

TKW Variation in Maize in Relation to Mineral Fertilization – Comparative Analysis

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Abstract. The study evaluated the variation of the TKW (thousand kernel weight) parameter in corn in relation to differentiated mineral fertilization. The field experiment was placed within the ARDS Lovrin, in the climate and soil conditions specific to the Western Plain of Romania. The biological material was represented by the maize genotype 'DEKALB DKC 4109'. The maize crop was organized in a non-irrigated system, in the agricultural year 2024 – 2025. Mineral fertilization was done with phosphorus and potassium in autumn and nitrogen in spring. Phosphorus was applied in two doses (0, and 80 kg ha⁻¹ a.s.; a.s. – active substance). Potassium was applied in four doses (0, 40, 80, and 120 kg ha⁻¹ a.s.). Nitrogen was applied in three doses (0, 100, and 200 kg ha⁻¹ a.s.). The experiment included 16 experimental variants, in randomized blocks, in four repetitions. Sowing was done on April 15, 2025, with a density of 65000 plants ha⁻¹. Uniform crop technology was applied for the experimental variants. At harvest maturity, 9 BBCH Code, corn cob samples were taken from each experimental variant and repetition. Subsamples were extracted from the grain samples on which the values of the parameter TKW (thousand kernel weight, g) were determined. The average values, by experimental variants, were analyzed in the study. The thousand kernel weight values ranged from TKW = 211.20±3.09 g (V9) to TKW = 262.40±3.09 g (V14). The data series presented a normal distribution, with $r = 0.980$. No outliers were recorded, according to Grubbs test ($G = 2.286$; $p = 0.195$), respectively Dixon Q test ($Q(r22) = 0.4804$; $p = 0.119$). Polynomial models described the variation of TKW in relation to NPK, as variables in different combinations. Convergent contribution was recorded for N and P in the TKW variation, and divergent contribution was recorded for N and K, respectively P and K in the variation of TKW. The comparative analysis highlighted five variants with differences above the mean value (V7, $p < 0.01$, **; V13, $p < 0.01$, **; V14, $p < 0.001$, ***; V15, $p < 0.001$, ***; V16, $p < 0.01$, **), and four variants with differences below the mean value, under conditions of statistical safety. Cluster analysis grouped the variants based on similarity in relation to TKW values.

Keywords: clustering, mathematical models, maize, quality index, regression analysis, TKW

INTRODUCTION

Maize is one of the five main agricultural crops worldwide, with significant importance for food safety and security (Nuss, 2010; Bordini et al., 2019; Rizwanullah et al., 2023; Mdoda et al., 2025). Corn production is useful for human nutrition, for feed, for industrialization, in the biofuel industry, but also in other economic fields (Nuss and Tanumihardjo, 2010; Revilla et al., 2022; Zhang et al., 2022).

In the structure of crop plants, corn has an important share, with specific agronomic implications in relation to agricultural systems and types of crop rotations (Satorre, 2013; Bruno et al., 2025; Nascimento et al., 2025; Miranda, 2026). Corn crop performance was studied in relation to different agricultural practices, soil conditions, and soil quality and health indices (White et al., 2023; Conde-Barajas et al., 2025; Suri et al., 2026). The sustainability of the corn crop was analyzed in relation to climate change, abiotic stress generated by rainfall deficit and thermal regime (Kim and Lee, 2023; Rizwanullah et al., 2023; Tran et al., 2025). Within crop technologies, the tillage system was evaluated in relation to corn production efficiency (Liu and Wiatrak, 2012; Wang and Hu, 2021; Zeng et al., 2021).

The relationship of corn with nutrients and fertilizers was analyzed in different crop systems and fertilization rates, for quantitative and qualitative performance of useful biomass production (Batyrbek et al., 2022; Brodowska et al., 2022; Zhang et al., 2022). The contribution of mineral elements was evaluated in the performance of maize crop, in relation to different fertilization systems, farm systems and climate and soil conditions (Alouch et al., 2022; Agegnehu et al., 2025; Hlisenikovsky et al., 2026). Fertilization models have been communicated for agricultural crops in order to optimize technologies, yields and some economic indicators (Boldea and Sala, 2010; Cassim et al., 2022; Kaur et al., 2024).

Agronomic parameters in corn cobs vary in relation to genotype, environmental conditions, cultivation technology, and the role of mineral elements has been evaluated in particular in the formation of corn cob productivity elements (Selassie, 2015; Risman et al., 2025; Cui et al., 2026).

