

Working Model for Improving Corn Crop Technology through Fertilization – Case Study in Farm Conditions

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Abstract. This study presents a way of working to improve corn cultivation technology (KWS Kashmir hybrid) under differentiated fertilization conditions. The study was conducted within the ATU Cenai, Timis County, during 2023 - 2024. Two fertilized variants were created, with complexes 20/20/20+SO₃+Zn (235 kg ha⁻¹, fertilized – F /0 kg ha⁻¹ unfertilized – UF). On the two created variants, a common fertilization fund with urea (250 kg ha⁻¹) and foliar products (Albit, 40 ml ha⁻¹; Solar verde, 3 L ha⁻¹) was ensured. For the differentiated evaluation, the following parameters and indices were determined: agronomic parameters (plant height – PH, number of leaves per plant – LN), physiological indices (chlorophyll content – Chl, carotenoid content – Car), productivity elements (number of ears per plant – EP, ear diameter – ED, ear length – EL, ear weight – EW, grain weight – GW, rachis weight – RW). Hectoliter weight (HW, kg hl⁻¹) was determined for grain samples. In both fertilization variants, high variability was recorded for the EP parameter. In the fertilized variant, higher values were recorded with significant differences compared to the unfertilized one for PH ($p<0.05$), for Chl ($p<0.01$) and for Car ($p<0.001$). In the case of productivity elements, in the unfertilized variant, negative differences were recorded compared to the fertilized variant, with statistical certainty, for EW and GW ($p<0.05$), and in the case of ED ($p<0.001$). Quadratic polynomial models described the variation of the EW parameter in relation to the ED and EL elements, with statistical certainty ($R^2 = 0.883$ in the fertilized variant; $R^2 = 0.965$ in the unfertilized variant). Convergent action of the ED and EL elements was recorded in the formation of EW in the fertilized variant, and divergent action in the case of the unfertilized variant.

Keywords: small-scale farming, crop technology, maize, fertilizers, comparative analysis

INTRODUCTION

Recent studies have shown that the majority of agricultural farms in the world are small farms, which have an important position in sustainable agricultural development (Ricciardi et al., 2021). The study authors found differentiated relationships between farm sizes and their economic and ecological elements, respectively, and showed the ecological and ecosystem advantages of small farms compared to large ones.

Small-scale agriculture provides a series of direct and indirect, economic, socio-cultural and environmental benefits (Dhillon and Moncur, 2023). At the same time, small-scale agriculture faces a series of challenges, of an ecological nature (e.g. climate change, water scarcity, soil degradation), economic (e.g. inputs, marketing) and social (e.g. labor force, level of qualification). Access to technological progress has also been a sensitive issue for small and medium-sized farms (Dhillon and Moncur, 2023). A number of barriers have been identified that limit small farms' access to technological progress (Dhillon and Moncur, 2023).

In relation to different categories of indicators (direct, and indirect), agricultural sustainability is a complex issue, involving both individual and collective aspects (Oukil et al., 2023). Sustainability approach studies have identified the need and desire at the farm level for information, for learning, for the exchange of knowledge and experience (Sadovska and Fernqvist, 2023). Sustainable agriculture is based on "key agricultural practices", with low ecological costs, that support soil functions and health (Sharma et al., 2024).

Sustainable agricultural practices were analyzed in the conditions of small family farms specific to Germany (Wuepper et al., 2020). The study authors identified greater spatial diversity within small family farms, and greater temporal diversity, with differentiated effects on ecological sustainability.

Recent studies based on data from different European countries (e.g. Poland, Romania, Lithuania), through qualitative evaluation methods, have shown that in rural areas, small farms fulfill a number of important environmental functions (Stępień et al., 2022). A prospective analysis in different regions of Europe regarding small farms and their role in agri-food security, showed the interest of the study participants in this direction, and certain strategies and action plans were outlined (Moreno-Pérez et al., 2024).

Advanced technologies in agriculture are based on high inputs and do not always synchronize with smallholder farmers (Parwada et al., 2023). Productivity among smallholder farmers is still low, variable from one season to another, precisely as a result of high costs per season. Within advanced technologies, synthetic fertilizers represent a high-cost component, so in many cases fertilizers are used in smallholder farms at suboptimal levels, with effects on soil and crop yields (Parwada et al., 2023).

