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Original Research

Response of Two Cultivar Types of Maize (*Zea mays* L.) Expressed in Protein Content and Its Yield to Varied Soil Resources of N and Mg and a Form of Nitrogen Fertilizer

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Abstract

The aim of our study was to assess protein content in grain and its yield for two types of hybrid maize cultivars at varied soil resources of nitrogen as well as the form of nitrogen fertilizer. Field trials were conducted in the years 2009-11 in the fields of the Teaching and Experimental Station in Swadzim that belong to the Department of Agronomy at the Poznań University of Life Sciences. Protein content in maize grain was directly proportional to air temperature while it was inversely proportional to total precipitation. The dose of nitrogen as well as the type of nitrogen fertilizer has a significant effect on protein content and its yield. The stay-green hybrid ES Paroli was characterized by a greater protein content in grain and yield of protein in comparison to the traditional cultivar ES Palazzo. In each of the tested nitrogen fertilizers a higher yield of protein was recorded for the stay-green hybrid in comparison to the traditional cultivar. For slow-release nitrogen fertilizers such as ammonia sulfate and urea the advantage of the stay-green cultivar in terms of the yield of protein was significantly greater than in the treatments in which slow-release nitrogen fertilizers were applied. Protein content did not determine the yield of grain when no nitrogen fertilizer was applied. In experiment I the best effect on the yield of grain was found for protein content in grain at the nitrogen dose of 150 kg $N \cdot ha^{-1}$; variation of the independent trait, protein content, in 17.4% determined the yield of grain. In experiment II it was observed that at all the applied nitrogen fertilizers protein content statistically significantly determined the yield of grain. This dependence was best described by the regression equation for ammonium nitrate (NH_4NO_3).

Keywords: protein, nitrogen, type of nitrogen fertilizer, magnesium, type of hybrid, stay-green

Introduction

Maize (*Zea mays* L.) is a species of considerable economic importance [1]. Both grain and the whole above-ground part of the plant are used as silage material and recently also as a raw material to produce biofuel [2] and biogas [3]. The considerable production potential of maize results in its high nutrient requirements, particularly in relation to nitrogen. The application of high nitrogen doses, especially on light soils, poses a threat to the natural environment [4]. This may lead to contamination of ground waters and eutrophication of water bodies. Al-Kaisi and Yin

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Table 1. Soil conditions in Swadzim.

Specification	Year					
	2009		2010		2011	
	I*	II*	I*	II*	I*	II*
P, mg P·kg^{-1} of soil	36.1	31.7	37.8	36.1	61.2	16.7
K, mg K·kg^{-1} of soil	121.2	97.1	97.1	45.6	54.8	63.9
Mg, mg Mg·kg^{-1} of soil	44.0	69.0	40.0	34.0	81.0	62.0
pH in 1 mol·dm^{-3} KCl	5.2	5.3	5.5	7.6	5.1	5.1

*I – experiment I, *II – experiment II

[5] reported that current levels of applied nitrogen fertilization in maize growing may be connected with pollution of ground and surface waters. On the other hand, nitrogen deficiency in maize leads to a reduction of its yield potential. A key role in this respect may be played by the capacity of nitrogen uptake [6] and utilization [7] from the dose of mineral fertilizer, particularly on lighter soils. In breeding it is attempted to produce hybrids with a reduced nitrogen requirement [Low-Input Genotypes]. These cultivars are characterized by a better capacity to utilize nitrogen, while their ability to translocate this nutrient to grain is comparable to that in traditional cultivars [High-Input Hybrids] [8]. Also, the potential increase in the absorption of solar radiation (leaf area) by crops grown on poorer soils in the opinion of Hirel et al. [9] may result in a better utilization of nitrogen. Thanks to the high genotypic variation in maize (*Zea mays* L.), we may find and select certain genotypes capable of yielding under nitrogen stress conditions [10]. A solution in this respect also is provided by breeding toward enhanced plant health at a later period [11] or possessing the stay-green trait [12, 13]. This trait is an indicator of good plant health at a later vegetation period, reduced progress of aging, and drought tolerance after flowering [14]. Greater duration (leaf greenness) or the stay-green trait are positively correlated with plant yielding [15], although the cause-and-effect relationship between these traits and yield of grain is limited by the length of vegetation period and the genetic background of the tested cultivar [16].

It was assumed in the hypothesis that the level of nitrogen resources in soil, the type of nitrogen fertilizer, application of magnesium, and plant genotype may significantly influence protein content and yield volume.

Thus the aim of the field trials was to assess protein content in grain and its yield for two different types of hybrid cultivars of maize differing in the aging rate at varied soil resources of nitrogen and the form of nitrogen fertilizer.

Methods

Field Trials

Field trials were conducted at the Department of Agronomy, Poznań University of Life Sciences, in the fields of the Teaching and Experimental Station in Swadzim in 2009-11 in the split-split-plot design in four field replications.

In the first experiment the first degree factor comprised four doses of urea (0, 50, 100, 150 kg N·ha^{-1}) and the second degree factor consisted of two levels of magnesium doses: 0 kg MgO·ha^{-1} and 25 kg MgO·ha^{-1}. The third degree factor-types of maize cultivars: ES Palazzo and stay-green ES Paroli SG.