The present study evaluated the variation of 1000-seed weight (TKW) in maize, genotype 'DEKALB DKC 4109', in relation to variable-rate fertilization with NPK, in a non-irrigated cropping system.

MATERIAL AND METHODS

The study was conducted within ARDS Lovrin, in climate and soil conditions specific to the Western Plain of Romania, agricultural year 2024 - 2025, Figure 1. The corn crop, genotype 'DEKALB DKC 4109', was located in land conditions with medium fertility, chernozem soil, non-irrigated system.



Figure 1. Study location

The climatic conditions during the agricultural year 2024 – 2025 are presented in Figure 2. Higher temperatures were recorded compared to the multiannual average, except for May. The rainfall regime was deficient, compared to the multiannual average, in the months of April, June and August.



Figure 2. Climatic data for the experimental period (ARDS Lovrin Weather Station)

A classical system of works was used for land preparation; plowing in autumn and work with the combine in spring. In autumn, fertilization was done with phosphorus (concentrated superphosphate) and potassium (potassium salt). In spring, fertilization was done with nitrogen (ammonium nitrate), in two doses. Phosphorus was applied in two doses (0, and 80 kg ha⁻¹ a.s.; a.s. – active substance). Potassium was applied in four doses (0, 40, 80, and 120 kg ha⁻¹ a.s.). Nitrogen was applied in three doses (0, 100, and 200 kg ha⁻¹ a.s.).

The combination of fertilizer doses resulted in 16 experimental variants. Sowing was done on April 15, 2025, with a density of 65,000 plants ha⁻¹. Weed control was done by pre-emergence herbicide (Adengo, 0.6 L ha⁻¹). During the vegetation period, manual interventions were made occasionally, as needed.

At harvest maturity 9 BBCH Code (Meier, 2001), ear samples were collected for biometric determinations. 10 ear samples were taken randomly for each experimental variant and repetition.

The mass of 1000 kernels (TKW, g 100 kernels⁻¹) was determined from the obtained corn kernel samples. The determination was made by counting at the table and weighing with a laboratory balance.

Descriptive statistical analysis and characterization of the data series was performed. The variation of TKW values in relation to the applied fertilization was analyzed (quadratic regression analysis; $p < 0.05$ statistical significance). Comparative analysis of the variants was performed against the mean and median calculated at the experimental level (t Test; Wilcoxon Test; $p < 0.05$, and 95% confidence interval).

The trend of variation in the value series was assessed (Mann-Kendal trend test, $p < 0.05$). Linear regression analysis was used to describe the slope of the regression line and the trend of the distribution of variants. Cluster analysis was applied to group the variants based on similarity in relation to the performance for the TKW parameter (Coph.Corr., statistical parameter).

PAST software, v.4.14 (Hammer et al., 2001) and Mathematica software (2024) were used for data analysis and graph generation.

RESULTS AND DISCUSSIONS

Corn ear samples, 'DEKALB DKC 4109', were analyzed to determine the values of the parameter weight of 1000 kernels (TKW, g). Values ranging from TKW = 211.20±3.09 g (V9) to TKW = 262.40±3.09 g (V14) were recorded. The data series showed a normal distribution, with $r = 0.980$, Figure 3. The data series did not show outliers, according to Grubbs test ($G = 2.286$; $p = 0.195$), respectively Dixon Q test ($Q(r22) = 0.4804$; $p = 0.119$).

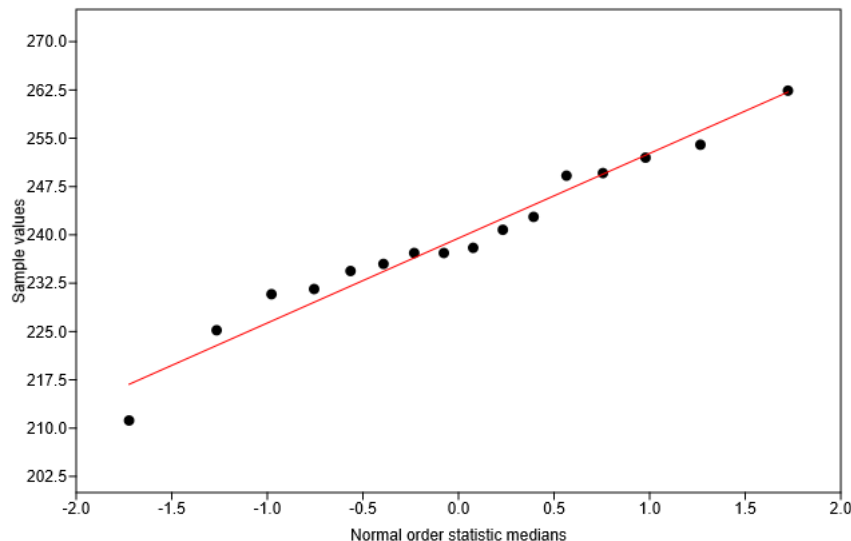


Figure 3. Normal distribution of the data series for the TKW parameter in maize, genotype 'DEKALB DKC 4109'