Farmers' transition from unilateral use of N fertilizers to more balanced fertilizations, or to complex crop structures, requires information, documentation and trials to find the appropriate variant for specific crop

conditions, as well as confidence in the new variants (Aguiar-Noury et al., 2025).

Agricultural crops have been studied in relation to different fertilizers and fertilization systems, with the aim of optimizing yields, soil conservation and the sustainability of agricultural practices (Boldea and Sala, 2010; Agapie and Sala, 2022; Gheith et al., 2022; Zhou et al., 2024; Mhoro et al., 2025).

Maize is a major crop that is suitable for all types of farms and cropping systems (Cecil et al., 2023; Erenstein et al., 2022; Ali et al., 2024). Corn production was analyzed in relation to fertilization strategies and farm sizes, in the context of interest in the sustainability of small farms (Yu et al., 2023). The authors of the study took into account different variables (farm resources, yield, socio-economic elements, farmers' knowledge level, perceptions, etc.), and through regression analysis found the differentiated contribution of fertilizers to the corn crop under the study conditions. Different correlations were found between the level of farm size, farmers' interest, and recorded yields (Yu et al., 2023).

The study analyzed the influence of some fertilization options on corn cultivation, as an attempt by the farmer to improve cultivation technology in conditions specific to small, family farms.

MATERIAL AND METHODS

The study was conducted during the agricultural years 2022 - 2024, and the field experiment in the agricultural year 2023 - 2024, in the area of the Cenei locality, Timis County, Romania, figure 1. The soil was of chernozem type, with pH = 6.4, humus content at the level H = 3.8%, organic matter content MO = 11%, nitrogen index NI = 2.55, phosphorus content P₂O₅ = 74 ppm, and potassium content K₂O = 243 ppm.



Figure 1. Study location, ATU Cenei, Timis County, Romania (27)

The land was prepared by scarification in the fall and a pass with a disc harrow in the spring. At sowing, a fertilization with complexes (20:20:0+SO₃+Zn), 235 kg ha⁻¹, was made for the fertilized variant (F), and respectively 0 kg ha⁻¹ for the unfertilized variant (UF). In vegetation, fertilization with urea, 250 kg ha⁻¹, was applied.

Pre-emergence herbicide was applied with Glyphosate (3 L ha⁻¹). Two herbicides were applied in the vegetation. At the beginning of May, Amino 600SL Acid 2,4D (1 L ha⁻¹) and Nicogan 40 OD nicosulfuron (1.3 L ha⁻¹) were applied. Albit (40 ml ha⁻¹) was applied in association with the first post-emergence herbicide. At the beginning of June, Radial Extra (1 L ha⁻¹) and Compas Super (500 ml ha⁻¹) were applied. Solar verde (3 L ha⁻¹) was applied in association with the second post-emergence herbicide.

The maize hybrid 'KWS Kshmir', FAO group 370, was cultivated. A treatment with Albit was applied to the seed. The maize crop was in a non-irrigated system, at a density of 64,000 plants ha⁻¹.

By mineral fertilization of the soil with complexes (20:20:0+SO₃+Zn), two variants were created, fertilized (F) and unfertilized (UF). Within each variant, an area of 0.25 ha was considered for observations, with plant study modules. The other elements of the technology were common.

During the vegetation period, determinations were made on corn plants for agronomic parameters and physiological indices, at stage 6 BBCH code (Meier, 2001). Plant height (PH, cm), number of leaves per plant (LN), number of leaves up to ear (LNuE), and number of ears per plant (EP), chlorophyll content (Chl, SPAD-502Plus device), carotenoid content (Car, ACM-200 Plus device) were determined.

At harvest maturity, 9 BBCH code (Meier, 2001) ear samples were collected and productivity elements were determined: ear length (EL, cm), ear diameter (ED, mm), ear weight (EW), grain weight (GW) and rachis weight (RW). Weighing was done with a laboratory balance, precision ± 0.05 g. Hectoliter weight (HW, kg hl⁻¹) was determined from the grain samples, on the two given technological variants of fertilization.