In the second experiment the first degree factor consisted of forms of nitrogen fertilizers at six levels: no fertilization, ammonium nitrate (NH_4NO_3), ammonium sulfate ($(NH_4)_2SO_4$), urea ($CO(NH_2)_2$), Canwil nitro-chalk (NH_4NO_3+$CaCO_3$+$MgCO_3$), ammonium nitrate 50% dose N + urea 50% dose (NH_4NO_3 + $CO(NH_2)_2$), the second degree factor was the dose of magnesium at two levels: 0 kg MgO·ha^{-1} and 25 kg MgO·ha^{-1}, while the third degree factor comprised the types of maize cultivars ES Palazzo and stay-green ES Paroli SG.

In both field experiments phosphorus at 80 kg P_2O_5·ha^{-1} was applied in the form of granulated triple superphosphate 46% P_2O_5, while potassium was at a dose of 120 kg K_2O·ha^{-1} in the form of potash salt 60% K_2O. In experiment II nitrogen at 120 kg N·ha^{-1} was applied in accordance with the level of the first degree factor.

Each year of the experiments nitrogen, phosphorus, and potassium fertilizers and kieserite (Mg) were broadcast before maize sowing. Cultivation measures and the other cultivation practices were performed following recommendations for growing maize for grain.

The content of humus in the arable layer (0-25 cm) in the years of research ranged from 1.40% to 1.43%. Soil abundance with basic macronutrients and pH of soil in individual years of the experiments are given in Table 1. Assessment of the macronutrient content and pH of the soil was determined each year before the experiment in accordance with the research procedure/norm of the Regional Agrochemical Station in Poznań: P_2O_5 – PB.64 ed. 6 of 10/17/2008; K_2O – PB.64 ed. 6 of 17.10.2008; Mg – PB.65 ed. 6 of 17.10.2008; and pH – PB.63 ed. 6 of 17.10.2008.

Thermal and Humidity Conditions

Total precipitation and mean diurnal air temperature in individual years of the study are presented in Fig. 1. It was shown that years in which field trials were conducted were highly varied in terms of temperature and humidity conditions. The lowest precipitation total was recorded in 2011 (424.2 mm), while the highest in 2010 (500.7 mm). In turn, mean diurnal air temperature (measured at a height of 2 m) ranged from 14.5ºC (2010) to 15.9ºC (2011).

Methods of Parameter Determination

In the present study nitrogen content in grain was assessed using the Kjeldahl method with the Kjeltec™ 2200 FOSS device. Next, nitrogen content in grain was multiplied by 6.25 and protein content in grain was thus calculated. Protein content was determined for the bulk sample from four replications.

$$\% \, Protein = \%N \times 6.25$$

Yield of protein was calculated based on the formula:

Yield of protein [kg·ha^{-1}] = [(*yield of dry grain* kg·ha^{-1} × *protein content in grain* %)]/100

Statistical Analysis

In both experiments one-way analyses of variance (ANOVA) were performed in order to verify zero hypotheses on a lack of effect of years on protein content. Four-factorial analyses of variance were performed in order to assess the effects of nitrogen doses, magnesium doses, type of hybrid, and years, as well as respective interactions in terms of the yield of protein. Dependencies between protein content and the yield of grain for individual levels of differentiating factors were estimated using regression analyses.

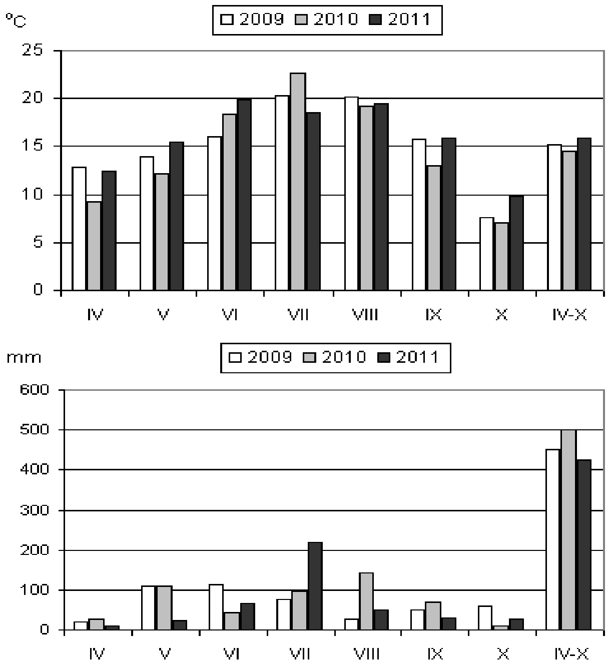

Fig. 1. Mean air temperature and total precipitation.

Regression lines were plotted and the percentage of variation explained by a given model was estimated. Percentage variance (coefficient of determination $R^2 \cdot 100$) was calculated by the formula:

$$R^2 = 1 - \frac{SS_E}{SS_T}$$

...where SS_E denotes the sum of squares of residuals (also called the residual sum of squares) and SS_T is the total sum of squares (proportional to the sample variance). R^2 is a statistic that will give some information about the goodness of fit of a model. In regression, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points. All calculations in statistical analysis were performed using the statistical package GenStat 15th Edition.