TKW values were analyzed in relation to the applied fertilizers. Quadratic regression analysis described the variation of TKW in relation to NPK doses, according to the general model given by Equation (1) and the values of the statistical safety parameters in Table 1. The graphical distribution of TKW values in relation to the considered variables is presented in Figure 4 ($x = N$, $y = P$), in Figure 5 ($x = N$, $y = K$), and in Figure 6 ($x = P$, $y = K$), respectively.

$$\text{TKW} = ax^2 + by^2 + cx + dy + exy + f \quad (6)$$

where: TKW – thousand kernel weight ($\text{g } 1000 \text{ kernel}^{-1}$); x , and y – variables of Equation (1), Table 1; a , b , c , d , e , f – coefficients of the Equation (1), Table 1.

Table 1. Variables and coefficients related to Equation (1)

Variables	Equation (1) coefficients						Statistical parameters		
	a	b	c	d	e	f	R ²	F	p
$x = N, y = P$	0.000727	4.41E+12	0	-3.5E+14	0.000271	238.372078	0.744	8.0153	0.0028
$x = N, y = K$	0.000879	-0.001848	-0.061600	0.293281	-0.000134	226.025000	0.636	3.4909	0.0438
$x = P, y = K$	3.67E-05	-0.001848	0	0.255094	0.000620	232.928750	0.134	0.4275	0.8197

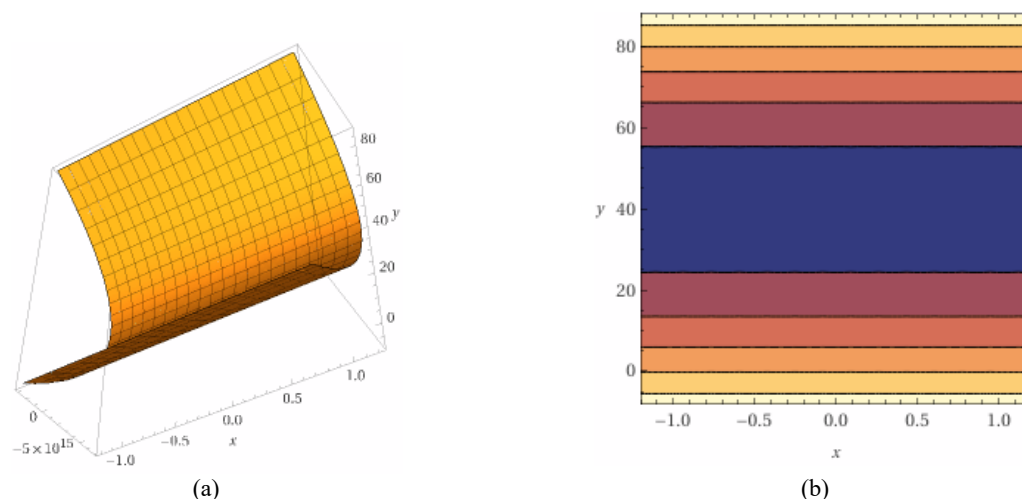


Figure 4. Graphical distribution of TKW in relation to N (x – axis) and P (y – axis), corn hybrid 'DEKALB DKC 4109'; (a) 3D model, (b) model in isoquants format