Descriptive statistical analysis was used for the general evaluation of the experimental data. Data variability was evaluated through statistical and graphical analysis (diversity profile). Correlation analysis was used to quantify the interdependence relationship between the parameters in the ears. Regression analysis was applied to find out the variation of the weight of the ears in relation to dimensional elements. Mathematical and statistical tools were used in relation to the purpose of the investigations (Hammer et al., 2001; Wolfram Alpha, 2020; JASP, 2022). The study was carried out based on the flow chart designed by the authors, figure 2.

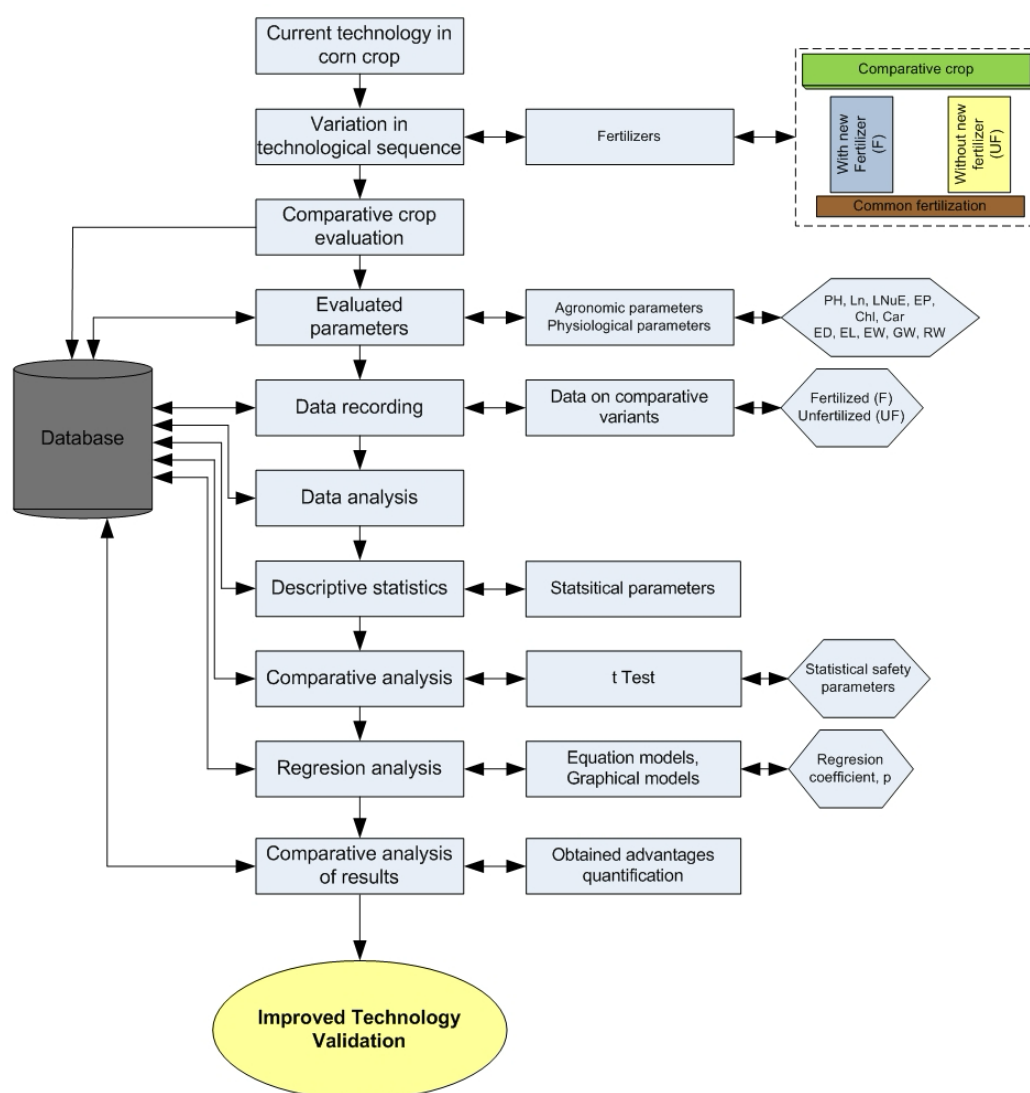


Figure 2. Flowchart for evaluating the technological advantages of fertilization in corn cultivation

RESULTS AND DISCUSSIONS

On the two corn cultivation variants, fertilized / unfertilized, agronomic parameters of the plants, physiological indices, and biometric parameters of the corn ears were determined. Descriptive statistical analysis led to the data in table 1 (plant parameters) and table 2 (ear parameters).

