114.1 bb	114.5 bb

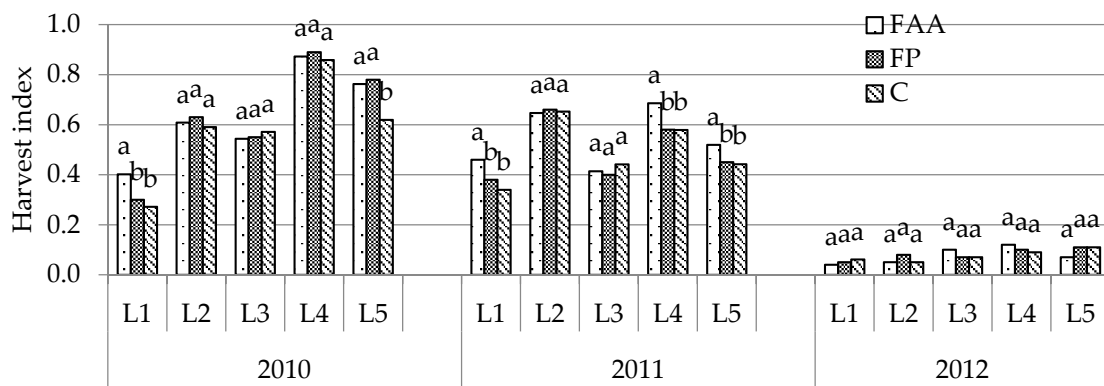
L1–L5—maize lines, FAA—amino acid foliar fertilizer, FP—phosphorus foliar fertilizer, C—control. Means followed by the same letter do not differ by LSD test at  $\alpha = 0.05$  (small letter for FAA and the control; capital letter for FP and the control; double small letter for the anthesis stage). L1—FAO 200; L2—FAO 300; L3—FAO 500; L4—FAO 600; L5—FAO 600.

According to obtained results, foliar fertilizing provided higher GY, compared to the control. Maize GY was higher when FAA fertilizer was applied (Figure 2). In 2010, lines L1 (32%), L2 (13.9%), L4 (10.6%) and L5 (10.2%) had higher GY in FAA treatment, compared to the control. No differences were observed when FP was applied. All lines had higher GY in 2011, except the line L5 (fertilized by FP). The highest difference of 32% of GY increase was recorded in L1. In the line L3, an increase of 21.1% and 17.0% was recorded when fertilized with FP and FAA, respectively. No differences between treatments were observed in 2012, due to meteorological impact (Figure 3). The meteorological conditions during the experiment significantly influence grain yield. 2010 and 2011 were better for maize production, compared to 2012. In 2012, the lack of precipitation and high GDD have large impact on maize yield, resulting in very low yield.

In general, low variation of HI was observed. Applied FAA increased HI in lines L1 (32.5%) and L5 (19.7%) in 2010. When FP was applied, an increase of 20.0% of HI was recorded, compared to the control. In the lines L2, L3, and L4 no differences were recorded. In 2011, only application of FAA induces significant increase in HI in lines L1 (26.1%), L4 (14.7%), and L5 (15.4%). Other treatments did not differ, as well as none of the treatments in 2012 (Figure 3).