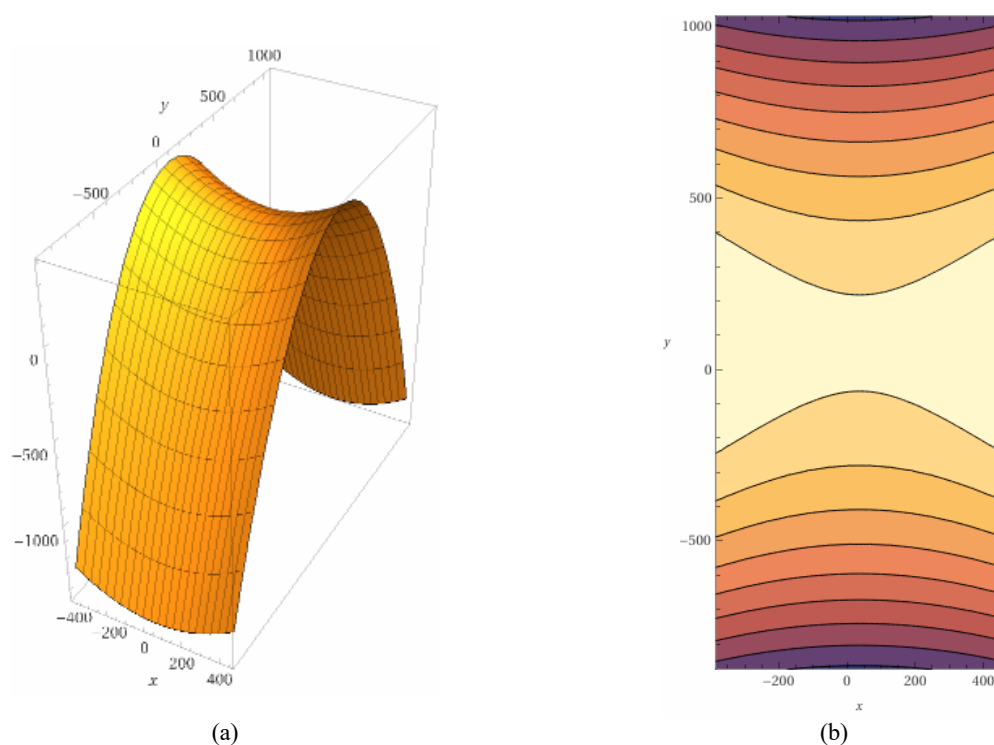


Figure 5. Graphical distribution of TKW in relation to N (x – axis) and K (y – axis), corn hybrid 'DEKALB DKC 4109'; (a) 3D model, (b) model in isoquants format

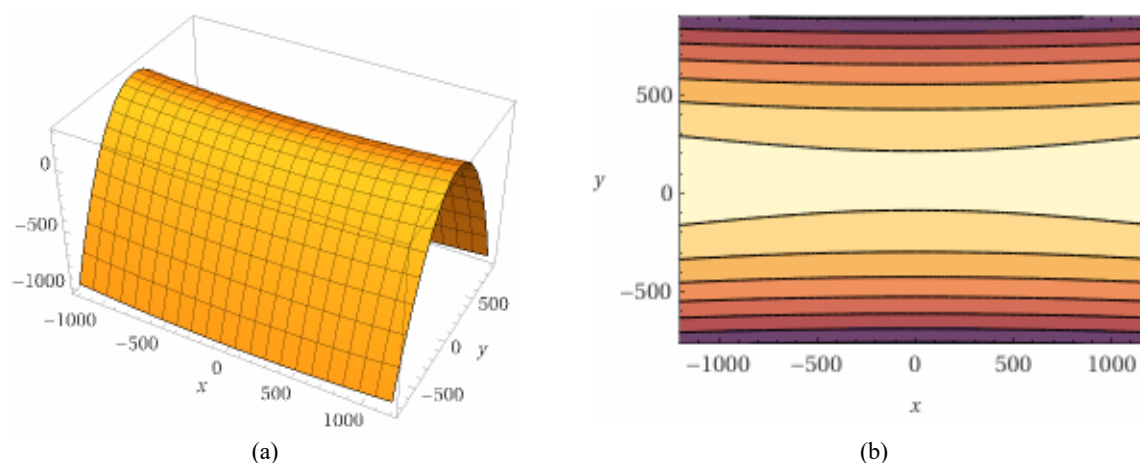


Figure 6. Graphical distribution of TKW in relation to P (x – axis) and K (y – axis), corn hybrid 'DEKALB DKC 4109'; (a) 3D model, (b) model in isoquants format

From the analysis of the values of the coefficients of Equation (1), Table 1, as well as from the graphic distribution, Figures 4 – 6, the convergent contribution of the variables N and P to the formation of the TKW values and the divergent contribution of the variables N and K, respectively P and K to the formation of the TKW values were observed.

The performance of each experimental variant was evaluated for the formation of the TKW parameter values. In the average case, at the experiment level, the TKW value was calculated = 239.49 g. Based on the comparative analysis (t Test), the experimental variants were positioned differently, Table 2.