Table 1. Descriptive statistics for corn plant parameters

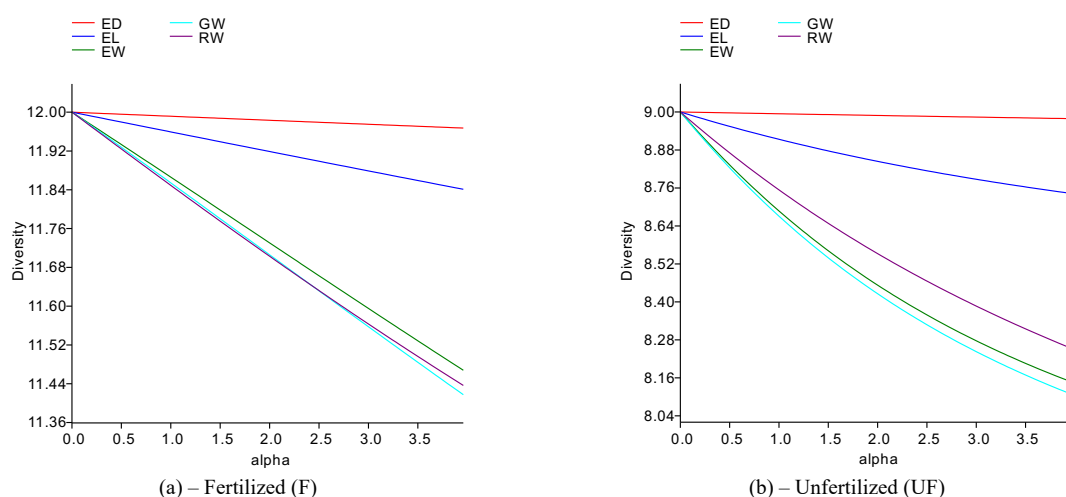
Statistical Parameters	Fertilized (F)						Unfertilized (UF)					
	PH	LN	LNuE	EP	Chl	Car	PH	LN	LNuE	EP	Chl	Car
Min	228.00	14.00	8.00	1.00	53.50	13.50	183.00	13.00	7.00	1.00	55.50	13.90

Max	253.00	15.00	9.00	3.00	64.30	20.40	229.00	15.00	8.00	2.00	59.20	16.30
Mean	240.60	14.40	8.20	2.20	59.19	17.44	216.00	14.00	7.20	1.60	57.36	14.97
Std. error	4.86	0.24	0.20	0.37	1.11	0.71	8.44	0.32	0.20	0.24	0.44	0.23
Std. dev	10.88	0.55	0.45	0.84	3.51	2.24	18.88	0.71	0.45	0.55	1.38	0.72
Median	236.00	14.00	8.00	2.00	59.05	17.70	224.00	14.00	7.00	2.00	57.15	14.90
25 prentil	231.50	14.00	8.00	1.50	55.88	15.75	200.50	13.50	7.00	1.00	56.20	14.40
75 prentil	252.00	15.00	8.50	3.00	62.55	19.28	227.50	14.50	7.50	2.00	58.78	15.48
Skewness	0.25	0.61	2.24	-0.51	-0.04	-0.57	-1.99	0.00	2.24	-0.61	0.03	0.31
Kurtosis	-2.46	-3.33	5.00	-0.61	-0.85	-0.47	4.08	2.00	5.00	-3.33	-1.60	-0.03
Coeff. var	4.52	3.80	5.45	38.03	5.94	12.84	8.74	5.05	6.21	34.23	2.41	4.83