Results

Experiment I

In the case of protein content in maize grain the direction of changes under the influence of the investigated experimental factors was similar in all years of the study ($F_{2.69}$=2.84, P=0.065). It was shown that the dose of nitrogen and the type of maize hybrid significantly determined protein content in grain. Significantly, the lowest protein content was found for the dose of nitrogen of 0 kg N·ha^{-1} (7.97%) in comparison to the other levels of this factor. Protein content in maize grain within the range of nitrogen doses from 50 kg N·ha^{-1} to 150 kg N·ha^{-1} was statistically identical (Table 2). On average for the years of the study a significantly greater protein content was observed for grain of hybrid ES Paroli SG in comparison to the traditional cv. ES Palazzo. The difference between the investigated types of maize cultivars was 1.19%.

Recorded results indicate the significance of weather conditions varying between the years of the study in the modification of the yield of protein ($F_{2.144}$=96.34, P<0.001) (Table 3). The mean highest yield of protein was recorded for the year 2011 (795.1 kg·ha^{-1}), while it was lowest in 2009 (687.9 kg·ha^{-1}). Synthetically for the three years of the study the yield of protein was significantly modified by the doses of nitrogen ($F_{5.15}$=67.59, P<0.001) and magnesium ($F_{1.18}$=4.43, P=0.050), and the type of maize hybrid ($F_{1.36}$=1,687.72, P<0.001) (Table 3). The increasing level of nitrogen application from 0 kg N·ha^{-1} to 150 kg N·ha^{-1} was shown to cause an increase in the yield of protein. Significantly, the lowest yield of protein was recorded for 0 kg N·ha^{-1} (560.1 kg·ha^{-1}), while it was significantly the highest for the doses of 100 kg N·ha^{-1} and 150 kg N·ha^{-1}, for which the value of this parameter was statistically the same (Table 3). In this study the application of 25 kg MgO·ha^{-1} caused a significant increase in the yield of protein by 27.3 kg·ha^{-1} in comparison to 0 kg MgO·ha^{-1} (Table 3). In turn, when investigating the effect of the type of maize hybrid on the yield of protein, it was shown that the hybrid ES Paroli SG had a significantly high-

Table 2. Protein content of maize grain (2009-11).

Experimental factor Factor levels – experiment I		%	Experimental factor Factor levels – experiment II		%
Dose of nitrogen kg N·ha^{-1}	0	7.97±0.526	Type of nitrogen fertilizer	no fertilization	8.04±0.586
	50	8.90±0.730		NH_4NO_3	8.69±0.568
	100	9.28±0.688		$(NH_4)_2SO_4$	9.17±0.962
	150	9.23±0.909		$CO(NH_2)_2$	9.12±0.910
$LSD_{0.05}$		0.318		NH_4NO_3+$CaCO_3$+$MgCO_3$	8.87±0.906
Dose of magnesium kg MgO·ha^{-1}	0	8.79±0.903		NH_4NO_3+$CO(NH_2)_2$	8.89±0.858
	25	8.90±0.873	$LSD_{0.05}$		0.239
$LSD_{0.05}$		ns	Dose of magnesium kg MgO·ha^{-1}	0	8.78±0.886
Type of hybrid	ES Palazzo	8.25±0.538		25	8.82±0.864
	ES Paroli SG	9.44±0.752	$LSD_{0.05}$		ns
$LSD_{0.05}$		0.244	Type of hybrid	ES Palazzo	8.10±0.391
				ES Paroli SG	9.50±0.612
			$LSD_{0.05}$		0.139

ns – non-significant difference

Table 3. Protein yield depending on nitrogen and magnesium dose and type of maize hybrid [kg·ha^{-1}].

Experimental factor Factor levels		Years			Mean
		2009	2010	2011	
Dose of nitrogen kg N·ha^{-1}	0	486.2±85.9	512.1±61.5	682.0±61.0	560.1±112
	50	672.7±144	649.5±92.2	804.9±108	709.0±130
	100	770.0±153	688.6±99.1	838.2±109	765.6±153
	150	823.0±127	641.6±121	855.4±121	773.3±139
$LSD_{0.05}$		47.91	25.39	34.76	19.47
Dose of magnesium kg MgO·ha^{-1}	0	658.4±182	622.2±121	784.4±114	688.4±157
	25	717.5±179	623.7±110	805.8±128	715.7±159
$LSD_{0.05}$		39.03	ns	ns	15.26
Type of hybrid	ES Palazzo	619.5±153	537.4±61.9	708.2±61.6	621.7±123
	ES Paroli SG	756.4±184	708.5±89.2	882.0±101	782.3±149
$LSD_{0.05}$		46.09	15.36	16.86	16.55
Mean		687.9±181	623.0±115	795.1±121	-

ns – non-significant difference

er yield of protein by as much as 160.6 kg·ha^{-1} in comparison to the hybrid ES Palazzo (Table 3).

In this study the yield of protein in maize was significantly modified also by the interaction of the nitrogen dose with the type of maize hybrid ($F_{5.36}$=28.94, P<0.001) (Fig. 2). This dependence for both tested types of maize hybrids was described by a 1° linear equation (increasing), while for the hybrid ES Paroli SG values for this dependence were higher than in the hybrid ES Palazzo. For cv. ES Paroli SG each applied kg N·ha^{-1} caused an increase in the yield of protein by 1.57 kg·ha^{-1}, whereas for cv. ES Palazzo it was by 1.20 kg·ha^{-1} (Fig. 2).