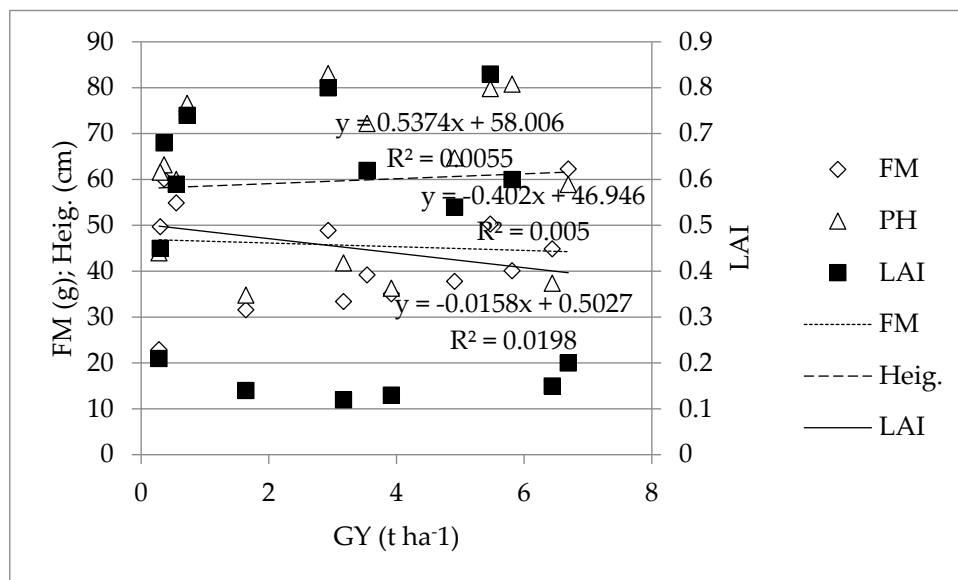


**Figure 2.** Effects of applied fertilizers on maize grain yield ( $\text{t ha}^{-1}$ ). L1–L5—maize lines. FA—amino acid foliar fertilizer, FP—phosphate foliar fertilizer, C—control. L1—FAO 200; L2—FAO 300; L3—FAO 500; L4—FAO 600; L5—FAO 600. Averages followed by the same letter do not differ by LSD test at  $\alpha = 0.05$ .



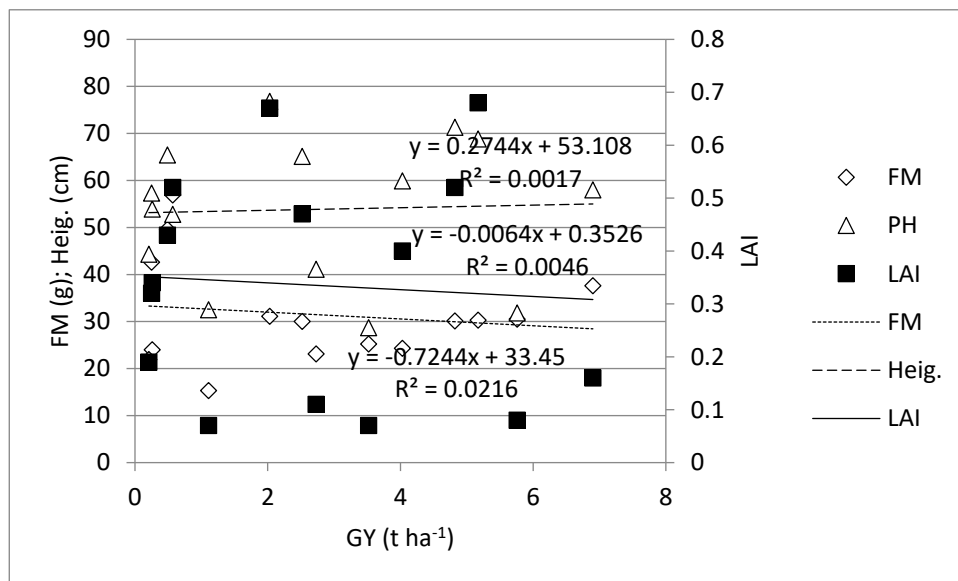
**Figure 3.** Effects of applied fertilizers on maize harvest index. L1–L5—maize lines. FAA—amino acid foliar fertilizer, FP—phosphate foliar fertilizer, C—control. L1—FAO 200; L2—FAO 300; L3—FAO 500; L4—FAO 600; L5—FAO 600. Averages followed by the same letter do not differ by LSD test at  $\alpha = 0.05$ .