Table 2. Descriptive statistics for corn ear parameters

Statistical Parameters	Fertilized (F)					Unfertilized (UF)				
	ED	EL	EW	GW	RW	ED	EL	EW	GW	RW
Min	41.28	16.00	127.00	111.60	13.70	37.88	12.50	70.00	60.50	9.50
Max	46.80	21.00	203.50	180.30	23.20	43.18	21.00	172.80	151.90	22.90
Mean	44.30	18.38	158.25	140.27	17.98	41.23	18.90	137.58	120.48	17.10
Std. error	0.50	0.46	7.23	6.70	0.86	0.51	0.89	12.38	11.12	1.38
Stand. dev	1.73	1.58	25.06	23.22	2.99	1.52	2.66	37.13	33.36	4.15
Median	43.87	18.15	152.25	134.40	17.55	41.60	20.00	141.70	122.70	17.30
25 prentil	43.51	17.33	139.10	123.18	15.48	40.48	18.05	107.60	93.75	13.85
75 prentil	45.61	19.85	180.53	160.10	20.70	42.13	20.75	169.30	149.55	20.15
Skewness	-0.21	0.16	0.69	0.77	0.23	-1.33	-2.05	-0.87	-0.84	-0.55
Kurtosis	-0.70	-1.05	-0.57	-0.52	-1.09	2.54	4.64	-0.38	-0.45	-0.01
Coeff. var	3.90	8.62	15.83	16.56	16.64	3.69	14.09	26.98	27.69	24.26

According to the coefficient of variation (CV) values, low variability was recorded in agronomic and physiological parameters of the plants, except for the EP parameter (ears per plant) where high variability was recorded in both variants, fertilized (CV = 38.03), unfertilized (CV = 34.23). In the fertilized variant, the lowest level of variability was recorded for the LN parameter (CV = 3.80), and in the unfertilized variant, the lowest level of variability was recorded for the Chl parameter (CV = 2.41). In the case of corn ear parameters, in the fertilized variant all parameters showed low variability, with the lowest value in the ED parameter (CV = 3.90). In the unfertilized variant, low variability was recorded in the ED and EL parameters, with the lowest value in the ED parameter (CV = 3.69) and moderate variability in the other parameters. The diversity profile for corn ear parameters is presented in figure 3.

**Figure 3.** Diversity profiles for corn ears parameters, by fertilization options

For agronomic parameters of plants and productivity parameters at the ear level, a comparative analysis was made between the two crop variants, based on average values.

For plant height (PH) and photosynthetic pigment content (Chl, Car), the results of the comparative analysis are presented in table 3. The PH parameter in the fertilized variant presented a positive difference compared to the unfertilized variant, in conditions of statistical safety ($p < 0.05$, *).

The chlorophyll (Chl) content in the leaves of the fertilized corn plants showed a positive difference compared to the unfertilized variant, in conditions of statistical safety, at the $p < 0.01$ level, **. The carotenoid (Car) content in the leaves of the fertilized corn plants showed a positive difference compared to the unfertilized variant, at the $p < 0.001$ level, ***.

In the case of productivity parameters at the ear level, the results of the comparative analysis are presented in table 4.

Table 3. Significance of differences in some parameters in corn plants

Statistical Parameters	Plants parameter		
	PH	Chl	Car
Given mean: F	240.60	59.19	17.44
Sample mean: UF	216.00	57.36	14.97
95% conf. interval:	(192.56 239.44)	(56.373 58.347)	(14.453 15.487)
Difference:	24.60	1.83	2.47
95% conf. interval:	(1.1559 48.044)	(0.84269 2.8173)	(1.953 2.987)
t :	-2.9133	-4.1929	-10.8070
p (same mean):	0.044	0.002	1.87E-06
Significance of differences	*	**	***