Table 2. Variant performance and significance of differences for the TKW parameter in relation to the average value of the experiment

Trials	Given value	Sample mean	95% conf. interval	Difference	95% conf. interval	t	p (same mean)	Sig
V1	235.50	239.49	(232.9 246.09)	3.9937	(-2.6016 10.589)	1.2907	0.2164	ns
V2	225.20			14.2940	(7.6984 20.889)	4.6194	0.0003	ooo
V3	238.00			1.4937	(-5.1016 8.0891)	0.4827	0.6363	ns
V4	234.40			5.0937	(-1.5016 11.689)	1.6462	0.1205	ns
V5	237.20			2.2937	(-4.3016 8.8891)	0.7413	0.4700	ns
V6	242.80			3.3063	(-3.2891 9.9016)	-1.0685	0.3022	ns
V7	249.20			9.7063	(3.1109 16.302)	-3.1368	0.0068	**
V8	240.80			1.3063	(-5.2891 7.9016)	-0.4222	0.6789	ns
V9	211.20			28.2940	(21.698 34.889)	9.1439	1.60E-07	ooo
V10	230.80			8.6937	(2.0984 15.289)	2.8096	0.0132	o
V11	237.20			2.2937	(-4.3016 8.8891)	0.7413	0.4700	ns
V12	231.60			7.8937	(1.2984 14.489)	2.5511	0.0222	o
V13	249.60			10.1060	(3.5109 16.702)	-3.2661	0.0052	**
V14	262.40			22.9060	(16.311 29.502)	-7.4028	2.21E-06	***
V15	254.00			14.5060	(7.9109 21.102)	-4.6881	0.0003	***
V16	252.00			12.5060	(5.9109 19.102)	-4.0417	0.0011	**

Note: “*” – symbol for positive differences significance; “o” – symbol for negative differences significance; “ns” – not significant differences; * / o, $p < 0.05$; ** / oo, $p < 0.01$; *** / ooo, $p < 0.001$

Five variants with differences above the mean value were recorded, and four variants with differences below the mean value, under conditions of statistical certainty. In the case of the other seven variants, the differences did not present statistical certainty. With differences above the mean value, in conditions of statistical safety, the variants V7 ($p < 0.01$, **), V13 ($p < 0.01$, **), V14 ($p < 0.001$, ***), V15 ($p < 0.001$, ***), respectively

V16 ($p < 0.01$, **) were positioned. With differences below the mean value, in conditions of statistical safety, the variants V2 ($p < 0.001$, ooo), V9 ($p < 0.001$, ooo), V10 ($p < 0.05$, o), V12 ($p < 0.05$, o) were positioned. The graphic distribution of the differences, in relation to the mean value, is presented in Figure 7.

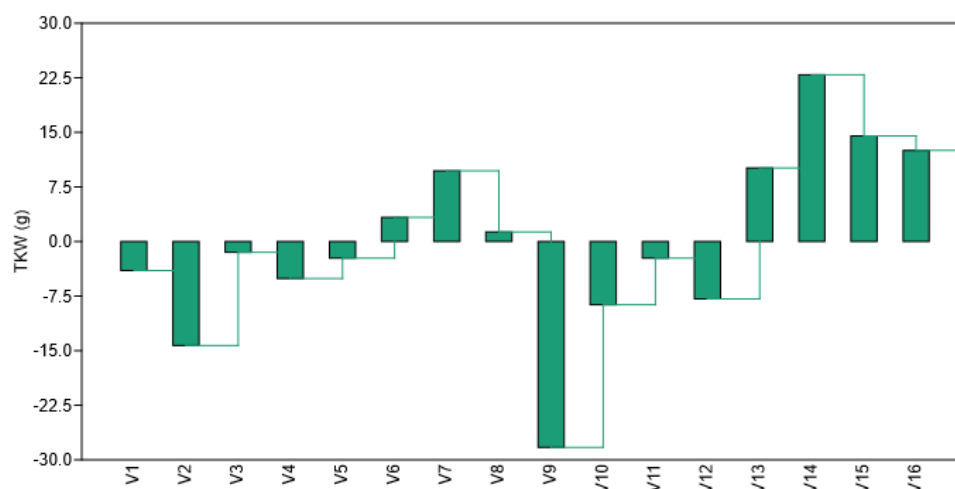


Figure 7. Graphical distribution of differences in relation to the average TKW value

In the case of the median, at the experiment level the value $TKW = 237.60$ g was calculated. Based on the comparative analysis (Wilcoxon Test), the experimental variants were positioned differently, Table 3. Five variants with differences above the median value were recorded, and four variants with differences below the median value, in conditions of statistical safety.