Experiment II

In the case of protein content in maize grain the direction of changes under the influence of the tested experimental factors in all the years was similar ($F_{2.45}$=1.69,

Table 4. Protein yield depending on type of nitrogen fertilizer, magnesium dose, and type of maize hybrid [kg·ha^{-1}].

Factor Levels of factor		Years			Mean
		2009	2010	2011	
Type of nitrogen fertilizer	no fertilization	564.3±150	584.4±71.9	662.1±61.5	603.6±109
	NH_4NO_3	852.4±117	678.1±114	756.4±46.9	762.3±120
	$(NH_4)_2SO_4$	901.9±195	740.5±149	812.5±132	818.3±171
	$CO(NH_2)_2$	890.5±161	737.4±149	820.4±122	816.1±155
	NH_4NO_3+$CaCO_3$+$MgCO_3$	820.8±111	716.4±143	790.0±118	775.7±130
	NH_4NO_3+$CO(NH_2)_2$	881.4±115	717.4±144	805.2±125	801.4±143
$LSD_{0.05}$		86.49	23.75	18.20	24.82
Dose of MgO·ha^{-1}	0	817.8±182	686.7±146	768.9±125	757.8±161
	25	819.3±187	704.7±132	779.9±109	768.0±153
$LSD_{0.05}$		ns	12.01	ns	ns
Type of hybrid	ES Palazzo	711.3±127	578.5±48.2	686.6±50.6	658.8±101
	ES Paroli SG	925.8±169	812.9±92.7	862.2±97.7	867.0±132
$LSD_{0.05}$		25.40	18.33	16.99	11.61
Mean		818.6±183	695.7±139	774.4±117	-

ns – non-significant difference

P=0.196). It was shown that protein content in maize grain was significantly modified by the type of nitrogen fertilizer and the type of maize hybrid (Table 2). The lowest protein content in maize grain was recorded in the treatment with no-nitrogen fertilization (8.04%). Significantly, the highest value of this trait was found for maize fertilized with ammonium sulfate (9.17%) and urea (9.12%), for which protein content in grain was statistically the same (Table 2). On average for the years of the study a significantly greater protein content was found for grain of the hybrid ES Paroli SG in comparison to cv. ES Palazzo. The difference between the tested types of maize hybrids was 1.40%.

Protein content in maize grain also was significantly modified by the interaction of the type of nitrogen fertilizer with the type of maize hybrid (Fig. 3). For each of the applied nitrogen fertilizers a greater protein content in grain was found for the stay-green hybrid in comparison with the traditional cultivar. The difference between the tested cultivars ranged from 0.78% to 1.79%. For such fertilizers as ammonium sulfate, urea, Canwil nitro-chalk, and a mixture of ammonium sulfate with urea an advantage of the stay-green cultivar was significantly greater than on treatments with no nitrogen fertilization and with ammonium nitrate applied (Fig. 3).

Results indicate a significant effect of weather conditions varying between the years of the study ($F_{2,96}$=108.11, P<0.001) on yield of protein (Table 4). The mean highest yield of protein for years was recorded in 2009 (818.6

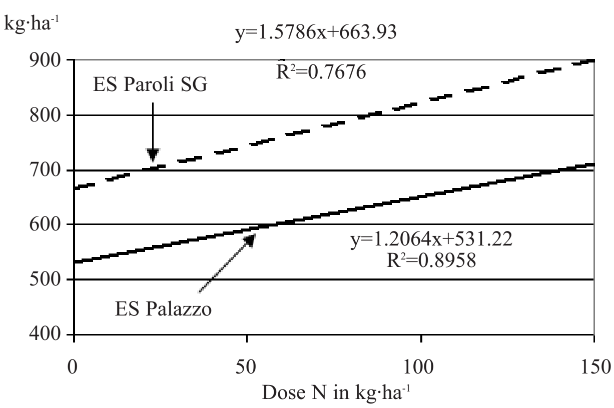

Fig. 2. The effect of nitrogen dose and type of maize hybrid in modification of protein yield (2009-11).

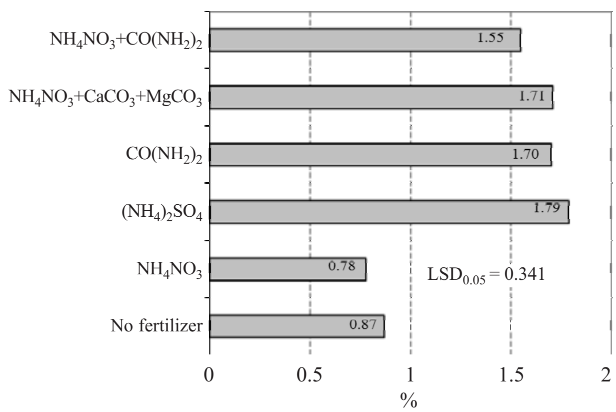

Fig. 3. Interaction of type of nitrogen fertilizer with type of maize hybrid expressed in increment of protein content in grain between hybrid ES Paroli SG and traditional cv. ES Palazzo (2009-11).

Table 5. The effect of the type of nitrogen fertilizer and the dose of magnesium on yield of protein [kg·ha^{-1}] (2009-11).