Table 4. Significance of differences in some parameters in corn ears

Statistical Parameters	Maize ears parameter				
	ED	EL	EW	GW	RW
Given mean: UF	41.23	18.90	137.58	120.48	17.10
Sample mean: F	44.30	18.38	158.25	140.27	17.98
95% conf. interval:	(43.2 45.393)	(17.377 19.39)	(142.33 174.17)	(125.51 155.02)	(16.082 19.885)
Difference:	3.07	0.52	20.67	19.79	0.88
95% conf. interval:	(1.97 4.1633)	(-0.4897 1.523)	(4.7503 36.59)	(5.0321 34.541)	(-1.0183 2.785)
t :	6.1548	-1.1300	2.8577	2.9516	1.0224
p (same mean):	7.16E-05	0.283	0.016	0.013	0.329
Significance	ooo	ns	o	o	ns

In the case of ear diameter (ED, mm), the average value in the unfertilized variant ($ED = 41.23 \pm 0.51$ mm) presented a negative difference compared to the fertilized variant ($ED = 44.30 \pm 0.50$ mm), in conditions of $p < 0.001$ (ooo).

In the case of the ear weight parameter (EW, g) the average value in the unfertilized variant ($EW = 137.58 \pm 12.38$ g) showed a difference from the average value in the fertilized variant ($EW = 158.25 \pm 7.23$ g) in conditions of $p < 0.05$ (°). Similarly, in the case of the grain weight parameter (GW, g) the average value in the unfertilized variant ($GW = 120.48 \pm 11.12$ g) showed a difference from the average value in the fertilized variant ($GW = 140.27 \pm 6.70$ g) in conditions of statistical safety, $p < 0.05$ (°).

For the ear length parameter (EL, cm), and for the rachis length parameter (RL, cm), the differences between the average values in the unfertilized variant and the average values in the fertilized variant did not present statistical significance ($p > 0.05$).

The interdependence between the ear parameters was evaluated by correlation analysis, with the results presented in Table 5. In the case of the fertilized variant, a correlation was recorded between GW and EW, $r = 0.995^{***}$. Strong correlation was recorded between EW and EL, $r = 0.849^{**}$, respectively between GW and EL, $r = 0.827^{***}$. A weak correlation was recorded between EW and ED, $r = 0.634^*$, between GW and ED, $r = 0.615^*$, between RW and EL, $r = 0.689^*$ and respectively between RW and EW, $r = 0.650^*$. At the level of the other ear parameters, correlations were recorded but without statistical certainty, table 5. In the case of the unfertilized variant, seven very strong correlations and three strong, positive correlations were recorded, in conditions of statistical certainty, table 5.

Table 5. Correlation coefficient values at the level of corn ear parameters

Variable		Fertilized (F)					Unfertilized (UF)				
		ED	EL	EW	GW	RW	ED	EL	EW	GW	RW
ED	Pearson's r	—					—				
	p-value	—					—				
EL	Pearson's r	0.447	—				0.927***	—			
	p-value	0.146	—				< .001	—			
EW	Pearson's r	0.634*	0.849***	—			0.908***	0.912***	—		
	p-value	0.027	< .001	—			< .001	< .001	—		
GW	Pearson's r	0.615*	0.827***	0.995***	—		0.900***	0.904***	0.999***	—	
	p-value	0.033	< .001	< .001	—		< .001	< .001	< .001	—	
RW	Pearson's r	0.535	0.689*	0.650*	0.572	—	0.885**	0.891**	0.917***	0.896**	—
	p-value	0.073	0.013	0.022	0.052	—	0.001	0.001	< .001	0.001	—

The variation in corn ear weight was analyzed in relation to the diameter and length of the ears (ED, EL), for the two situations, fertilized and unfertilized.

In the case of the fertilized variant, the variation of the EW parameter in relation to ED and EL was described by equation (1) under conditions of $R^2 = 0.883$, $F = 9.051$, $p = 0.0091$, with the graphical distribution in figure 4.

$$EW_{(F)} = a x^2 + b y^2 + c x + d y + e xy + f \quad (1)$$

where:

$EW_{(F)}$ – ear weight in fertilized variant (g)

x – ED, mm; y – EL, cm;

a, b, c, d, e, f – parameter of equation (1);

$a = 1.06015049$;

$b = 4.44216977$;

$c = -44.84374606$;

$d = -43.00444330$;

$e = -2.46284002$;