Table 3. Variant performance and significance of differences for the TKW parameter in relation to the median value of the experiment

Trials	Given value	Sample median	W	Normal appr. z	p (same median)	Sig
V1	235.50	237.60	85.00	1.4202	0.1556	ns
V2	225.20		112.00	2.9540	0.0031	oo
V3	238.00		68.00	0.4545	0.6495	ns
V4	234.40		87.50	1.5625	0.1182	ns
V5	237.20		65.50	0.8163	0.4143	ns
V6	242.80		76.00	0.9089	0.3634	ns
V7	249.20		105.00	2.5563	0.0106	*
V8	240.80		67.00	0.3977	0.6909	ns
V9	211.20		120.00	3.4085	0.0007	ooo
V10	230.80		104.00	2.4995	0.0124	o
V11	237.20		65.50	0.8163	0.4143	ns
V12	231.60		100.00	2.2732	0.0230	o
V13	249.60		106.00	2.6132	0.0090	**
V14	262.40		120.00	3.4085	0.0007	***
V15	254.00		116.00	3.1812	0.0015	**
V16	252.00		114.00	3.0676	0.0022	**

Note: “*” – symbol for positive differences significance; “o” – symbol for negative differences significance; “ns” – not significant differences; * / o, $p < 0.05$; ** / oo, $p < 0.01$; *** / ooo, $p < 0.001$

With differences above the median value, in conditions of statistical safety, the variants V7 ($p < 0.05$, *), V13 ($p < 0.01$, **), V14 ($p < 0.001$, ***), V15 ($p < 0.01$, **), and V16 ($p < 0.01$, **) were positioned. With differences below the median value, in conditions of statistical safety, the variants V2 ($p < 0.01$, oo), V9

($p < 0.001$, ooo), V10 ($p < 0.05$, o), and V12 ($p < 0.05$, o) were positioned. In the case of the other seven variants, the differences did not present statistical certainty. The graphical distribution of the differences, in relation to the mean value, is presented in Figure 8.

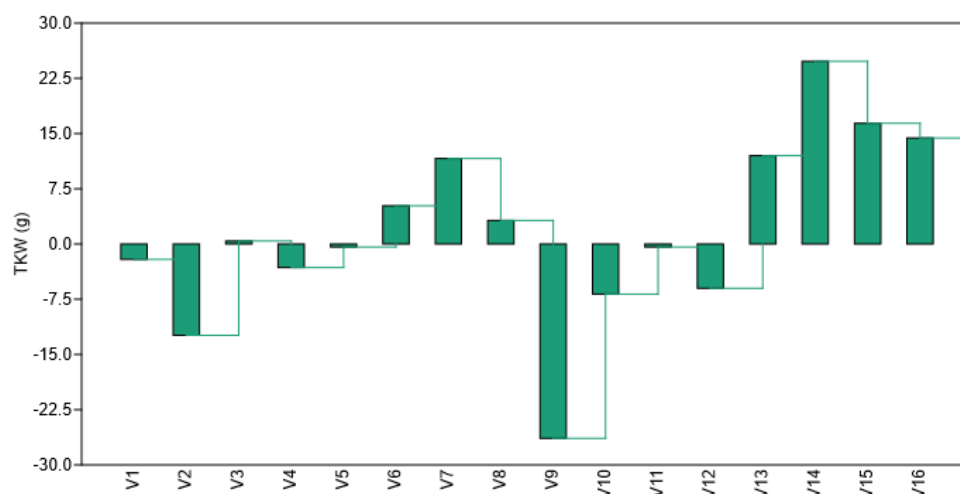


Figure 8. Graphical distribution of differences in relation to the average TKW value

Mann-Kendall trend test indicated an increasing trend in the data series, statistically significant, according to the statistical parameters $S = 47$, $Z = 2.073$, $p = 0.038$.

Starting from the statistically confirmed trend, linear regression analysis was applied, with the graphical representation of the function (Slope $a = 1.2869$, $t = 2.1317$, intercept $b = 228.55$) and the distribution of variants in statistical safety conditions (95% confidence interval) in Figure 9. The positioning outside the 95% confidence interval (slope a (0.50245, 2.4465); intercept b (221.72, 237.77)) of variant V9 was observed, which otherwise recorded the largest negative deviation in relation to the mean and median at the experiment level. The other 15 variants were included in the confidence interval (95%).