Dose of MgO·ha^{-1}	The type of nitrogen fertilizer					
	No fertilization	NH_4NO_3	$(NH_4)_2SO_4$	$CO(NH_2)_2$	$NH_4NO_3+CaCO_3+MgCO_3$	$NH_4NO_3+CO(NH_2)_2$
0	593.5±95.8	750.8±132	837.1±192	798.7±143	756.7±126	810.2±150
25	613.7±122	773.7±108	799.5±149	833.5±168	794.8±133	792.5±138
$LSD_{0.05}$	I × II = 26.98 II × I = 34.57					
Difference	+ 20.2	+ 22.9	- 37.6	+ 34.8	+ 38.1	- 17.7

kg·ha^{-1}), while the lowest was in 2010 (695.7 kg·ha^{-1}). Synthetically, the yield of maize protein depended on the type of nitrogen fertilizer ($F_{3.9}$ = 253.39, P < 0.001) and the type of maize hybrid ($F_{1.12}$=10.14, P=0.008) (Table 4). Significantly the lowest yield of protein was recorded for maize in the control treatment (with no nitrogen applied). In turn, the highest yield of protein was recorded for maize fertilized with ammonium sulfate (818.3 kg·ha^{-1}), urea (816.1 kg·ha^{-1}), and ammonium nitrate with urea with a 50% share of each of the fertilizers in the dose of nitrogen (801.4 kg·ha^{-1}) (Table 4). In turn, when analyzing the effect of the type of maize hybrid on the yield of protein it was shown that the hybrid ES Paroli SG had a significantly greater yield of protein in comparison to the hybrid ES Palazzo, with the difference amounting to 208.2 kg·ha^{-1} (Table 4).

The yield of protein in maize was significantly modified also by the interaction of the type of nitrogen fertilizer with the type of maize hybrid ($F_{3.24}$=4.09, P=0.018) (Fig. 4). For each of the tested nitrogen fertilizers a greater yield of protein was recorded for the stay-green hybrid in comparison to the traditional cultivar. The difference between the tested cultivars ranged from 123.8 kg·ha^{-1} (with no fertilization) to as much as 285.4 kg·ha^{-1} (ammonium sulfate). However, for slow-release nitrogen fertilizers such as ammonium sulfate and urea the advantage of the stay-green cultivar was significantly greater than on objects on which the other slow-release nitrogen fertilizers were applied (Fig. 4).

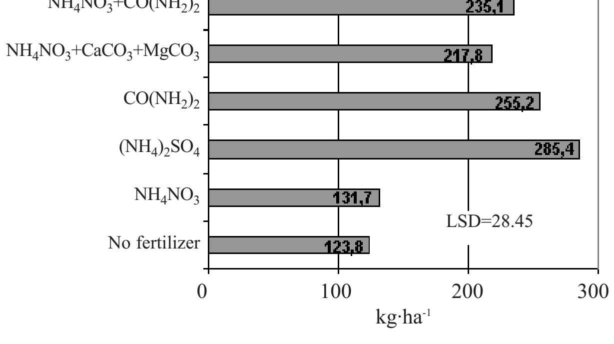

Fig. 4. Interaction of type of nitrogen fertilizer with type of maize hybrid expressed in increment in yield of protein between hybrid ES Paroli SG and traditional cv. ES Palazzo (2009-11).

The yield of protein in maize also was determined in this study by the interaction of the type of nitrogen fertilizer with a dose of magnesium (Table 5). In the case of each of the applied nitrogen fertilizers (except for ammonium sulfate and a mixture of ammonium nitrate with urea) the application of 25 kg MgO·ha^{-1} caused an increase in the yield of protein in relation to the treatment, in which this nutrient was not applied. When broadcasting urea and Canwil nitro-chalk with 25 kg MgO·ha^{-1} a significantly positive increase was obtained in the yield of protein in comparison to the other nitrogen fertilizers. In turn, when applying ammonium sulfate with 25 kg MgO·ha^{-1} a significantly negative increase was recorded for the yield of protein (Table 5).

Discussion

Maize is characterized by highly uniform grain, with a relatively low variation in the levels of energy and protein [17]. It has the highest energy value among all cereals. This results from high contents of starch and fat as well as low content of crude fibre [18]. Maize kernels contain almost all essential nutrients in readily available forms. The most important nutrients include carbohydrates, protein and fat. They constitute 95% dry weight of kernels. Protein content in maize grain ranges from 8 to 12% [19]. As reported by Bruździak [20], at the phase of full grain ripeness approx. 60% crude protein is found in grain. Protein in maize due to the contents of lysine and tryptophan has low biological value, while it has good digestibility [18].

Maize is a plant whose growth and development to a considerable degree depend on climatic conditions [21]. Also, Hopkins [22] has reported that weather conditions in the vegetation period have a considerable effect on plant yield and each deviation from the average course influences agricultural production. Both an excess and a deficit of precipitation, too low or too high temperature to a considerable degree, determine yield stability. Temperature and humidity conditions in the period of field trials were highly varied (Fig. 1). The coolest and at the same time wettest weather conditions were found in 2010 in comparison to 2009 and 2011. Szmigiel [23] emphasized that protein content in grain is influenced by changes in weather conditions during the vegetation period of maize. In his study he showed that the highest protein content in maize grain is obtained in dry

Table 6. Dependencies between protein content (x) and yield of grain (y) estimated for individual levels of differentiating factors.