$f = 1348.99007393$

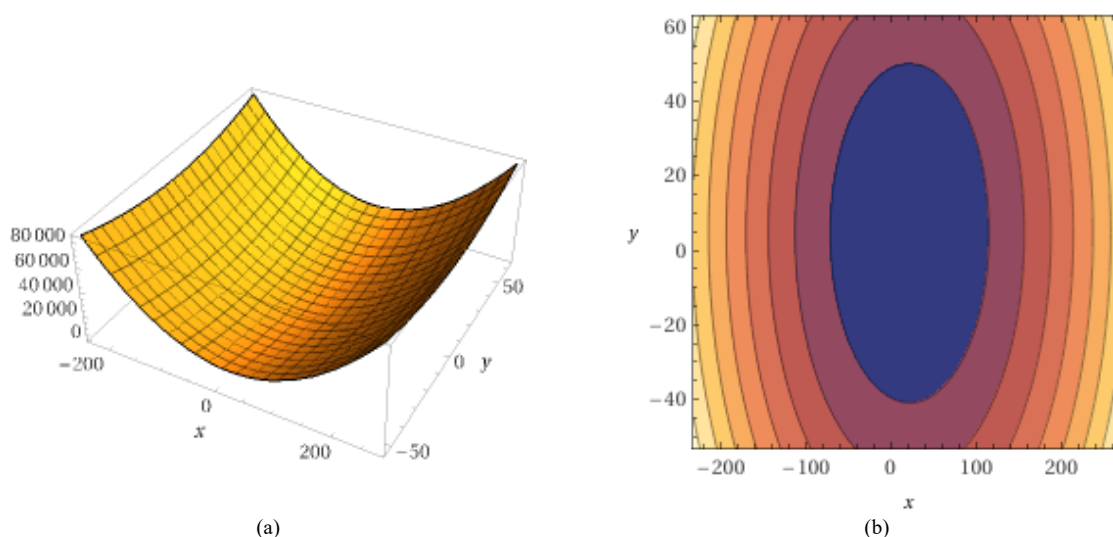


Figure 4. Graphical distribution of the EW parameter in relation to ED (x – axis), and EL (y – axes), fertilized variant

From the analysis of the results, represented by the values of the coefficients of equation (1) and the graphic models (figure 4), it was found the convergent action of the two parameters (ED and EL) in the formation of EW values, in the fertilized variant. A wider variation of EW was associated with the EL parameter.

The data show that the two parameters can be directed simultaneously by fertilization, under the study conditions.

In the case of the unfertilized variant, the variation of the EW parameter in relation to ED and EL was described by equation (2) under conditions of $R^2 = 0.965$, $F = 16.6505$, $p = 0.0213$, with the graphical distribution in figure 5.

$$EW_{(UF)} = a x^2 + b y^2 + c x + d y + e xy + f \quad (2)$$

where:

$EW_{(UF)}$ – ear weight in the unfertilized variant (g)

x – ED, mm;

y – EL, cm;

a, b, c, d, e, f – parameter of equation (2);

$a = -0.08987138$;

$b = 7.84200401$;

$c = 253.18773277$;

$d = 196.41459913$;

$e = -11.77147201$;