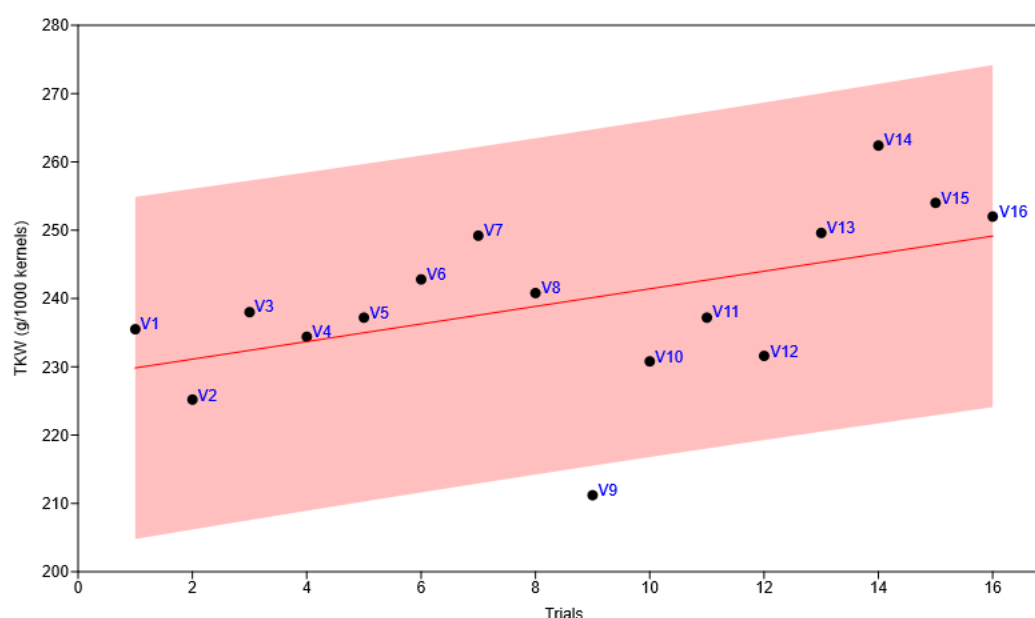


Figure 9. Graphical distribution of variants in relation to the regression line

Cluster analysis was applied to find out the grouping of variants based on similarity in relation to performance for TKW values. The dendrogram in Figure 10 resulted, in conditions of statistical safety

(Coph.corr. = 0.829). The independent positioning of variant V9 was observed, with the lowest performance for the TKW parameter under the study conditions. The other variants were grouped into two clusters based on similarity, with the SDI values (similarity and distance indices) presented in Table 4.

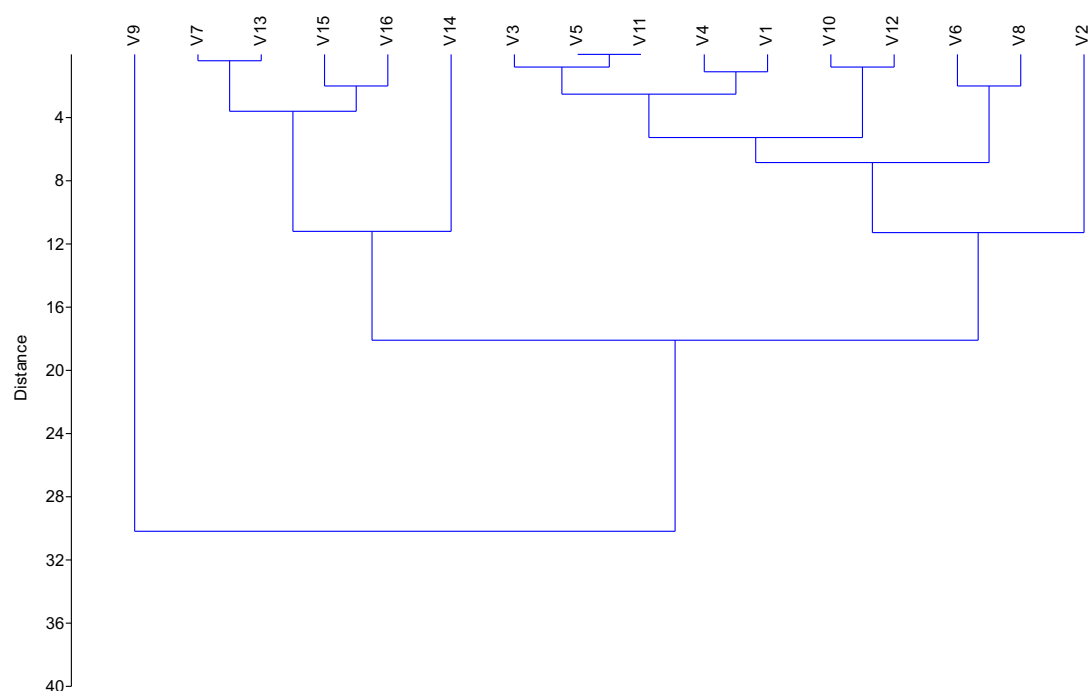


Figure 10. Cluster diagram with grouping of variants based on similarity in relation to TKW values in maize, genotype 'DEKALB DKC 4109'