Levels of factor	Equation	Percentage of explained variation	*t* probability for	
			Constant	Protein content
Experiment I				
0 kg $N \cdot ha^{-1}$	y=16.6+6.70x	6.1	0.537	0.050
50 kg $N \cdot ha^{-1}$	y=43.9+3.97x	8.0	0.008	0.029
100 kg $N \cdot ha^{-1}$	y=29.0+5.72x	13.6	0.122	0.006
150 kg $N \cdot ha^{-1}$	y=3.2+8.68x	17.4	0.895	0.002
0 kg $MgO \cdot ha^{-1}$	y=14.7+7.16x	23.8	0.202	<0.001
25 kg $MgO \cdot ha^{-1}$	y=14.2+7.36x	24.4	0.228	<0.001
ES Palazzo	y=-8.2+10.07x	18.3	0.642	<0.001
ES Paroli SG	y=15.4+7.11x	17.7	0.293	<0.001
Experiment II				
no fertilization	y=4388+385x	1.6	0.066	0.190
NH_4NO_3	y=-852+1103x	35.7	0.647	<0.001
$(NH_4)_2SO_4$	y=1708+778x	39.2	0.190	<0.001
$CO(NH_2)_2$	y=2199+732x	37.2	0.085	<0.001
$NH_4NO_3+CaCO_3+MgCO_3$	y=4391+485x	24.0	<0.001	<0.001
$NH_4NO_3+CO(NH_2)_2$	y=2435+734x	37.9	0.049	<0.001
0 kg $MgO \cdot ha^{-1}$	y=846+877.7x	46.2	0.229	<0.001
25 kg $MgO \cdot ha^{-1}$	y=2388+709.7x	27.6	0.005	<0.001
ES Palazzo	y=-2667+1330x	25.1	0.086	<0.001
ES Paroli SG	y=1190+832x	23.2	0.319	<0.001

and warm years, while in years of abundant precipitation high yields of grain are obtained at the simultaneous lower protein content. Also in this study a trend was observed, irrespective of the tested experimental factors, for greater protein content in maize grain to be found in drier and warm years (2009 and 2011) in comparison to grain of maize harvested in wet and cool weather (2010).

In this study protein content in grain was directly proportional to air temperature (r = 0.0762 in experiment I and r = 0.0762 in experiment II), while it was directly proportional to precipitation total (r = -0.1121 in experiment I and r = -0.0939 in experiment II); none of the four correlation coefficients was statistically significant. Prokszáné et al. [24] reported that protein content in maize grain was greater in dry years than in wet years.

Protein content and amino acid composition of maize grain are mainly determined genetically, but they may also be modified by ecological factors and cultivation measures. Among cultivation measures nitrogen fertilization modifies protein content in grain. Veress [25] stated that an adequate supply of nitrogen for plants increases protein content. Also, in this study it was shown that the lowest protein content was recorded for the dose of nitrogen of 0 $kg \cdot ha^{-1}$ (7.97%), while the highest for the doses of nitrogen at 100 $kg \cdot ha^{-1}$ (9.28%) and 150 $kg \cdot ha^{-1}$ (9.23%). In the opinion of Kruczek [26], in the case of nutrients in maize grain only protein content increases with an increase in nitrogen fertilization, with the increase being linear in character, which was also shown in this study. As reported by Sulewska and Ptaszyńska [17], in maize protein content was more strongly correlated with the course of weather conditions than with the genotype. In turn, in this study a significant effect was shown for the cultivar (genotype) in the modification of protein content in maize grain. A significantly greater protein content – in both field experiments – was observed in grain of cv. ES Paroli SG in comparison to cv. ES Palazzo. Also, Szmigiel et al. [21], when investigating the response to three maize hybrids to organic and mineral fertilization, recorded varied protein contents in maize grain depending on the type of fertilizer and the type of hybrid. Crude protein content in maize grain as well as its amino acid composition are not constant and may change depending on weather conditions in the vegetation period of plants, tillage and fertilization techniques, and the use of herbicides, as well as genetic factors, which also were indicated by Hwang et al. [27].

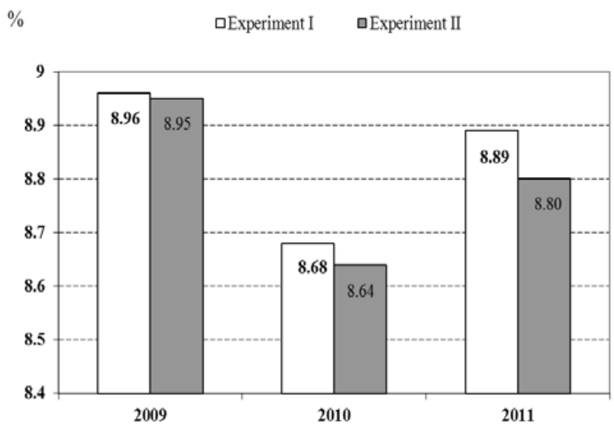

Fig. 5. Protein content in maize grain irrespective of experimental factors.