It is obvious that FM correlated positively with GY in FAA treatment and the control (Figures 4 and 5), having the lowest values when GY is 3–4 t ha<sup>-1</sup>. The higher R<sup>2</sup> coefficient was obtained in FAA treatment. LAI was negatively, but insignificantly correlated to GY, while PH did not express any connection with GY. In FP treatment and the control (Figures 6 and 7), significant dependencies between GY and other parameters examined were expressed. LAI and PH correlated linearly with GY in FP, while in the control, R<sup>2</sup> coefficients were slightly higher, with the highest values of LAI and height obtained when GY was in the range 4–5 t ha<sup>-1</sup>. FM was also significantly and positively connected to GY, with stronger correlation obtained in FP treatment (R<sup>2</sup> = 0.864) and slightly lower R<sup>2</sup> (0.7539) present in the control of this treatment, but the highest values are noticed when GY is 6 ha<sup>-1</sup>.

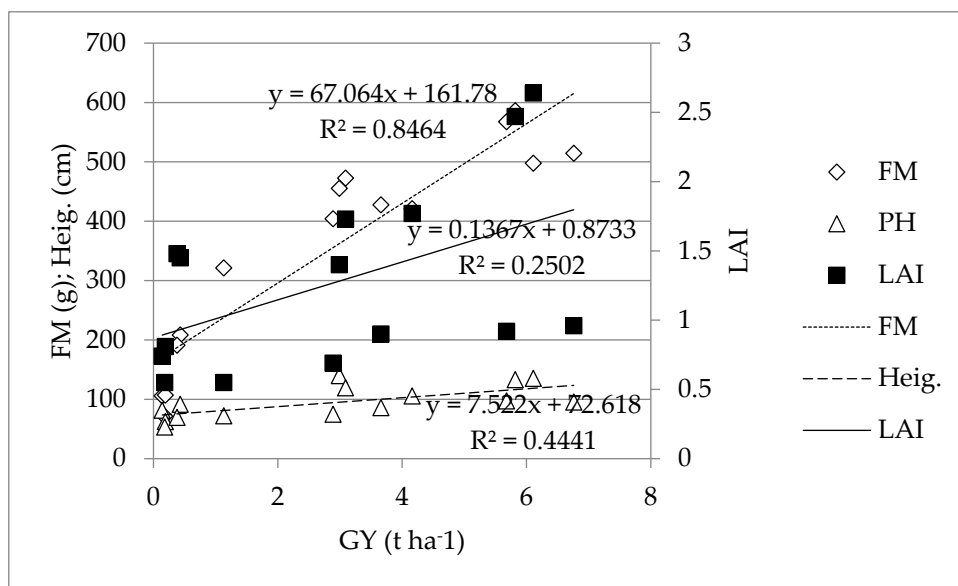


**Figure 4.** Correlation between grain yield (GY) and fresh matter (FM), plant height (Heig.) and leaf area index (LAI) 21 days after treatment (DAT) when FAA fertilizer was applied.

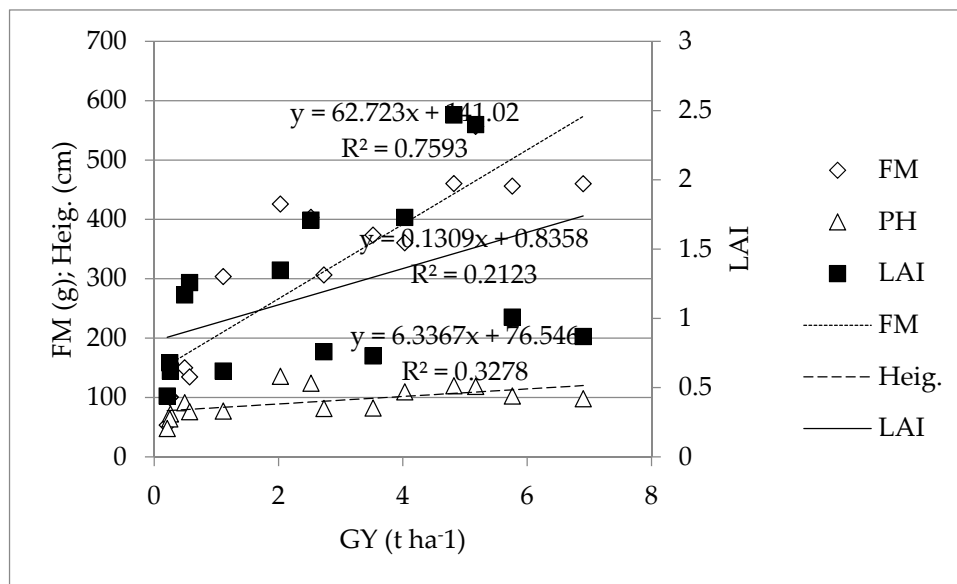




**Figure 5.** Correlation between grain yield (GY) and fresh matter (FM), plant height (Heig.) and leaf area index (LAI) 21 DAT in the control treatment (FAA).