Table 4. SDI values for experimental variants based on TKW parameter, 'DEKALB DKC 4109' maize genotype

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16
V1		10.30	2.50	1.10	1.70	7.30	13.70	5.30	24.30	4.70	1.70	3.90	14.10	26.90	18.50	16.50
V2	10.30		12.80	9.20	12.00	17.60	24.00	15.60	14.00	5.60	12.00	6.40	24.40	37.20	28.80	26.80
V3	2.50	12.80		3.60	0.80	4.80	11.20	2.80	26.80	7.20	0.80	6.40	11.60	24.40	16.00	14.00
V4	1.10	9.20	3.60		2.80	8.40	14.80	6.40	23.20	3.60	2.80	2.80	15.20	28.00	19.60	17.60
V5	1.70	12.00	0.80	2.80		5.60	12.00	3.60	26.00	6.40	0.00	5.60	12.40	25.20	16.80	14.80
V6	7.30	17.60	4.80	8.40	5.60		6.40	2.00	31.60	12.00	5.60	11.20	6.80	19.60	11.20	9.20
V7	13.70	24.00	11.20	14.80	12.00	6.40		8.40	38.00	18.40	12.00	17.60	0.40	13.20	4.80	2.80
V8	5.30	15.60	2.80	6.40	3.60	2.00	8.40		29.60	10.00	3.60	9.20	8.80	21.60	13.20	11.20
V9	24.30	14.00	26.80	23.20	26.00	31.60	38.00	29.60		19.60	26.00	20.40	38.40	51.20	42.80	40.80
V10	4.70	5.60	7.20	3.60	6.40	12.00	18.40	10.00	19.60		6.40	0.80	18.80	31.60	23.20	21.20
V11	1.70	12.00	0.80	2.80	0.00	5.60	12.00	3.60	26.00	6.40		5.60	12.40	25.20	16.80	14.80
V12	3.90	6.40	6.40	2.80	5.60	11.20	17.60	9.20	20.40	0.80	5.60		18.00	30.80	22.40	20.40
V13	14.10	24.40	11.60	15.20	12.40	6.80	0.40	8.80	38.40	18.80	12.40	18.00		12.80	4.40	2.40
V14	26.90	37.20	24.40	28.00	25.20	19.60	13.20	21.60	51.20	31.60	25.20	30.80	12.80		8.40	10.40
V15	18.50	28.80	16.00	19.60	16.80	11.20	4.80	13.20	42.80	23.20	16.80	22.40	4.40	8.40		2.00
V16	16.50	26.80	14.00	17.60	14.80	9.20	2.80	11.20	40.80	21.20	14.80	20.40	2.40	10.40	2.00	

One cluster included five variants, which presented superior values for the TKW parameter. Variant V14 was independently positioned within the cluster, along with four other variants associated based on similarity (V7,V13), respectively (V15,V16). The highest level of similarity in the cluster with performing variants was

recorded between variants V7 and V13 (SDI = 0.40). The second cluster grouped the other variants, with negative differences from the experiment average (V2, V9, V10, V12), or the variants with positive or negative differences, but without statistical certainty. Within this cluster, the highest level of similarity was recorded between variants V5 and V11 (SDI = 0.00).

CONCLUSIONS

The experimental variants generated differentiated variation in the values of the TKW parameter in maize, genotype 'DEKALB DKC 4109', in relation to the applied NPK rate.

The experimental data series presented a normal distribution, without outlier values, in conditions of statistical safety, which confirmed the experimental rigor.

Regression analysis led to polynomial models, which described in statistical terms the variation of the TKW parameter in relation to NPK, as independent variables in different combinations. Convergent contribution was recorded for N and P, and divergent contribution in the case of N and K, respectively P and K in the formation of TKW values. The results showed that the optimization of the three fertilizers requires a differentiated approach for TKW performance, under the study conditions.

The comparative analysis highlighted five experimental variants with performance above the average value of the experiment, in conditions of statistical safety: V7 ($p < 0.01$, **), V13 ($p < 0.01$, **), V14 ($p < 0.001$, ***), V15 ($p < 0.001$, ***), and V16 ($p < 0.01$, **).

Cluster analysis facilitated the grouping of variants based on similarity, in relation to performance for the TKW parameter, and thus provided useful information for selecting fertilization variants in relation to the TKW level considered as the objective.

The results need to be analyzed in conjunction with other corn crop performance parameters, in order to select technologically efficient variants.

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