In this study the highest yield of protein was obtained from the cultivation of cv. ES Paroli SG in comparison to cv. ES Palazzo. This cultivar was characterized by a significantly greater yield of protein in both field trials (the difference amounting to 160.6 kg·ha^{-1} and 208.2 kg·ha^{-1}). The result recorded in this study confirms earlier literature reports [28]. In the study published by those authors it was also shown that the stay-green hybrid had a significantly greater yield of protein in comparison to the traditional cultivar.

In this study it was also shown that cv. ES Paroli SG in comparison to cv. ES Palazzo was characterized by a significantly greater yield of protein for each of the six tested nitrogen fertilizers. Statistically significant differences were recorded only for slow-release nitrogen fertilizers (urea, ammonium sulfate). Szulc et al. [29] reported that the behavior of stay-green plants should imply the application of slow-release fertilizers. This is determined by the negative remobilization index (nitrogen transfer) at the phase of grain filling. Release of nitrogen from slow-release nitrogen fertilizers occurs according to the dynamics of requirement for nitrogen in such cultivars [29], which results in a significantly greater yield of grain and, as a consequence, the yield of protein.

Moreover, it was shown in this study that the yield of protein in maize was significantly modified also by the interaction of the type of nitrogen fertilizer with the dose of magnesium. It was stated that when broadcasting urea and Canwil nitro-chalk with 25 kg MgO·ha^{-1} a significant increase was obtained in the yield of protein in comparison to the other nitrogen fertilizers. In turn, when applying ammonium sulfate with 25 kg MgO·ha^{-1} in maize culture resulted in a significant reduction of the yield of protein. In the opinion of Marschner [30] the presence of ammonia nitrogen in soil causes a considerable reduction of magnesium uptake. Uptake of nitrogen in the form of ammonia cation by plants leads to a strong acidification of the rhizosphere, which as a consequence leads to a reduction of cation uptake. As a result the production of organic acids is reduced, limiting the growth rate of plants and decreasing plant yield.

In this study protein content in grain did not determine the yield of grain in the absence of nitrogen fertilizer (Table 6). In experiment I the most advantageous effect on the yield of grain was found for protein content at the dose of nitrogen of 150 N; variation of the independent trait, i.e. protein content, determined the yield of grain in 17.4% (Table 6). In experiment II it was observed that at all the applied fertilizers protein content statistically significantly determined the yield of grain (Table 6). This dependence was best described by the regression equation for NH_4NO_3 (y=-852+1103x) (Table 6).

Conclusions

1. A better utilization of nitrogen from soil by the stay-green hybrid in comparison to the traditional cultivar, manifested in a greater protein content in grain observed for the application of urea, ammonium sulfate, Canwil nitro-chalk and a mixture of ammonium nitrate and urea. In turn, in the case of the yield of protein a similar dependence was recorded only for slow-release fertilizers, i.e. urea and ammonium sulfate.
2. Among the tested traits, i.e. protein content in grain and the yield of protein, only its amount was dependent on the weather conditions in the years of the study, which probably resulted from the difference in maize yielding. A lack of the effect of weather conditions on protein content resulted from limited diversification of weather conditions in the years of the study, particularly sufficient precipitation levels.
3. Under conditions in which field trials were conducted, the application of magnesium as a nutrient potentially enhancing uptake and utilization of nitrogen was not justified, as it is indicated by a lack of effect of its application on protein content in grain.
4. The stay-green hybrid proved to be more pro-ecological, better adapted to integrated maize growing in comparison to the traditional hybrid thanks to its better capacity to utilize soil nitrogen (N_{min}), and fertilization nitrogen. This is evidenced by a greater protein content in grain and a greater yield of protein irrespective of years, dose of nitrogen, the type of nitrogen fertilizer, and the application of magnesium.

References

1. TWEETEN L., THOMPSON S. R. Long-term agricultural output supply-demand balance and real farm and food prices. Working Paper AEDE-WP 0044-08, Ohio State University, Columbus, OH, **2008**.
2. KSIĘŻAK J., BOJARSZCZUK J., STANIAK M. The productivity of maize and sorghum yields depending on the level of nitrogen fertilization. Polish J. Agron. **8**, 20, **2012** [In Polish].
3. KSIĘŻAK J., MATYKA M., BOJARSZCZUK J., KACPRZAK A. Evaluation of productivity of maize and sorghum to be used for energy purposes as influenced by nitrogen fertilization. Žemdribystė=Agriculture **99**, (4), 363, **2012**.