**Figure 6.** Correlation between grain yield (GY) and fresh matter (FM), plant height (Heig.) and leaf area index (LAI) 21 DAT when FP fertilizer was applied.



**Figure 7.** Correlation between grain yield (GY) and fresh matter (FM), plant height (Heig.) and leaf area index (LAI) 21 DAT in the control treatment (FP).

#### 4. Discussion

Optimal plant nutrition is the basis of every instance of plant production. Mineral fertilizers incorporated into soil are subjected to leaching, impact of microorganisms, and other processes by which they become poorly available to plants [22,23]. Nutrient deficiency affects more than 3 billion people worldwide, causing so-called “hidden hunger” [24]. A micro-nutrient deficiency can be successfully managed with foliar fertilization [25,26]. According to the previously mentioned research, foliar fertilizing as supplementary fertilizing provides rapid absorption and utilization of nutrients, thus including absorbed elements directly in the metabolism [27]. In this research, positive effects of foliar fertilizers were observed, with better results achieved by FAA fertilizer. The reason for this can be found in fertilizer formulation; FAA contains a higher percentage of N, as well as some amino acids, while FP contains P as the main element. Additionally, by recommendation, the time of their application was not the same; so they differently affect the measured parameters. N (the most important macro element) [4] and the amino acids, which are quickly metabolized in maize plants, can be one of the reasons why FAA provided much better results. The results of FM and LAI indicated the most positive effects of applied fertilizers even on 21 DAT. Therefore, maize responded relatively fast to applied treatments. This is the main reason why plants grow significantly faster when they are treated with foliar fertilizers. In addition, it has been reported by various researchers that foliar fertilizing has positive effects on plants [28–30].

In the literature, some negative effects of foliar fertilizing have been reported [31] like “foliar burn”. This can happen if applications were made outside of the proposed time period (phenophase), as well as during unfavorable meteorological conditions. In this research, no negative effects of applied fertilizers were noticed. Moreover, due to the extreme weather conditions (drought), low GY and HI were measured in 2012, and expected effects of applied fertilizers were absent, although some positive effects on FM, LAI and PH were recorded during the season, especially at 21 DAT. This refers to the importance of water in maize growth. The significant influence of applied F1 on HI was present, while in FP no significant ( $p > 0.05$ ) differences were obtained. FAA influenced positively on GY, while FP did not have the same influence on tested lines. FM is important for high GY achieving and their positive correlation even in earlier growth phases [32], like in 21 DAT of FAA and the control. It gives evidence that its measurement can be a useful tool for GY prediction, which is even more supported at the later growth phases, with higher  $R^2$  coefficients obtained in FP and the control.

## 5. Conclusions

Based on obtained results, it can be concluded that foliar fertilizing with fertilizer which contains N in a form of amino acids expressed positive effects on the maize parameters. The best results in the grain yield increase were observed in line L1 with a 30% increase. The same line showed positive effects on fertilizing by the highest increase in fresh matter, leaf area index, height, and harvest index. Line L5, which belongs to FAO 600, had an increase of 10% of grain yield when FAA was applied in 2010 and 2011. Line L3 had an increase of 21% of grain yield only in 2011. Due to unfavorable meteorological conditions in 2012, effects of fertilizers were absent. Fertilizing with fertilizer which contains P as the main element did not provide as good effects as FAA. According to this research, foliar fertilization should be used in order to achieve higher yields with fertilizers that contain N in the form of an amino acids complex.

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