$f = -7499.00806047$

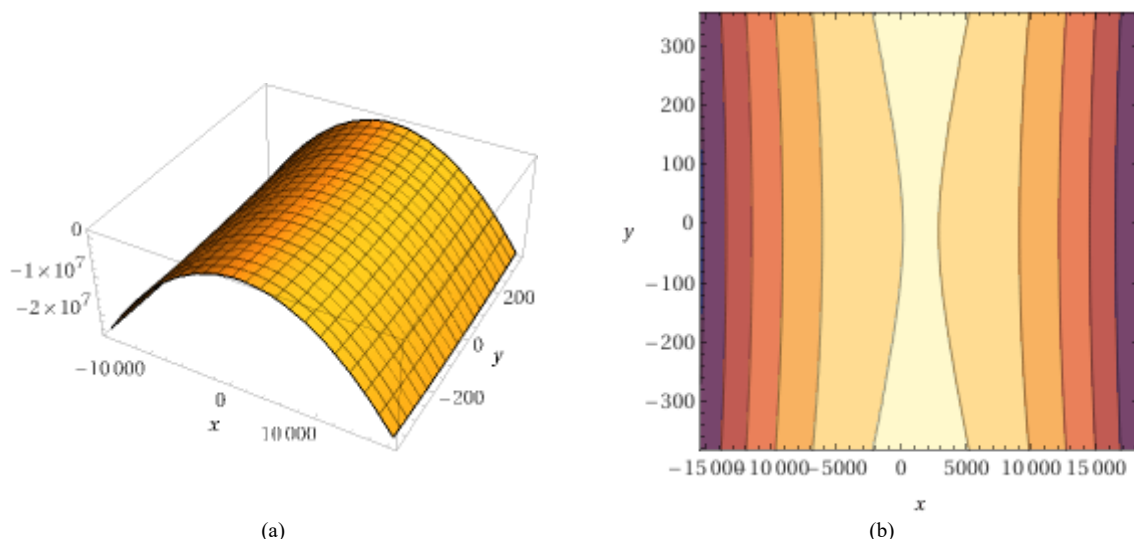


Figure 5. Graphical distribution of the EW parameter in relation to ED (x – axis), and EL (y – axes), unfertilized variant

From the analysis of the results, represented by the values of the coefficients of equation (2), as well as the graphic models (figure 5), it was found that the two parameters (ED and EL) diverged in the formation of EW values, in the unfertilized variant. The data showed that the two parameters varied independently, in response of the plants to the vegetation conditions without fertilization.

The hectoliter weight (HW, kg hl^{-1}) in the fertilized variant presented the value $HW(F) = 69.17 \text{ kg hl}^{-1}$, and in the unfertilized variant presented the value $HW(UF) = 68.40 \text{ kg hl}^{-1}$, with a statistically significant difference ($p = 0.0067$).

Small-scale agriculture, in addition to the advantages it presents, faces a series of challenges, and access to technological progress and immediate implementation, at the scale of the entire farm, often represent certain sensitive aspects (Dhillon and Moncur, 2023). Studies and simulations of situations have been carried out, which have analyzed technological but also economic aspects, in which the budget allocated to crop technology is limited (especially in small farms), and in such conditions the farmer is faced with the choice of options for allocating limited resources (within the budget), resources that generate maximum possible effects, under crop conditions (Boldea and Sala, 2010; Yigezu et al., 2018; Adams and Jumpah et al., 2021; Zhang et al., 2024).

The differentiated application of complex fertilization represented a step, a method, of improving corn cultivation technology through testing and recording the results under study conditions.

Differences were recorded in agronomic parameters, physiological indices, productivity elements in ears, and hectoliter weight between the fertilized and unfertilized variants. The differences recorded between the fertilized / unfertilized variants in the case of some plant parameters (PH, Chl, Car), some productivity elements

in ears (ED, EW, GW) and hectoliter weight (HW) presented statistical reliability. This confirmed that the fertilizer supplement through fertilization, in the form of complex fertilizer (20/20/0+SO₃+Zn), applied to part of the surface cultivated with corn, presented a positive influence on the corn crop under the study conditions.

CONCLUSIONS

The method of improving corn cultivation technology, considered in the present study, by allocating fertilizer resources only to part of the corn-cultivated area, presented the advantage of testing certain inputs with minimal costs, of comparatively analyzing the results obtained, of reducing risks, and of subsequently extending new technological elements to an extended area for corn cultivation.

The tested differentiated fertilization, based on the applied complex fertilizers, generated positive effects in the fertilized version compared to the unfertilized version, with significant differences in agronomic parameters and plant physiological indices (PH, Chl, Car), productivity elements at the ear level (ED, EW, GW), and grain quality, respectively hectoliter weight (HW).

Regression analysis showed mathematical and graphical models (3D, isoquants) that described the variation of ear weight (EW) in relation to ED and EL parameters in statistical safety conditions. The two dimensional elements of the ear (ED, EL) presented convergent action in the variation of EW in the fertilized variant and divergent action in the case of the unfertilized variant.

The recorded results validated the improved technological sequence, which will be extended to the entire area cultivated with corn under the study conditions, and opened other directions for approaching the technology to optimize the yield of corn crops.

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