4. ANDRASKI T., BUNDYG. L., BRYE K. R. Crop management and corn nitrogen rate effects on nitrate leaching. J. Environ. Quality **29**, 1095, **2000**.
5. AL-KAISI M. M., YIN X. Effects on nitrogen rate, irrigation rate and plant population on corn yield and water use efficiency. Agron. J. **95**, 1475, **2003**.
6. PENG Y., NIU J., PENG Z., HANG F., LI C. Shoot growth potential drives N uptake in maize plants and correlates with root growth in the soil. Field Crops Res. **115**, 85, **2010**.
7. NIU J., CHEN F. J., MI G. H., LI C. J., ZHANG F. S. Transpiration and nitrogen uptake and flow in two maize (*Zea mays* L.) inbred lines as affected by nitrogen supply. Annal. Botany **99**, 153, **2007**.
8. PRESTERL T., GROH S. Bedeutung der Stickstoof – Aufnahme und Verwertungsefficienz fur die Anpassung von Mais an unterschiedliche Dungungsniveau. Vortrage fur Pflanzenzuchtung **28**, 208, **1994**.
9. HIREL B., LE GOUIS J., GALLAIS A. The challenge of improving nitrogen use efficiency in crop plants: towards a more central role for genetic variability and quantitative genetics within integrated approaches. J. Exp. Bot. **58**, (9), 2369, **2007**.
10. CIU Z., ZHANG F., MI G., CHEN F., LI F., CHEN X., LI J., SHI L. Interaction between genotypic difference and nitrogen management strategy in determining nitrogen use efficiency of summer maize. Plant Soil **317**, 267, **2009**.
11. RUSSELL W. A. Comparison of the hybrid performance of maize inbred lines developed from the original and improved cycles of BSSS. Maydica **30**, 407, **1985**.
12. SZULC P. Effect of differentiated levels of nitrogen fertilization and the method of magnesium application on the utilization of nitrogen by two different maize cultivars for grain. Pol. J. Environ. Stud. **19**, (2), 407, **2010**.
13. SZULC P. Differences in the accumulation and redistribution of dry matter and N_{min} content in the cultivation of two different maize (*Zea mays* L.) cultivars for grain. Pol. J. Environ. Stud. **21**, (4), 1039, **2012**.
14. ROSENOW D. T., CLARK L. E. Drought tolerance in sorghum. In: Loden, H. D., Wilkinson D., (Eds). Proc. 36th Annu. Corn and Sorghum Industry Res. Conf. Chicago, IL, 9-11 Dec., ASTA, Washington, DC, pp. 18-31, **1981**.
15. OSAKI M., FUJISAKI Y., MORIKAWA K., MATSUMOTO M., SHINANO T., TADANO T. Productivity of high-yielding crops. IV. Parameters determining differences of productivity among field crops. Soil Sci. Plant Nutr. **39**, 605, **1993**.
16. WALTERS S. P., RUSSELL W. A., LAMKEY K. R. Comparison of phenotypic correlations among S1 lines, and their testcrosses, from four Iowa Stiff Stalk populations of maize. Maydica **36**, 39, **1991**.
17. SULEWSKA H., PTASZYŃSKA G. Influence of harvest date on content and yield of protein of six maize hybrids. Fragmenta Agronomica **1**, (97), 391, **2008** [In Polish]
18. PRASANNA M. B., VASAL S. K., KASSAHUN B., SINGH N. N. Quality protein maize. Current Sci. **81**, (10), 1308, **2001**.
19. IZSAKI Z. Relationship between the N_{min} content of the soil and the quality of maize (*Zea mays* L.) kernels. Res. J. Agricul. Sci. **43**, (3), 77, **2011**.
20. BRUŹDZIAK M. The dynamics of organic matter and accumulation of nutrients in the green parts of plants and the influence of some agrotechnical factors on yielding of maize. Zesz. Nauk. AR we Wrocławiu 70: pp. 1-57, **1998** [In Polish].
21. SZMIGIEL A., KOŁODZIEJCZYK M., OLEKSY A. The effect of organic and mineral fertilization on grain yield of maize. Fragmenta Agronomica **3**, (91), 70, **2006** [In Polish].
22. HOPKINS A. Potential impacts of climate change for grassland: farming industry perceptions, adaptations and mitigation options. Grass. Sci. Eur. **8**, 483, **2003**.
23. SZMIGIEL A. Wpływ kierunków rzędów względem stron świata i rozmieszczenia roślin na plon ziarna kukurydzy. Zesz. Nauk, AR Kraków **330**, (54), 239, **1998**.
24. PROKSZÁNÉ PAPLOGÓ, Z., SZÉLL, E., KOVÁCSNÉ KOMLÓS M. The effect of N-fertilisation on the yield and on several traits of maize under different seasonal effects on meadow silty soil. Növénytermelés **44**, 33, **1995**.
25. VERESS I. Changes in the amino-acids of maize grain as a response to nitrogen fertilization. Növénytermelés **22**, 125, **1973**.
26. KRUCZEK A. Effect of nitrogen fertilization on maize grain yield depending on the cultivar and sowing density. Pam. Puł. **81**, 105, **1983** [In Polish].
27. HWANG I. T., KIM K. J., LEE H. J., CHO K. Y., CHUN J. C. Inhibition characteristics of chlorsulfuron and imazaquin on acetolactate synthase activity of corn plants. Korean J. Weed Sci. **16**, (2), 122, **1996**.
28. SZULC P., WALIGÓRA H., SKRZYPCZAK W. Improvement of the effectiveness of maize (*Zea mays* l.) fertilization with nitrogen by the application of magnesium. Part II. Content of nutrients in grain and its energetic value. Acta Sci. Pol., Agricultura **7**, (4), 137, **2008**.
29. SZULC P., BOCIANOWSKI J., RYBUS-ZAJĄC M. Accumulation of N, P, K and Mg nutrient elements and nutrient remobilization indices in the biomass of two contrasting maize (*Zea mays* L.) hybrids. Fres. Envi. Bulletin **21**, (8), 2062, **2012**.
30. MARSCHNER H. Mineral nutrition of higher plants. Academic Press. 1st Ed., London, pp. 1-674, **1986**.